The effect of extensive and intensive production systems on the meat quality and carcass characteristics of Dohne Merino lambs

by

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DECLARATION

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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Summary

The aim of this study was to investigate the impact of an extensive (free-range) and intensive (feedlot) production system on the consumer's intrinsic preference cues (physical attributes, chemical composition, fatty acid profile, aroma, flavour, initial juiciness, sustained juiciness, first bite, residue, instrumental tenderness) for three muscles (*Biceps femoris*, *Longissimus dorsi*, *Semimembranosus*) of Dohne Merino lambs (8 months). Secondly to investigate the effect of natural exercise (grazing, extensive production systems) or restrictive movement (intensive production systems), on the muscle fiber type composition of the same lamb muscles and the subsequent effect on the meat quality characteristics.

Intensively raised lambs produced carcasses with a significantly higher dressing percentage, thicker subcutaneous fat layer (13^{th} rib and $3^{rd}/4^{th}$ lumbar vertebra) and a greater fat ratio (carcass composition). Meat of intensively raised lambs had a higher ($p < 0.050$) Homo-g-linolenic (C20:3n6), Eicosapentaenoic (C20:5n3), Docosapentaenoic acid (C22:5n3) content and n3:n6 ratio. Extensively reared lambs had a higher ($p < 0.050$) slaughter weight, cold carcass weight and the meat of these lambs had a higher myoglobin content.

Results of this study indicate that intensively reared lambs produced meat with more favourable sensory characteristics compared to the extensive production system as well as a significant increase in sensory tenderness for *Biceps femoris* muscle. Overall the *Biceps femoris* muscle was the muscle that was primarily affected by the treatment (production systems). The *Biceps femoris* from intensively raised lambs contained significantly more intramuscular fat and type IIB muscle fibers whereas the *Bicpes femoris* of the lambs from the extensive production system contained more ($p < 0.050$) insoluble collagen and type I muscle fibers.

During texture profile analysis (instrumental tenderness test) the *Longissimus dorsi* and *Semimembranosus* of extensively raised lambs required a higher ($p < 0.050$) compression force during the first cycle of compression, indicating that these muscles are tougher.

The results of this study provided valuable insight into the impact of production systems on lamb meat quality and that the application of intensive production systems will increase the sensory characteristics of the selected muscles from Dohne Merino lambs, especially the tenderness of the *Biceps femoris*, which has a high retail value. On the other hand health conscious consumers will prefer extensively produced meat due to the favourable n3:n6 ratio, intramuscular fat content and the presences of less visible fat (subcutaneous).

Opsomming

Hierdie studie was tweedoelig en is uitgevoer op die *Biceps femoris*, *Longissimus dorsi* en *Semimembranosus* spiere van Dohne Merino lammers (8 maande oud). Die eerste doel van die studie was om te bepaal wat die effek van ‘n ekstensiewe (weiding) en intensiewe produksie sisteem sal wees op vleis verbruikers se algemene kwaliteit voorkeure (fisiese eienskappe, chemiese samestelling, vetsuur profile, aroma, smaak, sappigheid, taaiheid,). Tweedens om te bepaal tot watse mate natuurlike oefening, verkry deur weiding asook beperkte beweging as gevolg van voerkraal omstandighede, die spier vesel tipe samestelling sal verander en die direkte impak van die samestelling op kwaliteit eienskappe van vleis.

Lammers van die intensiewe produksie sisteem het ‘n betekenisvolle verhoging in uitslagpersentasie, onderhuidse vet dikte (13^{de} rib en $3^{de}/4^{de}$ lende werwel) en vet ratio (karkas samestelling) getoon. Die vleis van die lammers het meer ($p < 0.050$) C20:3n6, C20:5n3 en C22:5n3 vetsure bevat asook ‘n hoër n3:n6 ratio gehad. Lammers van die ekstensiewe produksie sisteem het ‘n betekenisvolle hoër slag en koue karkas gewig gehad. Die vleis van die lammers het meer ($p < 0.050$) mioglobien bevat as intensiewe lammers.

Resultate van die studie dui aan dat die vleis van lammer van die intensiewe produksie sisteem meer gunstige sensories karakteristiek produseer in vergelyking met lammers van die ekstensiewe produksie sisteem, asook ‘n betekenisvolle verhoging in sensoriese sagtheid van die *Biceps femoris* spier. Die *Biceps femoris* was die spier in die studie wat die meeste geaffekteer was deur die behandeling (produksie sisteme). Die *Biceps femoris* spier van intensiewe lammers het meer intramuskulêre vet en tipe IIB spier vesels bevat teenoor die *Biceps femoris* van ekstensiewe lammers wat meer onoplosbare kollageen en tipe I spier vesels bevat het.

Gedurende die tekstuur profiel analise (instrumentele sagtheid toets) het die *Longissimus dorsi* en *Semimembranosus* van ekstensiewe lammers a hoër kompressie krag vereis, wat aandui dat die spiere taaier is as die ooreenstemmende spiere van intensiewe lammers.

Die resultate van die studie voorsien ons met waardevolle insig in die inpak van verskeie produksie sisteme op die kwaliteit van lams vleis. Die afleiding kan gemaak word dat die implementering van intensiewe produksie sisteem die sensoriese kwaliteit van die spiere van Dohne Merino lammers verbeter, veral die sagtheid van die *Biceps femoris* spier, wat ‘n hoë kommersiële waarde het. Laastens, gesondheidsbewus verbruikers sal verkies om vleis te koop van ekstensiewe lammers weens die gunstige n3:n6 ratio, spier vetinhoud en die minder sigbare vet (onderhuidse vet) op die vleis.

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LIST OF ABBREVIATIONS

BF	*Biceps femoris* muscle
LD	*Longissimus dorsi* muscle
SM	*Semimembranosus* muscle
mg	milligram
g	gram
ml	milliliter
mm	millimeter
ha	hectare
DFD	Dark, firm, dry meat
PSE	Pale, soft, exudative meat
WBSF	Warner Bratzler shear force
TPA	Texture Profile analysis
SFA	Saturated fatty acids
MUFA	Mono unsaturated fatty acids
PUFA	Polyunsaturated fatty acids
TUFA	Total unsaturated fatty acids
P:S	Polyunsaturated to saturated fatty acid ratio
n6	Omega 6 fatty acid
n3	Omega 3 fatty acid
n6:n3	Omega 6 to omega 3 ratio
EPA	Eicosapentaenoic fatty acid
DPA	Docosapentaenoic fatty acid
DHA	Docosahexaenoic fatty acid
ND	Non detected
NW	Not weighed
s	Seconds
LSD	Least Significant Difference
SD	Standard Deviation
pH_0	pH immediately after death
$Temp_0$	Temperature immediately after death
pH_{48}	pH 48 hours after death
$Temp_{48}$	Temperature 48 hours after death
r	Coefficient of variance

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Notes

This thesis represents a compilation of manuscripts; each chapter is an individual entity and some repetition between chapters, especially in the Materials and Methods section, is therefore unavoidable.

Chapter 1

General Information

INTRODUCTION

Over the past decade a progressive decline in the global sheep population was observed, and in 2008 the universal flock size was estimated at 1000 million sheep. This decline could be ascribed to seasonal droughts, unpredictable weather patterns, diminishing land resources and an unstable economy with fluctuating meat prices. In 2008 the total annual sheep meat production was approximately 14 million tonnes compared to 100 million tonnes pork, 90 million tonnes poultry and 65 million tonnes beef (FAO, 2008). The average person consumes approximately 41.6 kg of meat (combined species) annually, however, it seems as though the latter comprises only of 2.5 kg mutton (FAO, 2008).

Consumption of fresh meat and meat products are mainly driven by quality but also influenced by meat prices and per capita income (reviewed by Dickson-Hoyle & Reenberg, 2009; Wolmarans, 2009; Zhao & Schroeder, 2010). Schroeder *et al*. (2001) reported that in developed countries an 1% increase in disposable income, results in an 0.54% decrease in lamb consumption. This could be attributed to consumers perceiving lamb's meat to be of inferior quality compared to beef. Contraryto the findings of Schroeder *et al*. (2001), Shiflett *et al*. (2007) concluded that a significant positive correlation exists between per capita income and lamb consumption. This coincides with Morris (2009) who stated that a decrease in consumer income forces consumers to consume cheaper sources of protein, e.g. poultry. Consumers are also price sensitive, especially in developing countries. Results indicated a 1.09% decrease in per capita consumption of lamb with a 1% increase in the price of lamb's meat. Furthermore, there is a tendency that the demand for lamb increases with an increase in beef prices (Schroeder *et al*., 2001). In order for the lamb industry to expand their market share, they have to increase the demand for lamb meat through developing convenient, innovative, healthy and high quality products that appeals to high-income consumers (Schroeder *et al*., 2001). To further enhance the demand for lamb, lamb production efficiency should be improved to ensure that lamb retail prices are competitive, and the latter could possibly be achieved by intensification of livestock production systems (Schroeder *et al*., 2001).

The global trend in animal production is a systematic transition from small-scale extensive production to large-scale intensive production systems (FAO, 2006). This increases the efficiency of livestock production and subsequently productivity and profitability (FAO, 2006; Coetzee & Malan, 2007). The main driver for this transition could be attributed to intensive production systems being unaffected by various environmental factors (diminishing land, climate change, global warming) (Tisdell, 1998; Gerber, 2005; reviewed by Nordane *et al*., 2010). Nordane *et al*. (2010) are of the opinion that global warming not only has an impact on the environment but also affects livestock production systems, more specifically the health of the animals (welfare) and

efficiency of meat production. Climate changes can induce stress in the animal resulting in reduced feed intake and ultimately weight loss (thus a decrease in carcass yield) (Nordane *et al*., 2010). Climate changes also force animals to endure feed and water shortages, extreme weather conditions, and leads to an increase in vector-borne diseases (e.g. *Culicoides imicola*) and external parasites (Nordane *et al*., 2010). Extensive production systems (grazing, free-range animals) produce 30% of the global small ruminant meat and are solely dependent on natural resources (forage and water). Global warming can therefore jeopardize the future and sustainability of this system and may amount to great economic losses for the farmer/producer. Intensive production (feedlot) is the fastest growing sector in meat production systems and produces approximately 40% of meat globally (FAO, 2002; Nierenberg, 2005; reviewed by Dickson-Hoyle & Reenberg, 2009). In this type of production system animals are housed in confined areas and are fed specific formulated diets consisting predominantly of grains. Environmental climate change will have no direct impact on the health of intensively reared livestock or the productivity of this system, but may influence the availability of grains.

Issanchou (1996) stated that the global red meat industry has shifted from being predominantly production-focused to becoming more consumer-orientated. With the recent global trend of intensification of livestock production systems, concerns arose among producers on how this production system will affect the various meat quality characteristics (Santa-Silva *et al*., 2002).

Consumer preferences and purchase behaviors are very complex and are driven by various intrinsic (tenderness, juiciness, flavour, visible fat) and extrinsic cues (price, production systems, nutritional information, animal welfare, environmental impact) (Cardello, 1995; Aebron & Dopico, 2000; Napolitano *et al*., 2007). The modern red meat consumer still considers meat quality as the most important characteristic, but also demands healthier products that are environmentally friendly, promote sustainability and comply with animal welfare guidelines (Ministry of Agriculture, Fisheries and Food, 1991, 1997). The quality of meat is initially perceived by the consumer through a visual impression (colour, visible fat, and purge) and ultimately confirmed during consumption of the product (tenderness, juiciness, flavour) (Acebron & Dipico, 2000). Consumers regard meat tenderness as the primary determinant of quality and consider it as the most important meat palatability trait (Boleman *et al.*, 1997; Martin & Rodger, 2004). Taste panel results of various studies provide significant results to confirm that intensification of livestock production systems has no negative effect on meat tenderness, on the contrary, intensively produced meat is more tender than extensively produced meat (Bowling *et al.*, 1977; Bowling *et al.*, 1978; Harrison *et al.*, 1978; Hedrick *et al.*, 1983; Schroeder *et al.*, 1980; Schaake *et al.*, 1993; Sapp *et al.*, 1999; French *et al.*, 2000; French *et al.*, 2001).

Beilken *et al*. (1990) concluded that consumers prefer meat that is tender and juicy, and that juiciness as well as flavour contributes to overall acceptability of the meat (Risvik *et al.*, 1994). Santa-Silva *et al.* (2002) found that pasture fed animals had a higher water-holding capacity when compared to concentrate fed animals and therefore according to literature, would have a higher

initial juiciness score. On the other hand Priolo *et al.* (2002) reported that carcass fatness is positively correlated to sensory juiciness and animals from intensive production systems produce carcasses with a higher fat content due to the consumption of a high energy diet.

Consumer preferences regarding lamb flavour and aroma intensity depend on their degree of exposure to lamb's meat (Young *et al.*, 2003). European (Fonti *et al.*, 2009) and New Zealand (Prescott *et al.*, 2001) consumers prefer meat with lower lamb flavour and aroma intensity whereas Japanese consumers, which are relatively unfamiliar with lamb or mutton, prefer bland meat (Prescott *et al*., 2001). Pastoral flavours and aromas on the other hand are mainly associated with animals that are pasture fed. These flavours and aromas are generally described as "grassy", "animal-like", "rancid" or "barnyard" and are regarded as off-flavours and off-odours (Berry *et al.*, 1980; Larick *et al.*, 1987). Young *et al.* (2003) found that off-flavours and aromas are caused by 3-methylindole (skatole), indole, methyl phenol and dimethylsulphone present in the fat of pasture fed lambs (Claus *et al.*, 1994; Lane *et al*., 1999; Bendall *et al.*, 2001). Rousset-Atkin *et al.* (1997) concluded that the diet of pasture fed sheep is directly correlated to the increase in the flavour and odour intensity. Rancid off-flavours and off-odours are also associated with pasture fed animals and is caused by 4-heptanal, an aldehyde derived from linolenic acid (Josephson *et al.*, 1987; Calwallander *et al.*, 1994; Young *et al.*, 1999). The subcutaneous fat of pasture fed animals contains relatively higher concentrations of linolenic acid, due to a diet rich in n3 polyunsaturated fatty acids (Ray *et al*., 1975; Melton *et al*., 1982; Young *et al*., 1999; Wood *et al*., 2003; Diaz *et al*., 2005; Aurossou *et al*., 2007; Popova *et al*., 2007; Neurenberg *et al*., 2008).

Consumers have become more health conscious and prefer lean meat with less visible fat (Carpenter, 1966; as reviewed by Resurreccion, 2003). Issanchou (1996) stated that the negative impact of intramuscular fat, on health related issues, competes with fats' positive contributions to meat flavour and juiciness. The saturated fatty acid content and unfavourable omega 6 to omega 3 polyunsaturated fatty acid ratio associated with red meat, increases the consumer's risk to cancer and cardiovascular diseases (Enser *et al*., 2001). The British Heart Foundation (Allender *et al*., 2008) reported in 2008, that coronary heart disease is the leading cause of death in the United Kingdom and the American Heart Association (AHA, 2010) stated that coronary heart disease claimed 425 425 American lives in 2006 and remains the leading cause of death in the United States of American. The Heart and Stroke Foundation of South Africa reported that 195 South Africans die daily (1997 – 2004) of cardiovascular related diseases (Steyn, 2007). Animals on concentrate diets (intensive production systems) produce meat with a higher Linoleic (omega 6) to α-Linolenic (omega 3) ratio, which increases the consumers' risk to coronary heart disease. Forage diets of pasture fed animals are rich in C18:3n3 poly-unsaturated fatty acids and produces meat with a high total mono-unsaturated acid content, which promotes consumer health (Miller *et al*., 1967; Mitchell *et al*., 1991; Duckett *et al*., 1993; Patil *et al*., 1993; Enser *et al*., 1998; Sañudo *et al*., 2000; Scollan *et al*., 2001; Wood *et al*., 2003; Aurousseau *et al*., 2004; Nuernberg *et al*., 2005; Aurousseau *et al*., 2007; Popova, 2007; Scerra *et al*., 2007; Nuernberg *et al*., 2008).

Consumers demand that livestock production systems must adhere to animal welfare guidelines (rearing, transport and slaughter conditions) and state that they are willing to pay higher prices for certified human products (Oude Ophuis, 1994; Lister, 1995; Bennett, 1996; Mintel, 1996; Troy & Kerry, 2010). Over recent years the impact of production systems on animal welfare issues, has grown from having no significant effect on purchase behaviour to becoming a key factor, influencing consumer preferences (Mclnerney, 2004). Consumers prefer meat produced in natural environments (extensive production systems) and perceive intensive production systems as having a negative effect on animal welfare and wellbeing. Contradicting to consumer belief, Turner and Dwyer (2007) reported that extensively reared livestock experience various extreme conditions (food and water supply, weather conditions, disease risk), and these aspects could also have a negative effect on animal welfare. Farmers and producers are concerned about the growing demand for animal friendly products produced in animal friendly production systems. However, these production systems increase production costs, and although consumers stated that they are willing to pay premium prices for these products, this is not reflected in the purchasing figures (IGD, 2007).

Over the past decade, meat consumers have become more informed and concerned about the impact of livestock production on the environment and demand products that are more environmentally friendly (FAO, 2006). Intensive livestock production systems produce enormous amounts of manure, which emits 18% of the annual global greenhouse gas. During decomposition manure produces various solar heat trapping gasses (e.g. nitrous oxide, methane, carbon dioxide, ammonia), and this contributes to global warming (FOA, 2006; Saier & Trevors, 2010). Hansen and Francis (2007) reported that manure produced by intensive production systems are seen as a problematic waste and waste management is inadequate, resulting in phosphorus and nitrogen from manure polluting surrounding soil and water sources (Marks, 2001). Furthermore, livestock production systems also increases the strain on the already limited water resource and are responsible for 19% of the annual global water consumption (Nordane *et al*., 2010). Therefore, the increase in intensification of livestock production systems will have an overall negative effect on the environment.

Livestock production systems are being intensified to improve efficiency and productivity. It is evident that intensive production systems do not satisfy consumer preferences or needs regarding the extrinsic cues (health, animal welfare, environmental impact). The main objective of this study was to investigate the impact of an extensive (free-range) and intensive (feedlot) production system on the consumer's intrinsic preference cues (flavour, aroma, initial juiciness, sustained juiciness, first bite, residue, instrumental tenderness, physical attributes, chemical composition, fatty acid profile) for three muscles (*Biceps femoris*, *Longissimus dorsi*, *Semimembranosus*) of Dohne Merino lambs. Secondly to investigate the effect of natural exercise (grazing, extensive production systems) or restrictive movement (intensive production systems), on the muscle fiber type composition of various muscles (*Biceps femoris*, *Longissimus dorsi*,

Semimembranosus) of Dohne Merino lambs, and the subsequent effect on various meat quality characteristics. Evidence in literature (Valin *et al*., 1982; Maltin *et al*., 1997; Klont *et al*., 1998; Lefaucheur & Gerrard, 1998; Karlsson *et al*., 1999; Chang *et al*., 2003; Lefaucheur, 2010) suggests that the complex histochemical properties of skeletal muscles (muscle fiber type, fiber frequency, fiber dimensions and sarcomeres) is an important source of quality variation in meat and could be used as a predictor of meat quality (Valin *et al*., 1982) especially for the most important palatability trait, tenderness (Tuma *et al*., 1962; Calkins *et al*., 1981; Whipple *et al*., 1990; Crouse *et al*., 1991).

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Chapter 2

Literature Review

BACKGROUND

Dohne Merino breed

In the early 1930's a need arose in the Eastern Cape (South Africa) for a sheep breed that could adapt to the unfavourable conditions of the sourveld. The sourveld is situated in the summer rainfall region of South Africa and the pastures comprise of indigenous grasslands. The adaptation of conventional Merinos to this area was poor due to the wet and humid climate promoting fleece rot in the excessive skin folds of this breed as well as blowfly strike (Swanepoel, 2006). Productivity was further more reduced by the low nutritional value of the foliage, low fertility and high mortality rates and the selective grazing patterns of Merinos (Swanepoel, 2006; McMaster, 2010).

In 1939, under the guidance of Mr JJJ Kotze a dual purpose (meat and wool) sheep breeding program was initiated at the Dohne Agricultural Research Station near Stutterheim in the Eastern Cape (McMaster, 1991). The prerequisites requirements for this new dual purpose breed was excellent adaption to sourveld (climate and pastures), ability to produce high quality meat and wool (without hair or coloured fibers), exceptionally good reproduction characteristics, high fertility rate, lambing at regular intervals (autumn & spring), rapid lamb growth rate and be able to produce good quality slaughter lambs (SAIB, 2010; BKB, 2010). The Dohne Merino (hornless) breed was developed and originated from cross breeding German Mutton Merino rams (Elsenburg College of Agriculture) with South African Merino ewes (Kotze, 1951). This breed fulfils all the prerequisites mentioned and adapts exceptionally well to both extensive and intensive production systems (SAIB, 2010).

Sheep farming globally and in South Africa

Over the past decade a progressive decline in the global sheep population was observed, and in 2008 the universal flock size was estimated at 1 000 million sheep. Sheep stock also declined over the past 20 years by approximately 50% in New Zealand, Australia and Argentina (FAOSTAT, 2010; Woodford, 2010). The United States of America (USA) experienced a more dramatic decline, from 50 million sheep in 1940 to only 6 million in 2008 (FAOSTAT, 2010; Woodford, 2010). China which has the world's largest sheep flock also experienced a slight decline in stock numbers from 152 million in 2005 to 136 million in 2008 (FAOSTAT, 2010; Woodford, 2010). This global decline could be ascribed to seasonal droughts, unpredictable weather patterns, diminishing land resources, an unstable economy with fluctuating meat prices, decline in wool prices and environmental degradation (Woodford, 2010). The total annual global sheep meat production in

2008 was approximately 14 million tonnes compared to 100 million tonnes pork, 90 million tonnes poultry and 65 million tonnes beef meat (FAOSTAT, 2010).

Approximately 53% (590 000 km^2) of South Africa's agricultural land is used for cattle, sheep and goat farming (DAFF, 2009). The Department of Agriculture, Forestry and Fisheries (DAFF, 2009) estimated that the South African national sheep flock size decreased by 1% from 2008 (25.1 million) to 2009 (24.8 million). The total amount of sheep (including lambs) slaughtered in South Africa also decreased by 26.3% from mid 2007 to mid 2009 (DAFF, 2009). Approximately 118 000 tonnes of sheep meat was produced in South Africa in 2008 compared to 975 000 tonnes poultry (chicken), 805 000 tonnes beef meat and 150 000 tonnes pork (FAOSTAT, 2010).

Mutton/lamb consumption globally and in South Africa

Globally the average person consumes approximately 41.6 kg of meat (combined species) annually, but their diet contains only 2.5 kg sheep meat (FAO, 2008). The average per capita consumption of sheep/mutton/goat meat in South Africa in 2004 was approximately 3.5 kg compared to 3.3 kg pork, 14.0 kg beef and 22.0 kg poultry. The overall sheep meat consumption in South Africa decreased by 18.3% from 183 815 tonnes in 2007 to 150 147 tonnes in 2009, whereas beef (1.9%) and pork (1.5%) consumption increased for the same period (DAFF, 2009). The global decrease in lamb consumption phenomena was discussed in Chapter 1.

Production systems (Extensive vs. intensive)

In an intensive production system, animals are housed in a confined area (indoors or outdoors) and fed a specifically formulated diet with limited or no physical activity whereas in an extensive production system, animals roam freely without being confined. The Compassion in World Farming group (CIFW, 2010) estimated that approximately 1% of the global sheep flock are reared in intensive production systems. Sheep farming in South Africa is predominantly extensive and is found in the arid regions of the country (DAFF, 2009). No official statistics are currently available on the occurrence of intensive and extensive livestock production systems (DAFF, 2009).

Intensive production (feedlot) is the fastest growing sector in meat production systems and produces approximately 40% of meat (all species) globally (FAO, 2002; Nierenberg, 2005; reviewed by Dickson-Hoyle & Reenberg, 2009). The implementation of intensive livestock production systems benefits (efficiency, high productivity, high yields, high turn-over time, low production cost, high profit, low risk, minimal land needed) the farmer/producer and environmental changes has no direct impact on the productivity of this system, but may influence the availability of grains. Intensive production systems (feedlots) are implemented during pasture scarcity and to obtain a desired slaughter weight (Notter *et al*., 1991).

Consumer and animal right activists (Compassion in world Farming, People for the Ethical Treatment of Animals) feel that the negative aspects (human health, animal welfare, environmental impact) of intensive production systems far outweigh the minimal benefits (productivity, profitability)

associated with these systems. Approximately a third of US consumers indicated that “grass fed” (34%) and “free-range” (35%) product claims are “important to very important” to them, according to a survey conducted by Context Marketing (2009).

Experimental Units – muscles

Biceps femoris

The *Biceps femoris* is situated at the extensor of the hip, stifle, and hock joints and flexes the stifle when the hind foot is lifted off the ground. This muscle is primarily used during locomotion (walking and grazing) and therefore this muscle will be more active in animals in an extensive production system compared to animals in an intensive production system (Nickel *et al*., 1986; Frandson *et al*., 2003).

Longissimus dorsi

The *Longissimus dorsi* acts as an extensor of the back and loin and flexes the spine laterally. The *Longissimus dorsi* is highly active during galloping or jumping and less active during walking or trotting (locomotion) (Nickel *et al.*, 1986). This muscle is primarily a postural muscle and was included in this study as a control muscle because the muscle’s workload does not increase with an increase in grazing activity (locomotion) (Frandson *et al.*, 2003).

Semimembranosus

The *Semimembranosus* muscle acts as the extensor of the hip joints and flexor of the stifle. This muscle is primarily used during locomotion (walking and grazing) therefore this muscle will be more active in animals in an extensive production system compared to animals in an intensive production system (Frandson *et al*., 2003).

Consumer Concerns, perceptions and preferences

Meat quality

Modern red meat consumers consider meat quality as the most important characteristic and even though price is an important purchase driver, 60% of consumers indicated that they are willing to pay 10% more for higher quality products (Context Marketing, 2009).

Consumer preferences and purchase behaviours are very complex and are driven by various intrinsic and extrinsic meat quality cues. These cues are important to consumers at the point of purchase (colour, purge, visible fat), during consumption (juiciness, tenderness, flavour, aroma) and as individual product characteristics (safety, nutrition, sustainability, ethics, environmental impact, animal welfare) (Cardello, 1995; Acebron & Dopico, 2000; Napolitano *et al*., 2007). Juiciness, flavour and the texture (tenderness) of meat is considered as the main intrinsic factors influencing meat palatability and consumer acceptability (Bello & Calvo, 2000; Brewer & Novakofski, 2008). Beilken *et al*. (1990) concluded that consumers prefer meat that is tender and

juicy, and that juiciness as well as flavour contributes to overall acceptability of the meat (Risvik *et al.*, 1994).

Troy and Kerry (2010) stated that "The relationship between consumer perception of quality and the food industry's drive to satisfy consumer needs is complex and involves many different components". In an increasingly competitive market, it is crucial to constantly monitor, evaluate and analyse consumer perception of meat quality to ensure that the consumer's needs and expectations are being met. Consumer satisfaction increases the consumer's willingness to pay and encourages repeat purchasing (Troy & Kerry, 2010).

Diet/ Health relationships

The high-saturated fatty acid content and unfavourable omega 6 to omega 3 polyunsaturated fatty acid ratio associated with red meat, increases the consumer's risk to cancer and cardiovascular diseases (Enser *et al*., 2001). The British Heart Foundation (Allender *et al*., 2008) reported in 2008, that coronary heart disease is the leading cause of death in the United Kingdom and the American Heart Association (AHA, 2010) stated that coronary heart disease claimed 425 425 American lives in 2006 and remains the leading cause of death in the United States of American. The Heart and Stroke Foundation of South Africa reported that 195 South Africans die daily (1997 – 2004) of cardiovascular related diseases (Steyn, 2007). Animals on concentrate diets (intensive production systems) produce meat with a higher Linoleic (omega 6) to α-Linolenic (omega 3) ratio, which increases the consumers' risk to coronary heart disease. Forage diets of pasture fed animals are rich in C18:3n3 poly-unsaturated fatty acids and produces meat with a high total mono-unsaturated fatty acid content, which promotes consumer health (Miller *et al*., 1967; Lantham *et al*., 1972; Marmer *et al*., 1984; Mitchell *et al*., 1991; Duckett *et al*., 1993; Patil *et al*., 1993; Enser *et al*., 1998; Sañudo *et al*., 2000; Scollan *et al*., 2001; Wood *et al*., 2003; Aurousseau *et al*., 2004; Nuernberg *et al*., 2005; Aurousseau *et al*., 2007; Popova, 2007; Scerra *et al*., 2007; Nuernberg *et al*., 2008).

Over the past few decade consumers have become more health conscious and prefer lean meat with less visible fat (Carpenter, 1966; as reviewed by Resurreccion, 2003). The National Heart Foundation of Australia reported in 1980 that only 42% of adults consumed trimmed (subcutaneous fat removed) meat but through public health initiatives and education programs the amount of adults consuming trimmed meat has more than doubled to 89% in 2007 (The Clever Stuff, 2007).

Various health authorities recommend that the Linoleic acid (C18:2n6) to α-linolenic acid (C18:3n3) ratio of meat should be approximately 5:1 and the polyunsaturated to saturated fatty acid ratio should be > 0.45, to promote health and minimise the risk of cardiovascular diseases (Warriss, 2010). Animals on concentrate diets (intensive production systems) produce meat with a high-unsaturated fatty acid content and a higher Linoleic (omega 6) to α-Linolenic (omega 3) ratio, which does not conform to the health guidelines for minimisation cardiovascular diseases.

Animal welfare

Results from a survey conducted by Context Marketing (2009), indicate that 48% of US consumers regard humanely-raised livestock products as “important to very important” and European meat consumers scored the importance of animal welfare 7.8 on a scale from 1 to 10 (European Commission, 2007). Over recent years the impact of production systems on animal welfare issues, has grown from having no significant effect on purchase behaviour to becoming a key factor, influencing consumer preferences (Mclnerney, 2004). Consumers demand that livestock production systems adhere to animal welfare guidelines (rearing, transport and slaughter conditions) and state that they are willing to pay higher prices for certified humane products (Oude Ophuis, 1994; Lister, 1995; Bennett, 1996; Mintel, 1996; Troy & Kerry, 2010). In a survey by the Institute of Grocery Distribution (2007), 20% of consumers indicated that animal welfare standards are the primary driver for purchase choice.

Consumers perceive intensive production systems as having a negative effect on animal welfare (Hughes, 1995) and prefer meat produced in natural environments (extensive production systems). Hughes (1995) compiled a list of key factors (increase in disposable income; higher educated levels; majority are animal-lovers; believe slaughtering of livestock is cruel) which contributed to the increase in UK consumer concerns about animal welfare as well as highlighted the fact that this spike in interest is complex and cannot be attributed to a single factor/event.

Contradicting to consumer belief, Turner and Dwyer (2007) reported that extensively reared livestock experience various extreme conditions (food and water supply, weather conditions, disease risk), which could also have a negative effect on animal welfare. Farmers and producers are concerned about the growing demand for animal friendly products produced in animal friendly production systems that promotes animal welfare, because these production systems increase production costs, and although consumers stated that they are willing to pay premium prices for these products, this is not reflected in the purchasing figures (IGD, 2007).

Environmental impact

Meat consumers have become more concerned about the impact of livestock production on the environment and demand products that are more environmentally friendly (FAO, 2006). The FAO (2006) reported that livestock production is one of the leading causes of land degradation, global warming and pollution (air and water) as well as loss of biodiversity. The enormous amounts of manure produced by livestock production systems emit 18% of global greenhouse gasses annually and exceed the gas emission of the transport sector (13.5%) (FAO, 2006). During decomposition manure produces various solar heat trapping gasses (e.g. nitrous oxide, methane, carbon dioxide, ammonia), which contributes to global warming (FOA, 2006; Saier & Trevors, 2010). Fossil fuels are considered a non-renewable resource and approximately 4.37 MJ of energy is needed to produce 1 kg of beef compared to potatoes which consumes 33% less energy (Nierenberg, 2005). The FAO (2006) estimated that 90 million metric tons of CO_2 are emitted annually from burning

fossils fuels which provide energy for the ever increasing daily operations of intensive livestock production systems (e.g. heating, cooling and ventilation in holding pens; feed crop production; operating of machinery). Meat production further contributes to the generation of 64% of the annual anthropogenic ammonia, which causes harmful acid rain, and the acidification of ecosystems (FAO, 2006; Saier & Trevor, 2010).

Hansen and Francis (2007) reported that manure produced by intensive production systems are seen as a problematic waste and waste management is usually inadequate, resulting in phosphorus and nitrogen from manure polluting surrounding soil and water sources (Marks, 2001). The Environmental Protection Agency in the United States of America released shocking statistics in 2004, stating that 35 000 miles of rivers, stretching over 22 states and the groundwater of 17 states are polluted due to the waste of animal production systems. Furthermore livestock production systems also increase the strain on the already limited water resource and are responsible for 19% of the annual global water consumption. It is estimated that to produce a kilogram of beef 23 tonnes of water is required and the consumption is mostly ascribed to irrigation of crop for feed (Nordane *et al*., 2010). Furthermore livestock production systems lead to land degradation, deforestation and loss of biodiversity and an increase in intensification of livestock production systems will have an overall negative effect on the environment which will influence consumer purchase behaviour (FAO, 2006; Gerber & Steinfeld, 2008).

Food safety

A survey conducted by Context Marketing (2009), indicated that 57% of US consumers are “very concerned” and 39% are “somewhat” concerned about food safety. Consumer anxiety regarding food safety is primarily fuelled by the recent increase in food safety scares and outbreaks of food-borne illnesses/diseases. The USDA Food Safety and Inspection Service, the US Food and Drug Administration, FoodNet (Food-borne Diseases Active Surveillance Network), and US Centers for Disease Control and Prevention (CDC) reported that the progress in the prevention of food-borne illnesses/diseases has stalled in the USA and current data on food related outbreaks (*Campylobacter*, *Cryptosporidium*, *Listeria*, *E. coli* 0157:H7, and *Salmonella*) indicate no decrease compared to data from 2005-2007 (Byrne, 2009).

The FAO warned that intensively reared livestock poses a risk to meat safety because animals are being raised in confined unsanitary conditions due to inadequate waste management (Elamin, 2007). Nierenberg (2003) stated that these conditions exacerbate the rapid spread of animal diseases through faecal contamination and ultimately results in food-borne illness.

Physical meat quality

Growth rate and slaughter weight

Animal growth consists of three growth phases (slow, rapid and plateau) and is achieved through hypertrophy and hyperplasmia (Lawrie, 1998). Animal tissue follows an exact sequence of

maturation: firstly bone then muscle and lastly fat (Rouse *et al*., 1970). According to Aberle *et al*. (2001), the growth rate of animals can be altered by various environmental and nutritional conditions.

Feedlot (intensive) production systems are associated with high energy diets, high plane of nutrition and a high feed efficiency rate which promotes rapid growth and the early onset of the fattening phase (Lawrie, 1998). Animals from intensive production systems reach physiological maturity (slaughter weight) at an earlier stage (age) compared to forage based production systems and therefore produce heavier carcass if slaughtered at the same age (Crouse *et al*., 1981; Notter *et al*., 1991; Haddad & Husein, 2004).

The low energy forage based diet of extensive production systems results in a slower growth rate and promotes muscle growth without excess fattening (Crouse *et al*., 1981; Lawrie, 1998). Lambs from extensive production systems have higher energy needs due to an increased basal metabolism (foraged based diet) and an increase in physical activity (grazing), which results in the production of lighter and leaner carcasses (Murphy *et al*., 1994; Diaz *et al*., 2002).

Muscle weight

Skeletal muscle hypertrophy occurs in the growth phase of an animal and is driven by various factors: hormonal, nutritional, age and physical activity. Shavlakadze and Grounds (2006) stated that an increase in skeletal muscle mass occurs in response to exercise or physical activity. The function of a specific muscle, intensity of the mechanical loading (exercise or physical activity) and the period of exposure, will determine the degree of skeletal muscle hypertrophy.

Dressing percentage

The dressing percentage (%) is the percentage of the live animal which ultimately becomes the carcass after dehiding/skinning, and removal of the head, feet and viscera (Schoenian, 2010). The dressing percentage of an animal is affected by various factors including the diet, production system, age, sex, breed and fasting period prior to slaughter (Sañudo *et al*. 1998; Evans, 2003). The digestive tract of extensively produced animals are more developed, due to the higher intake of dry matter compared to intensively produced animals, of the same age (Hatfield, 1994; Priolo *et al*., 2002 – lambs; Cañeque *et al*., 2003 – lambs). A more developed digestive tract will be larger and heavier which will decrease the dressing percentage of the animal, producing a lighter carcass. Intensive production systems produce animals with a higher dressing percentage compared to intensively reared animals (Williams *et al*., 1983 – cattle; Notter *et al*., 1991 – lambs; Murphy *et al*., 1994 – lambs; Moron-Fuenmayor & Clavero, 1999 – lambs). Borton *et al*. (2005 a, b) also concluded that the thin subcutaneous fat layer of extensively reared lambs, together with a well developed digestive system, contributes to an overall lower dressing percentage, compared to animals from an intensive production system.

Post mortem pH and temperature decline

Post mortem pH decline occurs from 7.0 (living animals) to 5.6-5.4, due to the accumulation of lactic acid in the muscle produced from glycogen during anaerobic glycolysis. At the iso-electric point of proteins (pH 5.4-5.5), the enzymes initiating glycolysis are inactivated and the ultimate muscle pH is reached. The ultimate pH of a muscle could be affected by the diet of the animal, ante-mortem stress and the temperature decline (Olsson *et al*., 1994; Lawrie, 1998; Sales, 1999; Immonen *et al*., 2000)

Extensively produced animals (free range) associated with low energy forage diets (low plane of nutrition) have relatively small but sufficient glycogen reserves to ensure a gradual decline in muscle pH post mortem producing meat with a slightly (insignificantly) higher pH compared to intensively reared livestock (Lawrie, 1998; as reviewed by Priolo *et al*., 2001). Animals from extensive production systems are also more susceptible to pre-slaughter stress as they are not accustomed to confinement (lairage) or handling (herding, transporting and slaughtering) (Bowling *et al*., 1977; Warriss *et al*., 1983; Barton-Gade & Blaabjerg, 1989; Muir *et al*., 1998). Pre-slaughter stress, accompanied with low glycogen reserves, produces meat with an ultimate high pH (> 6.0) known as DFD meat (dark, firm and dry), which is aesthetically unattractive to the consumer (Lawrie, 1998). A high pH also creates optimum conditions for spoilage bacteria to flourish, which negatively affects the shelf life of the product (Lawrie, 1998). However, the majority of studies reporting on the effect of production systems on ultimate muscle pH of livestock, concluded that production systems had no significant effect on the ultimate muscle pH of cattle (Bidner *et al*., 1986; Morris *et al*., 1997; Keane & Allen, 1998; French *et al*., 2001; Realini *et al*., 2004; Nuernberg *et al*., 2005), lambs (Sañudo *et al*., 1997; Diaz *et al*., 2002; Priolo *et al*., 2002; Ripoll *et al*., 2008; Carrasco *et al*., 2009) and pigs (Gentry *et al*., 2002; as reviewed by Olsson & Pickova, 2005).

The rate of post mortem glycolysis is affected by the internal muscle temperature and is optimum at high temperatures. A thick subcutaneous fat layer (associated with production) insulates the carcass (Marsh, 1977), decreasing the carcass-cooling rate, which promotes post mortem glycolysis ensuring a normal ultimate muscle pH is achieved (Olsson *et al*., 1994; Lawrie, 1998; as reviewed by Priolo *et al*., 2001). High muscle temperatures (7 - 15°C) post mortem also promote proteolysis, which contributes to the tenderness of meat (Dransfield, 1994; Tornberg, 1996; Geesink *et al*., 2000).

Subcutaneous fat

Four major fat depots are associated with an animal carcass of which the visceral fat is deposited first followed by intermuscular and subcutaneous fat, and lastly intramuscular fat (Lawrie, 1998; Gerbens, 2004; Hossner, 2005). The development of these fat depots is dependent on and affected by the diet of the animal (Carrasco *et al*., 2008). The subcutaneous fat layer is the most visible fat depot and is located between the muscle and skin (Hossner, 2005). Thickness of the

layer is normally measured at the 13th rib (Gilmour *et al*., 1994) and between the 3rd/4th lumbar vertebra (Bruwer *et al*., 1987), 25 mm off the midline of the spine.

High energy diets and minimal physical activity associated with intensive production systems contribute to the production of carcasses with significantly thicker subcutaneous fat layers compared to extensively reared livestock (Williams *et al*., 1983; Enfält *et al*., 1997; Diaz *et al*., 2002; Gentry *et al*., 2002; Realini *et al*., 2004; Borton *et al*., 2005 a, b). High energy diets promote the earlier onset of the fattening phase (Lawrie, 1998) and the subcutaneous fat layer of a carcass is inversely correlated with the meat yield of a carcass (Murphey *et al*., 1960; Cole *et al*., 1962; Ramsey *et al*., 1962; Brungardt & Bray, 1963). Diaz *et al.* (2002) proposed that extensive production systems (increase in physical activity and low plane of nutrition) alter the metabolism of the animals resulting in utilisation of lipid reserves to produce muscular tissue.

The thick subcutaneous fat layer acts as an insulator, preventing a sudden decrease in muscle temperatures during post-mortem cooling (Marsh, 1977). Higher muscle temperatures post mortem promotes the activity of proteolytic enzymes (7 - 15°C) and inhibits cold induced shortening (cold shortening) of the muscle fibers, resulting in an overall improvement of meat tenderness (Smith *et al*., 1976; Lochner *et al*.,1980; Marsh *et al*., 1981; Fishell *et al*., 1985; Brewer & Calkins, 2003; Martin & Rodger, 2004). Red meat consumers prefer meat with less visible fat and indicated that they are willing to pay premium prices for meat with less subcutaneous fat (Carpenter, 1966; Dransfield, 2001; as reviewed by Resurreccion, 2003) and The Industry Wide Lamb and Wool Planning Committee (1964) suggested that the subcutaneous fat covering of lambs should not exceed 0.76 cm (maximum) to comply with consumer preferences (as reviewed by Carpenter, 1964). Subcutaneous fat contains unsaturated fatty acids, which could contribute to the development of rancidity resulting in a decrease in consumer acceptability of the product (Duncan & Garton, 1967).

Ribeye area

The ribeye muscle (*Longissimus dorsi*; 12/13th rib) area is used by the industry as a predictor of meat yield as it is correlated with the overall retail cut yield of a carcass (O'Rourke *et al*., 2005). The total area of the ribeye is influenced by the live weight of an animal and various authors concluded that the ribeye area of animals from intensive production systems are significantly larger compared to extensively reared animals (Bowling *et al*., 1977; Bowling *et al*., 1978; Harrison *et al*., 1978; Schroeder *et al*., 1980; Hedrick *et al*., 1983; Schaake *et al*., 1993; Sapp *et al*., 1999; Zervas *et al*., 1999; French *et al*., 2000, 2001; Realini *et al*., 2004). The loin (*Longissimus dorsi* muscle) is the most preferred retail cut (Carpenter, 1964), and during a study by Sweeter *et al*. (2005), consumers indicated that they are willing to pay higher prices for larger beef loins.

Three-rib cut (muscle: bone: fat ratio)

Red meat consumers prefer meat with a high lean muscle content and less visible fat (Carpenter, 1966; as reviewed by Resurreccion, 2003). Mauldin and Mauldin (2010) suggested that a retail cut with a higher edible product (meat) to bone ratio is more beneficial to the farmer (higher prices for premium products) and preferred by the consumer (value for money). The three-rib cut (9-10-11th rib) method is used by the meat industry as an effective and accurate indicator of carcass composition and a predictor of overall lean meat yield (Moulton *et al*., 1922; Lush, 1926; Hankins *et al*., 1943; Hopper, 1944; Hankins & Howe, 1946; Crown & Damon, 1960; Busch *et al*., 1968; Crouse & Dikeman, 1976; as reviewed by Hedrick, 1983; Webb & Casey, 1999). Hankins *et al*. (1943) observed a strong positive correlation between the muscle: bone: fat ratio of the three-rib cut (9-11th rib) and the muscle: bone: fat composition of a dressed carcass. The muscle to bone ratio of a carcass increases with increase in slaughter weight and is influenced by the animal's age, breed and plane of nutrition (Berg & Butterfield, 1968; Bailey *et al*., 1985; Zupka *et al*., 1996). Contrary to these findings, Webb and Casey (1995) concluded that visible fat increases with an increase in slaughter weight and is inversely correlated to the percentage of muscle and bone. As the thickness of the subcutaneous fat layer increases the percentage edible lean tissue in the carcass decreases, which has a negative effect on the muscle ratio of retail cuts which affects consumer purchase behaviour (Kemp *et al*., 1970; Salomon *et al*., 1980).

Meat Colour

Various factors contribute to the appearance of fresh meat: concentration and type of myoglobin present, the chemical state of the myoglobin, pH of the meat and the light scattering properties of the cut surface (Lawrie, 1998). The appearance of fresh meat is one of the primary factors influencing consumer purchase behaviour and acceptance (Carpenter, 1966; Grunert, 2006). Consumers prefer meat with a bright red colour and associate it with high quality and freshness (Jeremiah *et al*., 1972). Consumers steer clear of meat with too dark/brown or too pale colour because they perceive the product as being of inferior quality (Issanchou, 1996; Berg, 2000; Viljoen *et al*., 2002).

Instrumental colour – CIELab system

The CIELab colour system (Commission International De l'Eclairage, 1976) is one of the most widely accepted objective meat colour measurement systems used by the meat industry (Honikel, 1998). The L* coordinate of the CIELab system represents the lightness (reflection) of the sample (0 = blacks; 100 = white), the a* coordinate the red/green spectrum (positive = red; negative = green) and the b* yellow/blue (positive = yellow; negative = blue).

It is evident from literature, that animals from extensive (free-range) production systems, produces meat with a lower L* value (darker) when compared to intensively (feedlot) raised animals, which could be attributed to the higher myoglobin content of these animals, as previously

discussed (Dufranse *et al*, 1995 - cattle; Vestergaard *et al*, 2000a - cattle; Priolo *et al*, 2001 - lambs; Priolo *et al*, 2002 – lambs; Raes *et al*., 2003 - cattle; Nuernberg *et al*, 2005 - cattle). Another aspect that may also cause a higher L* value on the muscle surface of meat produced from animals finished off in intensive systems is the presence of intramuscular fat (see later).

Extensively raised animals are frequently more susceptible to pre-slaughter stress, as they are not accustomed to confinement (lairage) or handling (herding, transporting and slaughtering) (Bowling *et al*., 1977; Warriss *et al*., 1983; Barton-Gade & Blaabjerg, 1989; Muir *et al*., 1998). The high susceptibility to stress of these animals and a low energy diet associated with extensive production systems (free-range) results in an ultimate high muscle pH post mortem (> 5.7) which subsequently produces meat with a low L* value known as DFD (dark, firm and dry) meat which is aesthetically unattractive to the consumer (Lawrie, 1998).

Intensive production systems (feedlot) are associated with relatively high energy diets and animals housed in these production systems are less susceptible to pre-slaughter stress, as they are accustomed to confinement and being handled (Bowling *et al*., 1977; Warriss *et al*., 1983; Barton-Gade & Blaabjerg, 1989; Muir *et al*., 1998). The ultimate muscle pH of intensively produced animals are normal (5.7) but a rapid decline in post mortem muscle pH (< 5.7) could be observed if the muscle contains large glycogen reserves (high energy diet) accompanied with pre-slaughter stress. Muscle with an ultimate low pH post mortem results in PSE (pale, soft, exudative) meat that is rejected by the consumer. A low pH contributes to myofibrillar denaturation which lowers the water holding capacity of the meat (Offer, 1991; Lawrie, 1998). PSE meat has a relative high L* due to the light reflecting/scattering property of the surface water (Warriss, 2010) and Woelfel *et a*l. (2002) concluded that the L* value of meat increases with an increase in drip loss.

Muscles with a high intramuscular fat content have higher muscular L* values as fats have high light reflection properties (Hedrick *et al*., 1983). The muscles of intensively produced animals contain more intramuscular fat due to the higher energy diet which also contributes to the lighter colour of the meat when compared to extensively raised animals.

Myoglobin

The red colour, synonymous with fresh meat, is due to the presence of myoglobin, a water-soluble colour pigment/protein. The myoglobin molecule has the ability to bind oxygen, and the myoglobin concentration of a muscle is directly correlated to the specific function and activity level of the muscle and animal. Active muscles contain more myoglobin and are significantly darker compared to less active muscles (Lawrie, 1998; Honikel, 1998, Young & West 2001). Various authors conclude that extensively reared animals produce darker meat due to high levels of activity associated with this production system (Bidner *et al*., 1986 - cattle; Varnam & Sutherland, 1995; Vestergaard *et al*., 2000b – cattle; Diaz *et al*., 2002 - lambs; Priolo *et al*., 2002 - lambs). The high myoglobin content of active animals can also be attributed to their muscles containing a high

concentration of oxidative type I muscle fibers, which are rich in myoglobin. Spontaneous physical exercise, associated with extensive (free-range) rearing systems, induces the transition of fast twitch fibers (type II) to slow twitch fibers (type I) (Aalhus & Price, 1991; Lefaucheur & Gerrard, 1998; Petersen *et al*., 1998; Pette & Staron, 2000; Vestergaard *et al*., 2000a; Pette & Staron, 2001; Gentry *et al*., 2004, Abreu *et al*., 2006). Postural muscles (e.g. *Longissimus dorsi*) are more oxidative (type I) when compared to muscles involved in locomotion (e.g. *Biceps femoris* and *Semimembranosus*) (Totland & Kryvi, 1991; Ono *et al*., 1995; Chang *et al*., 2003).

Water holding capacity

Sales (1996) defined the water holding capacity of meat, as the ability of the meat structure to hold/retain water during cutting, storage and heating. Lean meat is comprised of approximately 72-75% water (bound, free and immobilized), which is retained by thin actin/tropomyosin and thick myosin filaments (Lawrie, 1998; Kauffman, 2001; Huff-Lonergan & Lonergan, 2005).

Drip loss

Drip loss is an undesirable phenomenon that occurs in meat with an ultimate low pH (< 5.0). The iso-electric point of actin and myosin myofibril proteins are approximately 5.5 - 5.4, at this pH the myofibril proteins have a net charge of zero and lose their ability to bind water (Hamm, 1961; Warriss, 2010). When the myofibril protein structures are disrupted by cutting, excessive amounts of fluids exude to the cut surface resulting in an undesirable product (Warriss, 2010). A high drip loss is detrimental to the quality of meat and water exuded contains valuable nutritional components (vitamins, protein, minerals and flavour components) (Hamm, 1961). Meat with a high drip loss has a pale appearance (high L* value) because the meat's light scattering properties are increased by the excessive amount of moisture on the freshly cut surface (Woelfel *et al*., 2002; Warriss, 2010). Meat yield decreases with an increase in drip loss which could have significant economic implications for the farmer and producer. Spoilage bacteria flourish in environments with a high water activity (Aw) therefore an increase in drip loss of meat will have a negative effect on the shelf life of the product (Hamm, 1961). Consumers reject meat with a high drip loss percentage (purge) and perceive the meat as being of a poor quality (Chambers & Bowers, 1993; Rodger, 2001).

Cooking loss

Chambers and Bowers (1993) agreed that consumers regard cooking loss or shrinkage during cooking as an important sensory cue. Consumers perceive meat with a high percentage of cooking loss or shrinkage during cooking, as meat of poor or inferior quality (Barbera & Tassone, 2006).

Cooking loss is the amount of moisture released by the meat during cooking due to heat induced structural changes in the tissue of the meat (Honikel, 2004). The denaturation of the myofibrillar proteins are initiated by cooking (30 - 50°C and 55 - 65°C) and the proteins (myofibrillar and sarcoplasmic) coagulate, resulting in shrinkage of the myofilaments and the release of the water contained in these fibers (Honikel, 1998; Warriss, 2010). The degree of moisture loss during cooking is depended on the ultimate pH of the meat (Marsh *et al*., 1987; Aalhus, 1995; Lawrie, 1998; Honikel, 2004). A high ultimate muscle pH produces meat with a relatively lower cooking loss when compared with meat with a low pH (Lawrie, 1998; Honikel, 2004). The muscles of animals exposed to pre-slaughter stress have an ultimate low pH subsequently increasing the cooking loss of the meat due to extensive protein denaturation of the muscle fibers (Lawrie, 1998). Jeremiah *et al*. (2003) stated that that skeletal muscle containing a high concentration intramuscular fat, will have a low percentage of cooking loss and skeletal muscle containing a high concentration of moisture and insoluble collagen, will have a high level of cooking loss. Thomas *et al*. (2004) also concluded that cooking loss of meat is inversely correlated with drip loss therefore the cooking loss of a sample decreases with an increase in drip loss.

The effect of extensive and intensive production systems on the cooking loss of meat is not clear from literature and various authors have found contradicting results. Various authors concluded that production systems had no significant influence on the cooking loss percentage of meat from pigs (Enälft *et al*., 1997; Stern *et al*., 2003) and lambs (Carrasco *et al*., 2009). On the other hand, Vestergaard *et al*. (2000) found that the meat from extensively raised bulls had a significantly higher cooking loss when compared to intensively raised bulls. Summer *et al*. (1978) and Olsson *et al*. (2003) observed a higher cooking loss from pigs and lambs raised in an intensive production system, respectively.

Meat tenderness

Consumers regard meat tenderness as the primary determinant of quality and consider it as the most important meat palatability trait (Boleman *et al*., 1997; Dransfield *et al*., 1998; Lawrie, 1998; Martin & Rodger, 2004; Pietrasik & Shand, 2004). Toughness/tenderness of meat is linked to various factors, of which Miller *et al*. (1995) identified four main causes (marbling; connective tissue type and content; enzymatic ageing/tenderisation; muscle shortening).

Instrumental tenderness

Toughness/tenderness is the most important sensory texture attribute of meat (Chambers & Bowers, 1993). According to Hyldig and Nielsen (2001) it is the only sensory parameter of meat that could only by quantified by humans although various texture assessing instruments have been develop by measuring the tissue's resistance to shearing and/or compression (Huidobro *et al*., 2005). Szczesniak (1986) stated that subjective (sensory) tenderness is positively correlated with objective (instrumental) tenderness measurements.

The Warner Bratzler shear force (WBSF) test is the most widely acknowledged and used method for objectively evaluating the texture (toughness) of raw or cooked meat (Boleman *et al*., 1997; Miller *et al.*, 1995). Meat is sheared perpendicular to the muscle fiber direction and a tougher meat sample will have a higher resistance to shearing. The meat from intensively produced animals has a higher intramuscular fat content and a lower WBSF value, than extensively produced animals because intramuscular fat has a low resistance to shearing (Sañado *et al.*, 2003; Fonti *et al.*, 2009). Brewer and Calikin (2003) stated that animals raised on low energy diets (extensive production system) have a high connective tissue content which increases the meat's resistance to shearing thus contributing to the sensory toughness of the meat. Brewer and Calkins (2003) summarised the WBSF results of various studies (Bowling *et al.*, 1977; Bowling *et al.*, 1978; Harrison *et al.*, 1978; Schroeder *et al.*, 1980; Hedrick *et al.*, 1983; Schaake *et al.*, 1993; Sapp *et al.*, 1999; French *et al.*, 2000; French *et al.*, 2001) and concluded that extensively produced meat is tougher than intensively produced meat.

Texture Profile analysis (TPA) also known as the double bite test, which simulate human mastication was developed to measure multiple sensory parameters (toughness, cohesiveness, gumminess, resilience, adhesiveness, chewiness, elasticity and springiness) (Bourne, 1978). Toughness is the most important parameter of meat and is defined as the samples resistance against compression. Resistance to compression will be high in a sample with high collagen content and low in a sample with a high percentage of intramuscular fat. Toughness is measured during the first cycle of compression, known as first bite (Bourne, 1978). Huidobro *et al.* (2005) concluded that TPA accurately predicts sensory texture parameters of cooked meat when the analysis is performed on raw meat and predicts toughness better than WBSF.

Chemical composition of meat

PROXIMATE ANALYSIS

Moisture

Lean meat is comprised of approximately 72-75% water (Kauffman, 2001; Huff-Lonergan & Lonergan, 2005;) and post mortem muscle pH has an affect on the water holding capacity of meat (Lawrie, 1998). The moisture content of meat is inversely correlated with the intramuscular fat content of the muscle (Young *et al*., 2001). An increase in muscle protein results in an increase in

the intramuscular moisture content of meat because myofibrillar proteins are responsible for binding water (Goll *et al*., 1977).

It is evident from literature that the meat from extensively raised animals has a significantly higher moisture content than intensively produced animals (Summers *et al*., 1978 - lambs; Solomon *et al*., 1980 - lamb; Williams *et al*., 1983 - cattle; Rowe *et al*., 1999 - lambs; French *et al*., 2001 - cattle) which coincide with the fact that intensive production systems (high energy diets) produce carcasses with higher fat levels compared to extensively reared animals (Diaz *et al*., 2002 - lambs; Santos-Silva *et al*., 2002 - lambs).

The moisture content of meat contributes to various meat palatability traites (juiciness and tenderness) and could have a negative effect on the flavour of meat as most flavour carrying components are hydrophobic (Lawrie, 1998; Priolo et *al*., 2001; Jeremiah *et al*., 2003). Juiciness, flavour and the texture (tenderness) of meat are considered as the main intrinsic factors influencing meat palatability and consumer acceptability (Bello & Calvo, 2000; Brewer & Novakofski, 2008). Beilken *et al*. (1990) concluded that consumers prefer meat that is tender and juicy, and that juiciness as well as flavour contributes to overall acceptability of the meat (Risvik *et al.*, 1994).

Crude protein

Red meat is a valuable source of protein (≈20% in raw meat) that is rich in essential amino acids (lysine, leucine, isoleucine, sulphur containing amino acids) (Kauffman, 2001; Young *et al*., 2001; Huff-Lonergan & Lonergan, 2005;). Some authors' findings indicate that production system has an effect on the crude protein content of meat and that the meat from extensively produced livestock systems contains significantly more protein compared to intensive production systems (Summers *et al*., 1978; Solomon *et al*., 1980; Dworschák *et al*., 1995; Enfält *et al*., 1997; Olsson *et al*., 2003). Limited evidence is available that explain this phenomena but Theriez and Tissier (1981) concluded that muscle protein decreases with an increase in intramuscular fat content. Norton *et al*. (1970) suggested that an increase in the crude protein content of lamb's meat is related to an increase in dietary protein. A higher protein turn-over rate, as experienced in intensively produced livestock could also alter the crude protein content of the meat (Jones *et al*., 1990; reviewed by Olsson & Pickova, 2005). Diaz *et al.* (2002) proposed that extensive production systems (increase in physical activity and low plane of nutrition) alter the metabolism of the animals resulting in the utilisation of lipid reserves to produce muscular tissue, thereby increasing the protein content of the muscle.

Contradictory to these findings, various authors concluded that production systems had no significant effect on the protein content of meat (Keane & Allen, 1998 - cattle; Rowe *et al*., 1999 - lambs; French *et al*., 2000 - cattle; French *et al*., 2001 - cattle; Hoffman *et al*., 2003 – pigs; Pompa-Roborzynski & Kedzior, 2006 - lambs).

Total lipid content

Muscle tissue is comprised of approximately 5% fat containing (tri-, di-, mono-) acylglycerols, phospholipids, cholesterol esters and free fatty acids (Kauffman, 2001). Intramuscular fat of meat is a source of essential omega 3 and 6 fatty acids as well as fat-soluble vitamins (A, D, E and K), which are important for human nutrition and health (Nuernberg *et al*., 2005; Webb & O'Neill, 2008). Intramuscular fat stimulates saliva secretions during mastication, increasing the sustained juiciness of the meat as perceived by the consumer (Lawrie, 1998). Intramuscular fat also has a positive effect on meat tenderness and flavour of meat. Flavour carrying components are hydrophobic and are therefore dissolved in fat (Priolo *et al*., 2001, reviewed by Dinh, 2006). A high degree of marbling (intramuscular fat) is associated with intensive production systems (high energy diets) (Priolo *et al.*, 2002) and is positively correlated with tenderness due to dilution of muscle fibers (Smith *et al.*, 1976; Schönfeldt *et al*., 1993; Angood *et al.*, 2008). Fonti *et al.* (2009) indicated that consumers prefer meat with a higher degree of marbling, and positively associate it with tenderness. Health conscious consumers, on the other hand, demand lean meat which makes it extremely difficult for the meat industry to produce lean meat with good palatability traits. Issanchou (1996) stated that the negative impact of intramuscular fat on health related issues compete with the fats' positive contributions to meat flavour and juiciness.

Intensive production systems produce animals with higher slaughter weights and carcasses with a higher percentage of intramuscular fat when compared to extensive production systems (Solomon *et al*., 1980; Rowe *et al*., 1999; Pompa-Roborzynski & Kedzior, 2006; Vestergaard *et al*., 2000; French *et al*., 2001; Priolo *et al*., 2002). This could be ascribed to the high energy diets, high plane of nutrition and limited exercise associated with intensive production systems (Priolo *et al.*, 2002).

Ash

Meat contains approximately 1% ash, which is the mineral constituent (iron, potassium, phosphorus, oxides, sulphates, silicates and chlorides) of meat and these are essential for human nutrition (Lawrie, 1998; Higgs, 2000; Kauffman, 2001; Biesalki, 2005; MacRae *et al*., 2005). Various authors have concluded that production systems had no effect on the ash content of meat (Enfält *et al*., 1997 - pig; Rowe *et al*., 1999 - lamb; French *et al*., 2000 - cattle; French *et al*., 2001 - cattle; Hoffman *et al*., 2003 - pig). In contrast, Dworschák *et al*. (1995) reported a higher zinc and copper concentration in extensively produced pigs. Summer *et al*. (1978) and Solomon *et al*. (1980) reported that the meat of intensively reared lambs contained significantly less ash. The higher ash content of extensively produced animals could be attributed to a higher heam pigment concentration, improved capillarisation of muscles due to aerobic exercise and a higher metal binding capacity of muscle tissue from extensive production systems (reviewed by Olsson & Pickova, 2005).

Collagen

Meat contains three types of connective tissue, epimysium, endomysium and perimysium (Fung *et al*., 1981). Perimysium is more abundant in muscular tissue and is linked to the variation in meat tenderness (Light *et al*., 1985; McCormick *et al*., 1999; Purslow *et al*., 1999). The type, concentration and solubility of intramuscular collagen are a major determinant of meat tenderness (Cross *et al*., 1973).

High-energy diets, associated with intensive production systems, have a positive effect on meat tenderness as the rapid weight gain decreases the intramuscular collagen content of muscular tissue (Fishell *et al*., 1985). Muscles that are active during locomotion are less tender due to an increase in intramuscular collagen, and Petersen *et al*. (1997) concluded that physical activity increases the insoluble collagen content of meat as well as decreasing the solubility of collagen. The taste panel results of various studies (Bowling *et al*., 1977; Bowling *et al*., 1978; Harrison *et al*., 1978; Schroeder *et al*., 1980; Hedrick *et al*., 1983; Schaake *et al*., 1993; Sapp *et al*., 1999; French *et al*., 2000, 2001) confirms that intensively produced meat is more tender than extensively produced meat (reviewed by Brewer & Calkins, 2003).

Consumers regard meat tenderness as the primary determinant of quality and consider it as the most important meat palatability trait and organoleptic characteristic of meat (Boleman *et al*., 1997; Martin & Rodger, 2004).

Fatty acid profile

It has been reported that the feed composition of various ruminant production systems has an effect on the fatty acid profile of meat. Saturated fatty acids in meat of ruminants are derived directly from the diet (feed), biohydrogenated from mono- and polyunsaturated fatty acids by rumen bacteria, or synthesised from acetate and glucose in the liver or adipose tissue (Wood *et al*., 2008). Desaturase enzymes initiate the synthesising of saturated fatty acids to monounsaturated-*cis* fatty acids, in meat (Wood *et al*., 2008). Polyunsaturated fatty acids Linoleic acid (C18:2n6) and α-Linolenic acid (C18:3n3) are essential fatty acids which cannot be synthesised by mammals and are derived directly from the diet of the animal (Wood *et al*., 2008; Warriss, 2010). Grains and seeds are naturally rich in Linoleic acid (C18:2n6) and forage (plants) are rich in α-Linolenic (C18:3n3). Eicosapentaenoic acid (EPA; C20: 5) and Docosahexaenoic acid (C22:6) controls thrombosis and skeletal inflammation and are synthesised from α-Linolenic acid (C18:3n3) (Wood *et al*., 2008; Warriss, 2010). Arachidonic acid is synthesised from Linoleic acid (C18:2n6), which promotes skeletal muscle growth/repair (Wood *et al*., 2008; Warriss, 2010). High levels of Linoleic acid (C18:2n6) prevents the synthesis of Eicosapentaenoic (EPA; C20:5) and Docosahexaenoic acid (C22:6) from α-Linolenic (C18:3n3) which has a negative effect on the individuals health as n3 acids prevent blood clotting while n6 acids have a complete adverse effect on clotting (Wood *et al*., 2008; Warriss, 2010). Long chain polyunsaturated fatty acids (C20 - C22) in meat are derived from the diet of the animals as well as synthesised from α-Linolenic acid (C18:3n3) and Linoleic acid

(C18:2n6), initiated by ∆5 & ∆6 Desaturase and Elongase enzymes (Wood *et al*., 2008; Warriss, 2010).

Animals on concentrate diets (intensive production systems) produce meat with a high-unsaturated fatty acid content and with a higher Linoleic (omega 6) to α-Linolenic (omega 3) ratio, which increases the consumer's risk to cardiovascular diseases and cancers. Forage diets of pasture fed animals are rich in C18:3n3 poly unsaturated fatty acids and produce meat with a high total monounsaturated fatty acid content which support consumer health (Miller *et al*., 1967; Lantham *et al*., 1972; Marmer *et al*., 1984; Mitchell *et al*., 1991; Duckett *et al*., 1993; Patil *et al*., 1993; Enser *et al*., 1998; Sañudo *et al*., 2000; Scollan *et al*., 2001; Wood *et al*., 2003; Aurousseau *et al*., 2004; Nuernberg *et al*., 2005, 2008; Aurousseau *et al*., 2007; Popova, 2007; Scerra *et al*., 2007).

The fatty acid composition of meat lipids could also have various adverse affects on the quality of fresh meat (lipid oxidation and pigment stability, flavour, odour, subcutaneous and intramuscular fat hardness). An increase in the n3 PUFA ratio decreases the meat's oxidative stability, promoting the development of rancidity (Wood *et al*., 2003). Rancid meat has a short shelf life, unpleasant taste and is rejected by the consumer (Wood *et al*., 2003). Lipid oxidation produces volatile odorous compounds (4-heptenal a by-product of α-linolenic acid oxidation) which contributes to off-odours and flavour in meat (Wood *et al*, 2003). Renerre (2000) reported that lipid oxidation also initiates pigment oxidation (red oxymyoglobin to brown metmyoglobin) in meat, producing meat with an undesirable colour. Methyl-branched-chain fatty acids (4-methyloctanoic and 4-methylnonanoic acids) are the components responsible for the typical flavour and odour of cooked sheep/lamb meat (Mottram *et al*., 1998; Young *et al*., 1996). High concentration of methyl branched fatty acids (BCFA) in the subcutaneous and intramuscular fat of sheep/lamb results in an undesirable cooked flavour and odour (Wong *et al*., 1975a; Wong *et al*, 1975b) and van Soest (1994) reported a high concentrations of BCFA in grain fed animals.

Sensory meat quality of lamb

Sensory Juiciness

The two sensory descriptive words for juiciness, in cooked meat, are initial and sustained juiciness (Dryden & Marchello, 1970; Lyon & Lyon, 1989). Initial juiciness is the amount of fluid released by the cut surface of meat, during compression between the forefinger and thumb (AMSA, 1995). Initial juiciness of meat is positively correlated with the water holding capacity of meat, which is influenced by the muscle's ultimate end pH post mortem (Offer & Trinick, 1983). An ultimate low pH post mortem decreases the water holding capacity of meat by denaturation of the water binding proteins (Huff-Lonergan *et al*., 2005). Muir *et al.* (1998) stated that animals from extensive production systems are significantly more susceptible to ante-mortem stress than intensively produced animals, because they are not accustomed to confinement and handling. Pre-slaughter stress triggers ante mortem muscle glycogen depletion and results in a high ultimate pH post

mortem (Muir *et al.*, 1998). Post mortem glycogen depletion is also more common in animals from extensive production systems due to their low energy diets and increased exercise during grazing (Vestergaard *et al.*, 2000). Santa-Silva *et al.* (2002) found that pasture fed (free-range) animals had a higher water holding capacity when compared to concentrate fed (feedlot) animals and therefore according to literature would have a higher initial juiciness score.

Sustained juiciness is described as the perceived juiciness after a few seconds of mastication, due to the presences of intramuscular fat stimulating saliva secretion (Lawrie, 1998). Intensive production systems produce animals with higher slaughter weights and fatter carcasses with a higher percentage of intramuscular fat when compared to extensive production systems. This could be ascribed to the high energy diets and limited exercise associated with extensive production systems (Priolo *et al.*, 2002).

Sensory flavour and aroma

Flavour is experienced during mastication when volatiles are released in the oral cavity and aroma is perceived by the olfactory system. Lamb's meat has a distinct aroma and flavour when compared to other ruminants (Horstein & Cowe, 1960, 1963). Branched-chain fatty acids (4-methyloctanoic acid), present in the storage fat of lambs, are responsible for this unique species specific flavour and aroma (Wong *et al.*, 1975; Brennand & Lindsay, 1992; Priolo *et al.*, 2001). Higher concentrations of branched-chain fatty acids were found in the fat of grain fed lambs when compared to grass fed lambs (Young *et al.*, 2003; Vasta & Priolo, 2006). Pastoral flavours and odours on the other hand are mainly associated with animals that are pasture fed. These flavours and odours are generally described as "grassy", "animal-like", "rancid" or "barnyard" and are regarded as off-flavours and odours (Berry *et al.*, 1980; Larick *et al.*, 1987). Young *et al.* (2003) found that these off-flavours and odours were caused by 3-methylindole (skatole), indole, methyl phenol and dimethylsulphone present in the fat of pasture fed lambs. The high 3-methylindole content is attributed to the fact that a pasture fed (free-range) animal's diet is rich in protein (tryptophan) and low in fiber (Claus *et al.*, 1994; Lane *et al.*, 1999; Bendall *et al.*, 2001). Rousset-Atkin *et al.* (1997) concluded that the diet of pasture fed sheep is directly correlated to the increase in the flavour and odour intensity. Rancid off-flavour and odour are also associated with pasture fed animals and is caused by 4-heptanal, an aldehyde derived from linolenic acid (Josephson *et al.*, 1987; Calwallander *et al.*, 1994; Young *et al.*, 1999). The subcutaneous fat of pasture fed animals contains relatively higher concentrations of linolenic acid, due to a diet rich in n3 polyunsaturated fatty acids (Ray *et al.*, 1975; Melton *et al.*, 1982; Young *et al.*, 1999; Wood *et al.*, 2003; Diaz *et al.*, 2005; Aurossou *et al.*, 2007; Popova *et al.*, 2007; Neurenberg *et al.*, 2008). Consumer preferences regarding lamb flavour and aroma intensity depend on the degree of exposure to lamb's meat (Young *et al.*, 2003). European (Fonti *et al.*, 2009) and New Zealand (Prescott *et al.*, 2001) consumers prefers meat with a lower lamb flavour and odour intensity

whereas Japanese consumers which are relatively unfamiliar with lamb or sheep's meat prefer bland meat (Prescott *et al*., 2001).

Sensory tenderness

Consumers regard meat tenderness as the primary determinant of quality and consider it as the most important meat palatability trait and organoleptic characteristic of meat (Boleman *et al.*, 1997; Martin & Rodger, 2004). Miller *et al*. (1995) found that consumers could easily distinguish between different meat tenderness levels and indicated that they are prepared to pay premiums for certified tender meat (Boleman *et al*., 1997; Shackelford *et al.*, 2001).

Intensively raised animals' produces carcasses with thicker subcutaneous fat layers due to a high energy diet and minimal exercise. The thick subcutaneous fat layer insulates the carcass, slowing the post-mortem cooling of the carcass down. This prevents cold induced shortening (cold shortening) of the muscles, and increases the activity of proteolytic enzymes post mortem which result in an overall improvement of meat tenderness (Smith *et al*., 1976; Lochner *et al*.,1980; Marsh *et al*., 1981; Fishell *et al*., 1985; Brewer & Calkins, 2003; Martin & Rodger, 2004).

An animal on a high energy diet (intensive production systems) has a higher average daily weight gain compared to an animal on a low energy diet (extensive production system). The rapid weight gain decreases the intramuscular collagen (cross-linked) content, and increases the protein turnover rate and proteolytic enzymes concentrations in the muscles which has a positive effect on meat tenderness (Aberle *et al.*, 1981; Hall & Hunt, 1982; Miller *et al.*, 1983; Fishell *et al.*, 1985; Andersen *et al.*, 2005).

Marbling (intramuscular fat) is associated with high energy diets (intensive production system) (Priolo *et al.*, 2002) and is positively correlated with tenderness (Smith *et al.*, 1976; Schönfeldt *et al.*, 1993; Angood *et al*., 2008). Fonti *et al.* (2009) indicated that consumers prefer meat with a higher degree of marbling, and positively associate it with tenderness.

The taste panel results of various studies (Bowling *et al.*, 1977; Bowling *et al.*, 1978; French *et al.*, 2000; French *et al.*, 2001; Harrison *et al.*, 1978; Hedrick *et al.*, 1983; Sapp *et al.*, 1999; Schaake *et al.*, 1993; Schroeder *et al.*, 1980) as summarised by Brewer and Calkins (2003) confirms that intensively produced meat is more tender than extensively produced meat.

Histochemical

Skeletal muscles are heterogeneous and comprised of numerous multinucleated cylindrical cells known as muscle fibers. Muscle fibers are bound together in fascicular bundles by means of perimysium and each muscle fiber is enclosed with the connective tissue, epimysium (Lawrie, 1998). Muscle fibers are 10 - 100 µm in diameter, represent 75-90% of the volume of skeletal muscles and comprise of myofibrils (Choi & Kim, 2009; Lefaucheur, 2010;). Myofibrils are further separated into sarcomeres, which consist of thick myosin and thin actin myofilaments (Lawrie, 1998). Muscle fiber types are classified according to their inherent colour, molecular, structural,

metabolic and contractile properties (Klont *et al*., 1998, Pette & Staron, 2001; Lefaucher, 2010). Various classification techniques and nomenclature have been developed for the classification of mammalian muscle fibers (Peinado *et al*., 2004).

The most widely accepted classification technique is based on the contractile properties of the muscle fiber and the sensitivity of the myosin adenosine triphosphatase (*m*ATPase) enzyme activity to the pH of the pre-incubation solution in a staining assay developed by Brooke and Kaiser (1970). Each fiber type has a specific intrinsic pH range at which the *m*ATPase activity is stable and outside of which the *m*ATPase activity is inhibited. Type I fibers have a relatively low *m*ATPase activity under alkaline conditions and type II fibers have a low *m*ATPase activity under acidic conditions (Jones & Round, 1990). Type I fibers are alkali labile (low activity after pre-incubation) and acid stable (high activity after acid pre-incubation). Type II fibers are alkali stable and acid labile. The *m*ATPase staining assay (Brooke & Kaiser, 1970) consists of two main steps: pre-incubation and staining. Firstly three successive cross sections, of a tissue specimen, are pre-incubated in alkaline and acidic solutions. The *m*ATPase activity of type II fibers are inactivated at pH 4.0 (acidic) and *m*ATPase activity of type I fibers are inactivated at pH 10 (alkaline). The pre-incubated step inactivates the *m*ATPase activity in various sets of fibers within the section. The sections are incubated with ATP at 37°C at a slightly alkaline pH. If any active *m*ATPase enzymes are present in the fibers after the pre-incubation step, the active *m*ATPase will hydrolyze the ATP to produce inorganic phosphate in these fibers (Jones & Round, 1990). The inorganic phosphate is invisible, therefore the second part of the assay is essential to visualise the inorganic phosphate to successfully determine which fibers' *m*ATPase was active at the specific pre-incubation pH which will assist with fiber type classification. After the ATP incubation step, the sections are transferred to a calcium chloride solution. The inorganic phosphate present in the fibers precipitates as calcium phosphate (white colour). The sections are then placed in a solution of cobalt chloride and the calcium in the calcium phosphate precipitate is replaced by cobalt producing cobalt phosphate, a brown precipitate which is more visible and less soluble (Jones & Round, 1990). Lastly the sections are washed in ammonium sulphide and the phosphate in the cobalt phosphate precipitate is replaced with sulphide. A stable brownish-black precipitate of cobalt sulphide forms at the sites of the active *m*ATPase enzyme activity in the muscle fibers (Jones & Round, 1990). After the pre-incubation step the muscle fibers are classified into Type I, Type IIA and Type IIB fibers, according to the stabilities of the *m*ATPase activity in acidic and alkaline solutions.

Type I muscle fibers are oxidative, slow twitch, red fibers that contracts slowly on a continuous bases for long periods of time without being fatigued. Type I muscle fibers have a high myoglobin and low glycogen content, and are essential for aerobic activities (e.g. maintaining posture). Type IIA muscle fibers are oxidative glycolytic, fast twitch, red fibers that contracts fast, are resistant to fatigue and are active during locomotion. Type IIB glycolytic, fast twitch, white fibers contain a high concentration of glycogen, contract in short bursts, fatigues easily and is

active during rapid locomotion (as reviewed by Lefaucher, 2010). A thorough understanding of the biochemical properties of each muscle fiber type and its direct implication on meat quality, will assist the meat industry to minimize quality variations (Lefaucher & Gerrard, 1998).

Colour stability and water holding capacity (drip loss)

Muscle fiber type I, is rich in myoglobin and contains high concentration of mitochondria. Mitochondria has a higher oxygen consumption rate than myoglobin, reducing oxymyoglobin (the bright red colour is synonymous with fresh meat) to metmyoglobin (a pale brown colour which is rejected by consumers). Muscles containing a high percentage of type I muscle fibers are directly correlated with a decrease of meat colour stability (Monin & Ouali, 1992).

The metabolic properties and post mortem glycogen metabolism of each muscle fiber type could contribute to the aesthetically undesirable stress induced meat colour phenomena known as PSE (pale, soft, exudative) and DFD (dry, firm, dark) meat (Warriss, 2010). Oxidative fiber type I contains low concentrations of stored glycogen and rapid glycogen depletion occurs post mortem resulting in a relatively high (> 5.7) ultimate pH. The iso-electric point of actin and myosin proteins are approximately 5.5 resulting in the myofilaments of meat with an ultimate high post mortem pH (> 5.5) to be closely bounded to each other, increasing the water-holding capacity (bounded water) of the meat and decreasing post mortem protein denaturation which ultimately decreases the exudate (Lawrie, 1998; Warriss, 2010). The closely bounded myofilaments restrict oxygen diffusion to the superficial layer of the meat, limiting oxymyoglobin (bright red colour) formation on the surface of the meat. The closely bounded structure also promotes the activity of oxygen scavenging enzymes producing deoxymyoglobin (dark purple colour) in the deeper layers of meat (Adam & Moss, 2000; Warriss, 2010). The tightly bounded water results in meat with a high water holding capacity, which negatively influences the juiciness of meat as experienced by the consumer during mastication and consumption. Bounded water also absorbs more light than free water, lowering the L* value of the meat on the CieLAB colour scale resulting in visually darker meat. Meat containing a large percentage of type I fibers, will produce DFD (dry, firm and dark) meat post mortem if the animals were subjected to a stressful environment post mortem (Warriss, 2010). DFD meat has a high spoilage potential because the ultimate high pH of the meat creates an optimum environment for spoilage bacteria to flourish. Consumers steer clear of meat with a dark colour because they perceive it as being of inferior quality or that the product has passed the 'sell by date' (Berg, 2000).

Glycolytic fibers (type IIB) contain a high concentration of stored glycogen, which is converted to lactic acid post mortem via the glycolytic pathway (Warriss, 2010). The production of large concentrations of lactic acid results in a rapid decline of the muscle's pH (< 5.8) within the first 60 minutes post mortem whilst the intramuscular temperatures are still above 37°C (Penny, 1969). These conditions (high internal temperature and low pH) enhance proteolytic enzyme activity causing excessive protein denaturation and degradation of the muscle fiber structure,

producing meat with an undesirable soft texture (Lawrie, 1998). The intramuscular pH (< 5.8) of muscles containing large quantities of fiber type IIB, is relatively close to the iso-electric point of protein (5.5), therefore the net charge of actin and myosin proteins would be zero. Proteins with no net charge attract water poorly which results in a decrease in the water holding capacity of the meat and an increase in exudation of the product (Lawrie, 1998; Warriss, 2010). Low muscle pH promotes the oxidation of oxymyoglobin (bright red) to metmyoglobin (pale brown) and combined with the high light scattering/reflection capacity of low pH meat due to a decrease in water holding capacity, results in a pale coloured meat (Adam & Moss, 2000; King & White, 2006; Warriss, 2010). PSE (pale, soft, exudative) meat occurs in muscles containing a high percentage of muscle fiber type IIB and produces meat that is rejected by the consumer based on appearance (soft texture, pale colour and large amounts of exudates) (Warriss, 2010). PSE meat is predominantly present in animals, which were subjected to pre-slaughter stress.

Fiber type affecting tenderness

During post mortem cooling the sarcoplasmic reticulum (SR) and mitochondria surrounding each myofibril, is stimulated by low temperatures (< 15°C), releasing calcium ions in the vicinity of the myofibrils (Lawrie, 1998). Calcium ions in the presence of sufficient adenosine triphosphate (ATP), triggers muscle contractions resulting in the formation of permanent cross-bindings between actin and myosin molecules and a reduction in sarcomere length, which is known as cold shortening (Lawrie, 1998; Berg, 2000). Muscles containing relatively large quantities of red oxidative muscle fibers (type I) are more prevalent to cold shortening due to the inadequate functioning of this muscle fiber type's SR, the inability of the SR to pump back the calcium ions and because muscle fiber type I contains large concentrations of mitochondria which diffuses calcium ions into the cytoplasm (Foegeding *et al*., 1996). The sarcomere length is positively correlated with tenderness therefore muscles containing high concentrations of muscle fiber type I will produce tougher meat if cold shortening occurred (Davis *et al*., 1979; Ceña *et al*., 1992). Herring *et al*. (1965) concluded that muscle shorting results in a decrease in sacromere length which subsequently increases the muscle fiber diameter resulting in a decrease in meat tenderness.

The size (diameter and area) of a non-contracted muscle fiber is inversely correlated with the oxidative capacity of the fiber (Klont *et al*., 1998). Oxidative fiber type I has the smallest fiber size, glycolytic fiber type IIB the largest and oxidative glycolytic type IIA has an intermediate size fiber (Cassens & Cooper, 1971; Rosser *et al*., 1992; Maltin *et al*., 1997; Lieber, 2002; as cited by Lefaucheur, 2010). The muscle fiber diameter of an active individual is larger than immature, inactive or older individuals (Tuma *et al*., 1962). Maltin *et al*. (1997) stated that, prior to the onset of post mortem proteolysis, meat with larger muscle fibers tends to be less tender than meat with smaller fiber diameter.

Tenderisation of meat is promoted by post mortem proteolysis, which is activated by proteolytic enzymes (calpains) and inhibited by the presences of proteolysis inhibitors

(calpastatins) (Koohmaraie *et al*., 1988; Koohmaraie, 1992,1996). Ouali and Talmant (1990) stated that muscle fiber type IIB has a higher calpain to calpastatin ratio, compared to the other muscle fiber types, promoting post mortem proteolysis and tenderisation (Whipple & Koohmaraie, 1992). Sazili *et al*. (2005) reported that post mortem proteolysis is decreased in muscles containing a large percentage of type I fibers due to the presence of a large concentration of calpastatin. Minimal tenderisation will thus take place during ageing in meat with a high percentage of type I fibers (Calkins & Seideman, 1988; Whipple & Koohmaraie, 1992; Sazili *et al*., 2005).

A z-line is the horizontal border that segments myofibrils into several sarcomeres. Fiber type I has the thickest z-line, fiber type IIB the thinnest and the z-line thickness of fiber type IIA is intermediate (Payne *et al*., 1975; Sjostom & Squire, 1977; Eisenberg, 1983; Maltin *et al*., 2003). Degradation of the z-line contributes to the tenderisation of meat but to a lesser extent than other mechanisms as described by Taylor *et al.* (1995). Therefore it could be suggested that the thicker z-line of type I muscle fibers will be a minor factor contributing to meat toughness.

Muscle fiber type I and IIA contain a higher concentration intramuscular fat (phospholipids and triacylglycerols) when compared to fiber type IIB (Essén-Gustavsson *et al*; 1992, 1994; Alasnier *et al*., 1996; Malenfant *et al*., 2001). Meat with a high intramuscular fat (marbling) content is positively correlated with a pleasant meat flavour and aroma. This could be ascribed to the high phospholipid content of the meat, which contributes slightly to the falvour (Essén-Gustavsson & Fjelkner-Modig, 1981; as cited by Lefaucheur, 2010). The taste panel results of Valin *et al*. (1982) confirmed that meat containing large concentrations of oxidative (type I and IIA) fibers are juicier and had an intense meat flavour when compared to fiber type IIB. Although various authors concluded that oxidative fibers contributes to a pleasant meat flavour, Lefaucheur (2010) stated that the high polyunsaturated content of muscle fiber type I increases the meat's susceptibility to post mortem fatty acid oxidation, resulting in meat with a rancid taste which is an undesirable sensory attribute. Calkins *et al.* (1981) suggested that muscle fiber typing could be used as a predictor of marbling and ultimately tenderness after concluding that fiber type IIB is negatively correlated with tenderness and intramuscular fat (marbling) content, and that oxidative fibers (I and IIB) are positively correlated with tenderness and intramuscular fat (marbling) content.

Oxidative slow twitch fibers (type I) in rat muscle, contain higher concentrations of collagen when compared to glycolytic fast twitch fibers (type IIB) (Kovanen *et al.*, 1984; Kovanen, 1989; Dingboom & Weijs, 2004). Postural muscles contain large concentrations of fiber type I and muscles involved in locomotion contain more type IIB fibers (Kovanen, 1989; Berg, 2000). Lefaucheur (2010) stated that meat tenderness decreases with an increase in the total collagen concentration especially insoluble collagen and, that although various authors have investigated the relationship between muscle fiber type and collagen content, no clear evidence on livestock has been published (Gondret *et al*., 2005).

The histochemical characteristics of skeletal muscles are influenced by several intrinsic (muscle type, species, breed, individual, sex, age) and extrinsic (exercise, ambient temperature, growth promoting agents) factors (Lefaucheur & Gerrard, 1998). Spontaneous physical exercise associated with extensive (free-range) rearing systems induces the transitions of fast twitch fibers (type II) to slow twitch fibers (type I) (Aalhus & Price, 1991; Lefaucheur & Gerrard, 1998; Petersen *et al*., 1998; Pette & Staron, 2000; Vestergaard *et al*., 2000a; Pette & Staron, 2001; Gentry *et al*., 2004, Abreu *et al*., 2006;). Postural muscles (e.g. *Longissimus dorsi*) are more oxidative (type I) when compared to muscles involved in locomotion (e.g. *Biceps femoris* and *Semimembranosus*) (Totland & Kryvi, 1991; Ono *et al*., 1995; Chang *et al*., 2003).

CONCLUSIONS

The modern red meat consumer considers meat quality as the most important characteristic but also demands healthier products that are environmentally friendly, promote sustainability and comply with animal welfare guidelines. Livestock production systems are being intensified to improve efficiency and productivity. It is crucial to provide the consumer with a product that is consistent in quality to subsequently increase the consumer's confidence in the product and encourage repurchasing, therefore it is essential to investigate the full impact of both production systems (extensive and intensive) on various meat characteristics, to ensure the quality is maintained and consumer expectations are met.

The overall objective of this study is to investigate the impact of an extensive (free-range) and intensive (feedlot) production system on the quality characteristics of the *Biceps femoris*, *Longissimus dorsi*, *Semimembranosus* muscles of Dohne Merino lambs, using various physical, chemical, sensory and histochemical analyses.

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Chapter 3

The effect of extensive and intensive production systems on the carcass yield and physical attributes of the muscles of Dohne Merino lambs

ABSTRACT

The aim of this study was to investigate the impact of an extensive (free-range) and intensive (feedlot) production system on the carcass yield and physical attributes of the muscles of Dohne Merino lambs. The extensive production system produced larger lambs (8 months) with heavier carcasses ($p < 0.05$) but intensively reared lambs had a higher ($p < 0.05$) dressing percentage. The production systems had no effect on the post mortem muscle pH and temperature decline, colour (L, a*, b*, hue, chroma), drip and cooking loss, ribeye area, muscle weight and carcass yield. Intensively produced reared lambs had a ($p < 0.05$) thicker subcutaneous fat layer (13^{th} rib: 2.23 mm; $3^{rd}/4^{th}$ lumbar vertebra: 1.23 mm) compared to extensive lambs (13^{th} rib: 5.45 mm; $3^{rd}/4^{th}$ lumbar vertebra: 3.48 mm). Overall the physical attributes of the muscles of the lamb carcasses were unaffected by the production systems and therefore these production systems should have no direct impact on consumer acceptability of the meat, expect for the subcutaneous fat layer of intensively reared lambs.*

Keywords: Free-range; Feedlot; Meat quality; Three-rib cut; Ribeye area; Subcutaneous fat

INTRODUCTION

Issanchou (1996) stated that the global red meat industry has shifted from being predominantly production-focused to becoming more consumer-orientated. The progressively global declining per capita consumption of red meat has forced the industry to become consumer-driven because of an increasingly competitive market (Smith *et al*., 2005).

Consumer acceptance and purchase behaviours are driven by various preferences and perceptions of quality (Cardello, 1995). A survey conducted by the American Sheep Producers Council in 1964 revealed that various meat quality characteristics (meat colour, meat leanness, meat appearance, fat colour, width of fat, amount of bone and waist, size and thickness of cut, texture and firmness of fat) influence consumer product acceptability – these quality characteristics are still applicable today. Steenkamp (1989) suggested that the consumer uses various intrinsic and extrinsic product cues to form a perceived impression of the quality. Molnár (1995) also stated that the quality of a food is determined by the safety, nutritional value, convenience and most importantly the sensory quality of the product. The modern red meat consumer also demands

healthier products that is environmentally friendly, promotes sustainability and complies with animal welfare guidelines (Ministry of Agriculture, Fisheries and Food, 1991 & 1997).

The red meat industry is not only driven by consumer concerns and preferences but also influenced by economic factors and environmental changes (Woodstock, 2010). Livestock farming in South Africa, as well as globally, is shifting to more intensive farming systems to increase productivity and profitability (Brand *et al*., 2001; Coetzee & Malan, 2007).

The objective of this study was to investigate the impact of an extensive (free-range) and intensive (feedlot) production system on the physical attributes and carcass yield of Dohne Merino lambs. Quality is the main driver for consumer purchase behaviour, therefore it is essential to investigate the full impact of both production systems (extensive and intensive) on the various meat quality characteristics so as to ensure the quality is maintained and that consumer expectations are met (Santa-Silva *et al*., 2002). This study did not include the quantification of the effect of gender (ram, ewe, castrated) on the physical attributes and carcass yield of Dohne Merino lambs.

MATERIALS AND METHODS

LAMB MANAGEMENT, HANDLING AND SLAUGHTER PROCEDURE

The Dohne Merino lambs were born in March 2008 on Mariendahl (33° 51' 0 S; 18° 49' 60 E) Agricultural Experimental Farm, situated in the Western Cape, South Africa. Mariendahl is located in a winter rainfall region. All lambs were born from parents bred and raised under free-range/free roaming condition. At birth lambs were randomly assigned to two production systems, extensive (free range; n = 7) or intensive (feedlot; n = 7). The average birth weight of the lambs from both production systems was 4.0 kg ± 1.5 kg. Lambs were nursed by their biological mothers and received *ad libitum* colostrums during the first 24 hours after birth. Lambs were vaccinated against Pulpy kidney (3 months old), Pasteurella (3 months old) and Blue tongue (6 month old).

Extensive production system

After birth, the lambs roamed together with their dams in a free range system on a 10 ha plot at Mariendahl Agricultural Experimental Farm, with a herd density of 8 lambs / sheep per hectare. The foliage on the plot was abundant and consisted mainly of Subterranean clover (*Trifolium subterraneum*), Musk storksbill (*Erodium moschatum*), Medic clovers (*Medicago spp.*) and Ryegrass (*Lolium spp*.). The lambs received 500 g Veekos stud feed™ (Table 1 indicating the feed composition) as supplementation (daily) and had *ad libitum* access to fresh water. The plot contained no steep, uneven or elevated areas, which could have led to excessive or strenuous exercise. Lambs in this production system were not confined in any manner and received unlimited/unrestricted natural exercise (physical activity) through grazing. The lambs were weaned 100 days after birth.

Table 1 Feed composition of Veekos stud feed™ (intensive production system) and forage based diet (extensive production system)

	Veekos stud	Musk storkbill	Ryegrass	Medic clover	Subterranean
Total Moisture (%)	11.8	87.4	84.7	84.4	82.5
Crude protein (%)	14.8	21.0	26.8	25.3	27.8
Total Fat (%)	3.2	3.1	3.2	2.4	3.2
Crude Fiber (%)	15.1	11.3	24.8	16.7	19.8
Total Ash (%)	5.4	1.8	1.8	1.7	1.9
Energy (MJ/kg)	16.2	15.6	18.1	17.8	18.5

Intensive production system

Lambs were weaned from their biological mothers, at an age of 4 days. After weaning the lambs were moved to an indoor holding pen (1.6 m x 1.6 m) with a surrogate mother (Saanen goat - *Capra hircus*) and two other newborn lambs. The indoor pen had sufficient bedding and the design of the holding facilities were in compliance with South African Feedlot Association (SAFA, 2008), the National Environmental Guidelines for Feedlots (SAFA, 2005) and Animal Protection Act (Act No. 71 of 1962) (Anon., 1962). Lambs were nursed by the Saanen goats and were also weaned at an age of 100 days. After weaning the lambs were individually confined to 1 x 2 m indoor stalls and fed Veekos Stud Feed™ pellets, with a metabolisable energy of 9.8 MJ kg^{-1} and lucerne. Lambs had *ad libitum* access to lucerne, Veekos Stud Feed™ pellets and fresh water.

Slaughtering

Dohne Merino lambs from both production systems were slaughtered at an age of 8 months, using standard South African slaughtering methods (Cloete *et al.*, 2004). The slaughter weight of the lambs was recorded 24 hours prior to slaughtering. The lambs were transported approximately 60 km to a commercial abattoir in Malmesbury (33° 27' 0 S; 18° 41' 60 E) on a day with a maximum temperature of 25°C. The lambs were off-loaded at the abattoir, grouped together and housed in lairage overnight. The lambs had *ad libitum* access to fresh water and received no feed. The next morning the lambs were electrically stunned (4 s at 200 V), hang by the Achilles tendon and the jugular vein severed (Cloete *et al.*, 2004). After exsanguination the carcasses were skinned, dressed and stored at 4°C for 24 hours. After 24 hours the carcasses were transported approximately 60 km in a refrigerated truck (4 - 7°C) to the Meat Science Laboratory at Stellenbosch University. The carcasses were offloaded and stored in the deboning area (6 - 8°C) of the laboratory for another 24 hours. The carcasses (kidneys attached) were weighed before sampling commenced and the weights recorded as the cold carcass weight. The dressing percentage (%) of each lamb was calculated as follows:

Dressing percentage (%) = (cold carcass weight / live slaughter weight) * 100.

Experimental units

Whole skeletal muscles (*Biceps femoris*, *Longissimus dorsi* and *Semimembranosus*) were chosen as experimental units instead of retail cuts. This decision was made based upon the fact that retail cuts consist mainly out of two or more muscles, each with different endogenous metabolic systems, and functions, and may also contain bones, tendons or excessive connective tissue. The latter will act as unnecessary variables during analyses, thus masking the effect of the treatment being investigated.

The *Biceps femoris* is situated at the extensor of the hip, stifle, and hock joints and flexes the stifle when the hind foot is lifted off the ground (Nickel *et al*., 1986; Frandson *et al*., 2003). The whole *Biceps femoris* muscle was excised from the left side of the carcass 48 hours post mortem and weighed (g).

The *Longissimus dorsi* acts as an extensor of the back and loin and flexes the spine laterally (Nickel *et al*., 1986; Frandson *et al*., 2003). A portion (1^{st} - 8^{th} rib) of the *Longissimus dorsi* muscles was excised (48 hours post mortem) from the left side of the carcass for various physical measurements (drip and cooking loss, colour). The *Longissimus dorsi* muscle at the 9^{th} – 11^{th} rib was left intact (muscle not removed from bone/rib) and cut into a three-rib cut to determine the muscle, bone and fat ratio of the carcass which is used to predict carcass yield (Hankins & Howe, 1946). A second section of the *Longissimus dorsi* muscle (13^{th} rib to 3^{rd}/4^{th} lumbar vertebra) was left intact to measure the subcutaneous fat thickness of the carcass. The weight of the *Longissimus dorsi* was not recorded because the whole muscle was not removed and could lead to inaccurate comparisons.

The *Semimembranosus* muscle acts as the extensor of the hip joints and flexor of the stifle (Nickel *et al*., 1986; Frandson *et al*., 2003). The whole *Semimembranosus* muscle was excised from the left side of the carcass 48 hours post mortem and weighed (g). All muscle weights were expressed as a percentage (%) of the cold carcass weight = (muscle weight / cold carcass weight)*100.

Physical measurements

pH and temperature

The pH and temperature of the *Biceps femoris* (centre), *Longissimus dorsi* (last rib) and *Semimembranosus* (centre) muscles, were measured on the left side of each carcass immediately after deskining (pH_0; $Temp_0$) and 48 hours (pH_{48}; $Temp_{48}$) post mortem. The measurements were taken with a Testo 205 handheld portable pH meter with a temperature probe (Testo AG, Germany) and calibrated with standard buffers (pH 4.0 and pH 7.0) provided by manufacturer.

Sample preparations

All physical measurements were made on fresh muscles excised 48 hours post mortem.

Subcutaneous fat measurements

The subcutaneous fat layer of each carcass was measured with a handheld calliper (mm), 25 mm off the midline of the spine at the 13th rib (Gilmour *et al*., 1994) and between the 3rd/4th lumbar vertebra (Bruwer *et al*., 1987), to determine the thickness of the fat layer.

Ribeye area

The ribeye area was measured on the surface of the *Longissimus dorsi* muscle (left-side of the carcass) at the 13th rib interface, of all the lambs from both production systems (extensive and intensive). The area of the muscle was traced onto a transparent sheet of plastic and measured (mm^2) with a portable area meter (LI-COR, LI3000A, Lincoln, Nebraska, USA) (Gilmour *et al*., 1994). Measurements were repeated five times and the average ribeye area was recorded in mm^2.

Three-rib cut

Three-rib cut (9 - 11th rib) method was used to determine the muscle, fat and bone yield of each carcass (Hankins & Howe, 1946). Three-rib cut (9th - 11th rib) was cut from the left side of each carcass with a cut at the anterior side the 9th rib and the posterior side of the 11th rib, including the muscular tissue between the 11th and 12th rib. Three-rib cut of each carcass, was dissected into three anatomical components (muscle, fat and bone), each component was weighed (g) and expressed as a percentage (%) of the total cut.

Colour

Samples for colour measurements were prepared as described by Honikel (1998). Each muscle was cut into 1.5 cm steaks and bloomed (exposed to atmosphere) at 8°C for 30 minutes. Three meat colour measurements were taken on the bloomed surface, at random positions. A calibrated handheld colorimeter was used and the three colorimetric coordinates (L*, a* and b*) of the CIELab colormetric system was recorded (Honikel, 1998). The colorimeter was calibrated using black (L* = 0) and white (L* = 100) standards. The sample colour intensity (chroma) and dimension (hue angle) was calculated by using the a* and b* coordinates: Hue angle = $\tan^{-1}$ (b*/a*) and Chroma = $\sqrt{(A^{*2} + b^{*2})}$.

Drip loss

The drip loss (%) of the *Biceps femoris*, *Longissimus dorsi* and *Semimembranosus* muscles were determined by using the method described by Honikel (1998). Samples (1.5 cm thick) were

weighed and suspended inside a fridge (4°C) in individually sealed inflated plastic bags. After 24h the samples were removed from the bags, blotted dry with tissue paper and weighed (g). The total drip loss of each sample was calculated by determining the total weight loss (g) of the sample during storage and expressing it as a percentage (%) of the total weight (g) (Honikel, 1998).

Cooking loss

The total weight loss (g) of a fresh meat sample during cooking was determined by using the method described by Honikel (1998). A steak (1.5 cm) of each sample was weighed (g) and sealed in a plastic bag and placed in a preheated water bath (80°C) for 60 minutes. After the cooking period was completed, the fluids in the bag were drained and the sample was cooled at 4°C. Before recording the final weight (g), the sample was blotted with tissue paper to remove excess moisture. The following formula was used to calculate the cooking loss of each sample: Cooking loss (%) = (Cooked Weight/ Fresh Weight) x 100.

Statistical analysis of data

Slaughter and cold carcass weight, Dressing %, Subcutaneous fat, Ribeye area, Three-rib cut

A complete randomised experiment was performed with two independent treatments (extensive or intensive production system) with seven randomly selected lambs within each. A standard one-way analysis of variance was performed using SAS™ statistical software (Statistical Analysis System, Version 9.2). The studentised residuals were calculated for all the variables and tested for deviations from normality using Shapiro-Wilk's test (Shapiro & Wilk, 1965). Outliers were identified and removed before the final ANOVA's were performed (Snedecor, 1967). The significant level of the F-Ratio test ($p \leq 0.05$) will be considered as a significant difference.

Muscle weight, pH, Temperature, Colour, Drip and Cooking loss

A random split-plot design, with two production systems (extensive and intensive) as the main-plot, was used as the experimental design in this study. Seven carcasses were randomly drawn from each main-plot and the sub-plot factor consisted of three muscles (*Biceps femoris*, *Longissimus dorsi* and *Semimembranosus*). A random split-plot analysis of variance (ANOVA) was performed on the recorded physical attributes and chemical characteristics. The studentized residuals were calculated for all the variables and tested for deviations from normality using Shapiro-Wilk's test (Shapiro & Wilk, 1965). Outliers were identified and removed before the final ANOVA's were performed (Snedecor, 1967). Means of significant effects were compared using Student's t-LSD (Least Significant Difference) at a 5% level of significance.

Pearson's correlation coefficients were calculated for comparison between physical (Chapter 3), chemical (Chapter 4), sensory attributes (Chapter 5), instrumental tenderness (Chapter 5), and histochemical characteristics (Chapter 6) variables. All above procedures were analyse using SAS™ statistical software (Statistical Analysis System, Version 9.2).

RESULTS & DISCUSSION

Slaughter and Cold carcass weight

In Table 2 it is clear that lambs from the extensive production system produced significantly larger lambs (slaughter weight) and heavier carcasses (cold carcass weight). These results are inconsistent with the findings of Crouse *et al*. (1981) who noted that the feedlot production system produces larger and heavier lambs (live slaughter weight) compared to forage-based diets (free-range). The possibility exists that the intensively reared lambs, in this study, experienced an early stress when removed from their biological mothers, which consequently retarded growth during the fostering period by the Saanen goat ewes. A possibility also exists that the lambs may have been immunologically challenged when placed on goat milk – this aspect warrants further research. On the other hand, the well-developed digestive tract of extensively reared animals could contribute to a higher slaughter weight of these animals compared to lambs in an intensive production system (Hatfield, 1994; Priolo *et al*., 2002).

Dressing percentage

Intensively produced lambs had a higher dressing percentage ($p = 0.014$) compared to the extensive production system (Table 2), similar results were obtained by various authors (Williams *et al*., 1983 – cattle; Notter *et al*., 1991 – lambs; Moron-Fuenmayor & Clavero, 1999 – lambs; Murphy *et al*., 1994 – lambs). The difference in dressing percentage (%) could be ascribed to the well-developed digestive tract of extensively produced animals (Hatfield, 1994; Priolo *et al*., 2002) and it could also be assumed that the kidneys of the significantly fatter intensively reared lambs (Table 4) in this study, would be enclosed with more fat (not measured) which could also have an effect on the dressing percentage (%). Kidneys were not removed prior to weighing of the carcasses.

Borton *et al*. (2005 a & b) also concluded that the thin subcutaneous fat layer of extensively reared lambs, together with a well developed digestive system, contributes to an overall lower dressing percentage, compared to animals from an intensive production system.

Claasen (2008) conducted a similar study on the effect of feedlot and free-range production systems on the growth rate and carcass characteristics of Dorper lambs, under South African conditions. Feedlot conditions produced Dorper lambs with a significantly higher cold carcass weight (kg) and dressing percentage.

Table 2 The mean (±SD) slaughter weight (kg), cold carcass weight (kg) and dressing percentage (%) of Dohne Merino lambs produced in extensive (n = 7) and intensive (n = 7) production systems

	Extensive	Intensive	p-Value
Slaughter weight (kg)	48.29 ±2.14	39.76 ±3.08	<0.0001
Cold carcass weight (kg)	18.59 ±0.63	16.43 ±1.23	0.001
Dressing percentage (%)	38.55 ±1.95	41.36 ±1.69	0.014

SD (Standard Deviation)

Muscle weight

Production systems had no significant effect on the muscle weight of the *Biceps femoris* , *Longissimus dorsi* and *Semimembranosus* (Table 3).

Shavlakadze and Grounds (2006) reported that an increase in skeletal muscle mass occurs in response to physical activity (grazing). The function of a specific muscle will determine the degree of skeletal muscle hypertrophy occurring as well as the intensity of the mechanical loading (exercise or physical activity) and the period of exposure. On the other hand Aalhus *et al*. (1991) concluded that the weight of muscles are not affected by exercise alone but also by the period exposed to physical exercise. Therefore it could be argued that if the extensively reared lambs in this study were exposed to the production system (extensive) for a longer period (> 8 months), the production system would have had a significant effect on the final weight of the *Biceps femoris* and *Semimembranosus* (locomotive muscles; Nickel *et al*., 1998; Frandson *et al*., 2003).

pH

The production systems (extensive and intensive) had no effect ($p > 0.050$) on the post mortem pH (0 to 48 hours) decline of the *Biceps femoris*, *Longissimus dorsi* and *Semimembranosus* (Table 3).

Extensively produced animals (free range) associated with low energy forage diets or a low plane of nutrition, have relatively small but sufficient glycogen reserves to ensure a gradual decline in muscle pH post mortem. The ultimate muscle pH_{48} of free-range animals are normal but slightly higher compared to intensively produced livestock (Priolo *et al*., 2001). Results obtained in this study are in concurrence with literature and it could be concluded that the diet of both production systems in this study had no effect on the ultimate pH of the muscle 48 hours post mortem (Bidner *et al*., 1986 - cattle; Morris *et al*., 1997 - cattle; Sañudo *et al*., 1997 - lambs; Keane & Allen; 1998 - cattle; French *et al*., 2001 - cattle; Diaz *et al*., 2002 - lambs; Gentry *et al*., 2002 - pigs; Priolo *et al*., 2002 - lambs; Realini *et al*., 2004 - cattle; Nuernberg *et al*., 2005 – cattle; as reviewed by Olsson & Pickova, 2005 – pigs; Ripoll *et al*., 2008 - lambs; Carrasco *et al*., 2009 – lambs).

Animals from extensive production systems are also more susceptible to pre-slaughter stress because they are not accustomed to confinement (lairage) and being handled (herding,

transporting and slaughtering) (Bowling *et al*., 1977; Warriss *et al*., 1983; Barton-Gade & Blaabjerg, 1989; Muir *et al*., 1998). From these results it could be concluded that the extensively reared lambs experienced insignificant amounts of pre-slaughter stress and had no effect on the ultimate muscle pH.

Temperature

The production systems (extensive and intensive) had no significant effect on the temperature decline post mortem of the *Biceps femoris*, *Longissimus dorsi* and *Semimembranosus* muscles (Table 3).

A thick subcutaneous fat layer associated with intensively produced livestock, acts as an insulator and decreases the cooling rate of the carcass during post mortem cooling (Olsson *et al*., 1994; Lawrie, 1998; Priolo *et al*., 2001). The significantly thicker subcutaneous (Table 4; 13^{th} and $3^{rd}/4^{th}$ lumbar vertebra) fat coverage of intensively produced lambs in this study, could explain the tendency observed in Table 3, that the post mortem ($Temp_{48}$) temperatures of the intensively produced lamb are slightly higher. The overall anatomical position of the muscle could also have had an effect on the cooling rate of these muscles, post mortem. Superficial muscles (*Longissimus dorsi*) have a more rapid cooling rate compared to deeper muscle (*Biceps femoris* and *Semimembranosus*) (Lawrie, 1998), which explains the slight temperature differences between the muscles in Table 3.

Subcutaneous fat

Production systems had an effect on the subcutaneous fat coverage (mm) of the Dohne Merino lambs (Table 4). Intensively produced lambs had a significantly thicker subcutaneous fat coverage (mm) at the 13^{th} rib and $3^{rd}/4^{th}$ lumbar vertebra. High energy diets and minimal physical activity associated with intensive production systems contributes to the production of carcasses with significantly thicker subcutaneous fat layers (mm) compared to extensively reared livestock (Williams *et al*., 1983 - cattle; Enfält *et al*., 1997 - pigs; Diaz *et al*., 2002 – lambs; Gentry *et al*., 2002 - pigs; Realini *et al*., 2004 - cattle; Borton *et al*., 2005 a & b - lambs).

Consumers have became more health conscious and prefer lean meat with less visible fat (Carpenter, 1966; Resurreccion, 2003) therefore the significantly higher subcutaneous fat thickness of intensively produced lambs could have a negative effect on consumer purchase behaviour. The Industry Wide Lamb and Wool Planning Committee (1964) in the USA, suggested that the subcutaneous fat covering of lambs should not exceed 0.76 cm (maximum) to comply with consumer preferences (as reviewed by Carpenter, 1964). Results obtained in this study comply with these guidelines.

Ribeye area

The production systems had no ($p = 0.910$) effect on the ribeye area (mm^2) of the lambs in this study (Table 4) and would therefore have no negative effect on consumer purchase behaviour. Various authors concluded that the total area (mm^2) of the ribeye is influenced by the live weight of an animal and that the ribeye area (mm^2) of animals from intensive production systems are significantly larger compared to extensively reared animals (Bowling *et al*., 1977; Bowling *et al*., 1978; Harrison *et al*., 1978; Hedrick *et al*., 1983; Schaake *et al*., 1993; Sapp *et al*., 1999; Zervas *et al*., 1999; French *et al*., 2000; French *et al*., 2001; Realini *et al*., 2004). No correlation ($r = 0.031$; $p = 0.917$) was observed between the ribeye area (mm^2) and live weight (kg) of lambs used in this study.

Three-rib cut

Production systems had no significant effect (at the 5% level) on the muscle, fat and bone yield of Dohne Merino lambs (Table 5). Although no significant differences were detected, lambs from the extensive production system produced carcasses with a higher muscle to bone yield and less fat ($p = 0.055$) compared to intensively reared lambs. The muscle to bone ratio of a carcass increases with increase in slaughter weight and is influenced by age, breed and nutrition (Berg & Butterfield, 1968; Bailey *et al*., 1985; Zupka *et al*., 1996). The heavier slaughter weight of lambs from the extensive production system (Table 2) supports this theory and could explain the slightly higher muscle to bone ratio of these lambs compared to lambs from the intensive production system. No correlations were observed between the muscle ($r = 0.173$; $p = 0.5549$) and bone ($r = 0.280$; $p = 0.332$) when compared to the live weight (kg) of the lambs. The higher fat percentage (fat ratio; $p = 0.055$) of intensively produced lambs coincides with the significantly thicker subcutaneous (13^{th} and $3^{rd}/4^{th}$ lumbar vertebra) fat layer of lambs from intensive production system (Table 4), although no significant correlation was observed between the fat ratio and subcutaneous fat layer.

Red meat consumers prefer lean meat with less visible fat (Resurreccion, 2003). Mauldin and Mauldin (2010) suggested that a retail cut with a higher edible product (meat) to bone ratio is more beneficial to the farmer (higher prices for premium products) and preferred by the consumer (value for money). As production system (extensive and intensive) had no effect on the muscle to fat to bone ratio there should be no negative effect on the purchase behaviour of consumers if either production system was followed.

Table 3 The mean (±SD) muscle weight (*Biceps femoris* and *Semimembranosus*) of expressed as a percentage of cold carcass weight (kg), pH and temperature (time of death to 48 hours post mortem; °C) of the *Biceps femoris*, *Longissimus dorsi* and *Semimembranosus* muscles of Dohne Merino lambs reared in an extensive (n = 7) or intensive (n = 7) production system

	Biceps femoris			***Longissimus dorsi***			***Semimembranosus***		
	Extensive	**Intensive**	**p-Value**	**Extensive**	**Intensive**	**p-Value**	**Extensive**	**Intensive**	**p-Value**
Weight (kg)	1.60 ±0.24	1.71 ±0.22	0.711	NW	NW	NW	3.05 ±0.31	2.85 ±0.34	0.294
pH_0	6.30 ±0.27	6.28 ±0.30	0.861	6.80 ±0.20	6.62 ±0.30	0.214	6.21 ±0.30	6.34 ±0.26	0.436
pH_{48}	5.98 ±0.15	5.90 ±0.20	0.407	5.79 ±0.09	5.71 ±0.13	0.227	5.73 ±0.07	5.76 ±0.14	0.630
$Temp_0$ (°C)	29.37 ±1.77	29.04 ±1.29	0.698	33.27 ±3.11	35.03 ±3.10	0.311	31.06 ±1.67	31.17 ±0.75	0.885
$Temp_{48}$ (°C)	5.40 ±0.66	5.59 ±0.55	0.578	5.14 ±0.37	5.29 ±0.44	0.524	5.76 ±0.97	5.94 ±0.65	0.682

SD (Standard Deviation); NW (not weighed)

Table 4 The mean (±SD) ribeye (M. *longissimus dorsi)* area (mm^2) and subcutaneous fat coverage (13^{th} rib and $3^{rd}/4^{th}$ lumbar vertebra) of Dohne Merino lambs reared in an extensive (n = 7) or intensive (n = 7) production system

	Extensive	**Intensive**	**p-Value**
13^{th} rib (mm)	1.23 ±0.39	2.23 ±0.69	0.007
$3^{rd}/4^{th}$ lumbar vertebra (mm)	3.48 ±1.47	5.45 ±1.37	0.023
Ribeye area (mm^2)	13.69 ±2.8	13.83 ±1.72	0.910

SD (Standard Deviation)

Table 5 The mean (±SD) muscle, bone and fat yield of a three-rib cut from the *Longissimus dorsi* (9 - 11th rib) of Dohne Merino lambs reared in an extensive (n = 7) or intensive (n = 7) production system, expressed as a percentage of the total weight of the three-rib cut

% of three-rib cut weight	Extensive	Intensive	p-Value
Muscle (%)	47.19 ±4.00	47.79 ±4.20	0.790
Bone (%)	35.84 ±6.54	30.73 ±4.03	0.104
Fat (%)	16.97 ±4.06	21.48 ±3.89	0.055

SD (Standard Deviation)

Colour

L coordinate*

No significant differences were observed (Table 6) between the lightness (L*) of extensively and intensively produced meat (Table 6).

Extensively produced lambs (*Biceps femoris* and *Semimembranosus*) had a slightly higher L* value which is in contrast with the findings of various authors (Dufranse *et al.*, 1995; Vestergaard *et al.*, 2000a; Priolo *et al.*, 2001; Priolo *et al.*, 2002 – lamb; Raes *et al*., 2003; Nuernberg *et al.*, 2005 - cattle) who concluded that animals from extensive production systems produced darker meat (lower L*) due to a higher myoglobin content (Chapter 4). The unexpected results could be explained by the slightly higher drip loss of meat from extensively produced lambs (Table 7). Woelfel *et al*. (2002) concluded that the L* value of meat increased with an increase in drip loss because water has a higher light reflecting property compared to protein. No correlations were observed between the drip loss (%) and the L* value of the muscles (*Biceps femoris*: r = 0.257, = 0.375; *Longissimus dorsi*: r = 0.131, p = 0.656; *Semimembranosus*: r = 0.003, p = 0.993). The slightly higher L* value of the *Longissimus dorsi* of intensively produced lambs could be ascribed to the significantly lower myoglobin (Chapter 4) and slightly higher lipid content (Chapter 4) of this muscle. Muscles with a high intramuscular fat content increases the L* value of the meat as fats have a high light reflection/scattering property (Hedrick *et al*., 1983).

No correlations were observed between the intramuscular fat content (%) and the L* value of the *Biceps femoris* (r = 0.180; p = 0.538), *Longissimus dorsi* (r = 0.293; p = 0.309) and *Semimembranosus* (r = 0.124; p = 0.674). Significant negative correlations were observed between the L* value and myoglobin (mg/ml) of the *Longissimus dorsi* (r = - 0.765; p = 0.014) and *Semimembranosus* (r = - 0.555; p = 0.039) muscles of lambs used in this study. No significant correlation was observed for the *Biceps femoris* muscle, between L* value and myoglobin (mg/ml).

a and b* spectrum*

The production systems (extensive and intensive) had no significant effect (Table 6) on the red (a*) and yellow (b*) colour spectrum of the muscles (*Biceps femoris*, *Longissmus dorsi* and *Semimembranosus*). The significantly higher myoglobin content of the extensively reared lambs (Chapter 4) are reflected in the slightly higher a* value (Table 6) of these lambs. Carson *et al*. (2001) obtained similar b* values for concentrate fed lambs.

Hue and chroma

The *Longissimus dorsi* muscle from intensively reared lambs had a significantly higher ($p = 0.017$; Table 6) hue value (yellow spectrum). The production systems had no significant effect on the chroma of the *Biceps femoris*, *Longissimus dorsi* and *Semimembranosus* (Table 6).

Consumers prefer meat with a bright red colour and associate it with high quality and freshness (Jeremiah *et al*., 1972). Consumers steer clear of meat with a too dark/brown or to pale colour because they perceive the product of being of inferior quality (Issanchou, 1996; Berg, 2000; Viljoen *et al*., 2002). The production systems had no significant effect on the overall colour of the meat produced in this study and would therefore have no direct implications on consumer purchase behaviour and acceptability of the product regarding the appearance (colour) of the meat.

Drip loss

The production systems had no effect on the total drip loss percentage in any of the muscles (Table 7). Results in this study are similar to the findings of Keane and Allen (1998), who noted that production systems had no effect on the total drip loss (g/kg) of beef. In contrast, various authors concluded that meat from extensively produced livestock has a higher drip loss percentage (%) compared to animals housed in an intensive production system (Enfält *et al*., 1997 - pigs; Gentry *et al*., 2002 – pigs; Stern *et al*., 2003 – pigs; Pompa-Roborztnski & Kedzior, 2006 - lambs).

Table 6 The mean (±SD) CIELab, hue and chroma values for the *Biceps femoris*, *Longissimus dorsi* and *Semimembranosus* of Dohne Merino lambs reared in an extensive (n = 7) and intensive (n = 7) production systems

	Biceps femoris			***Longissimus dorsi***			***Semimembranosus***		
	Extensive	**Intensive**	**p-Value**	**Extensive**	**Intensive**	**p-Value**	**Extensive**	**Intensive**	**p-Value**
L*	39.48 ±1.19	39.45 ±1.85	0.970	36.65 ±1.87	39.78 ±2.85	0.124	36.61 ±1.53	34.81 ±1.71	0.061
a*	13.67 ±0.52	13.32 ±0.98	0.420	13.75 ±0.41	13.24 ±0.60	0.088	14.26 ±0.46	13.66 ±1.21	0.243
b*	10.25 ±0.75	10.94 ±1.10	0.194	11.41 ±0.71	11.61 ±1.51	0.747	9.77 ±2.11	9.65 ±1.02	0.892
Hue	36.84 ±2.25	39.36 ±3.01	0.101	39.65 ±1.00	42.43 ±2.40	0.017	36.07 ±2.93	35.24 ±2.93	0.619
Chroma	17.10 ±0.60	17.26 ±1.17	0.755	17.87 ±0.76	17.65 ±1.05	0.665	17.36 ±1.29	16.74 ±1.35	0.397

SD (Standard Deviation)

Table 7 The mean (±SD) drip and cooking loss (%) of the *Biceps femoris*, *Longissimus dorsi* and *Semimembranosus* of Dohne Merino lambs reared in an extensive (n = 7) or intensive (n = 7) production system

	Biceps femoris			***Longissimus dorsi***			***Semimembranosus***		
Loss (%)	**Extensive**	**Intensive**	**p-Value**	**Extensive**	**Intensive**	**p-Value**	**Extensive**	**Intensive**	**p-Value**
Drip	1.14 ±0.17	1.18 ±0.17	0.642	1.19 ±0.18	1.30 ±0.17	0.271	1.11 ±0.18	1.08 ±0.32	0.434
Cooking	34.04 ±2.01	32.85 ±0.99	0.180	30.68 ±3.02	30.03 ±3.81	0.733	39.01 ±1.77	37.01 ±2.97	0.150

SD (Standard Deviation)

Cooking loss

Consumers perceive meat with a high percentage of cooking loss or shrinkage during cooking, as meat of poor or inferior quality (Barbera & Tassone, 2006). No significant differences were detected between the total cooking loss (%) of lambs from both production systems for any of the muscles (Table 7) and would therefore have no direct impact on the purchase behaviour of consumers. Various authors also concluded that production systems had no significant influence on the cooking loss percentage of meat from pigs (Enälft *et al*., 1997; Stern *et al*., 2003) and lambs (Carrasco *et al*., 2009). Vestergaard *et al*. (2000b) found on the other hand that the meat from extensively raised bulls had a significantly higher cooking loss when compared to intensively housed bulls. Although the effect of the production system was not significant, a trend was observed (Table 7) that the total cooking loss of extensively reared lambs were higher, compared to lambs form the intensive production system. This tendency supports the findings of Jeremiah *et al*. (2003) who concluded that a skeletal muscle with a high intramuscular fat content (intensive production systems; Chapter 4) will have a low percentage of cooking loss and skeletal muscle containing a high concentration of moisture and insoluble collagen, will have a high level of cooking loss (extensive production system; Table 7). No correlations were observed between the moisture content (%) and cooking loss (%) of the *Biceps femoris* (r = 0.1801; p = 0.555), *Longissimus dorsi* (r = 0.380; p = 0.181) and *Semimembranosus* (r = 0.093; p =0.774). A significant positive correlation was observed between the cooking loss and insoluble collagen content of the *Biceps femoris* muscle (r = 0.532; p = 0.050). No correlations were observed between the cooking loss (%) and intramuscular fat content (%) of the *Biceps femoris* (r = -0.224; p = 0.442), *Longissimus dorsi* (r = -0.417; p = 0.138) and *Semimembranosus* (r = -0.078; p = 0.800).

Thomas *et al*. (2004) also concluded that cooking loss of meat is inversely correlated with drip loss therefore the cooking loss of a sample decreases with an increase in drip loss. The findings in Table 7 support this theory, especially the drip and cooking losses of the *Biceps femoris* with a significant negative correlation (r = - 0. 535; p = 0.049).

CONCLUSION

The aim of this study was to investigate the impact of an extensive (free-range) and intensive (feedlot) production system on the carcass yield and physical attributes of three muscles of Dohne Merino lambs. According to literature, intensity and exposure period of the animals to physical activity as well as feed composition (energy) of each production system could have various affects (negative and favorable) on meat quality.

The production systems had no effect on the post mortem pH and temperature decline of the muscles nor on the overall colour (L*, a*, b*, hue, chroma), drip and cooking loss of the meat, ribeye area of the loin, carcass components (muscle to bone to fat ratio; three-rib cut) and muscle

weight (*Biceps femoris*, *Longissimus dorsi* and *Semimembranosus*). The significantly thicker subcutaneous fat layer of intensively reared lambs might influence consumer acceptability, as consumers prefer lean meat with less visible fat. From a producer's viewpoint, the significantly higher dressing percentage of intensively reared lambs would be seen as a major economical benefit.

To thoroughly understand the full impact of a production system on the physical attributes and carcass yield of Dohne Merino lambs, it is proposed that the quantification of the effect of gender (ram, ewe, castrated) as well as the inclusion of an extended period (> 8 months) of exposure to a production system be analysed further. However, when lamb is produced, it is seldom that lambs will be slaughtered older than 8 months, especially in a mid-maturing breed such as the Dohne Merino when the point of slaughter is subcutaneous (minimum) fat thickness.

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Chapter 4

The effect of extensive and intensive production systems on the chemical characteristics of Dohne Merino lamb muscles

ABSTRACT

This study investigated the impact of an extensive and intensive production system on the chemical composition and fatty acid profile of the Biceps femoris, Longissimus dorsi and Semimembranosus muscles of Dohne Merino lambs. Extensively reared lamb contained more myoglobin (Biceps femoris: p = 0.027; Longissimus dorsi: p = 0.009; Semimembranosus: p = 0.017). The Biceps femoris muscle from intensively produced lambs contained more intramuscular fat (p = 0.002) and less insoluble collagen (p = 0.026). The Longissimus dorsi muscle from extensively reared lambs contained more moisture (p = 0.009) and less protein (p = 0.016). Meat of intensively raised lambs had a higher (p < 0.050) Homo-g-linolenic (C20:3n6), Eicosapentaenoic (C20:5n3) and Docosapentaenoic acid (C22:5n3) content. Lambs (Biceps femoris: p < 0.0001; Longissimus dorsi: p = 0.0004; Semimembranosus: p < 0.0001) from the extensive production system contained a lower and more favourable n6:n3 ratio which would be more attractive to health conscious consumers.

Keywords: Free-range; Feedlot; Collagen; Myoglobin; Proximate analysis; Fatty acids; Meat quality

INTRODUCTION

Troy and Kerry (2010) stated that "the relationship between consumer perception of quality and the food industry's drive to satisfy consumer needs is complex and involves many different components". In an increasingly competitive market, it is crucial to constantly monitor, evaluate and analyse consumer perception of meat quality to insure that consumer needs and expectations are being met. Consumer satisfaction increases consumer's willingness to pay and encourage repeat purchasing (Troy & Kerry, 2010). Even though price is an important purchase driver, 60% of consumers indicated that they are willing to pay 10% more for a higher quality product (Context Marketing, 2009).

The modern red meat consumer not only demands quality but also healthier products that are environmentally friendly, promote sustainability and comply with animal welfare guidelines (Ministry of Agriculture, Fisheries and Food, 1991 & 1997). Consumer preferences and purchase behaviours are very complex and are driven by various intrinsic and extrinsic meat quality cues. These cues are important to consumers at the point of purchase (colour, purge, visible fat), during

consumption (juiciness, tenderness, flavour, aroma) and as an individual product characteristics (safety, nutrition, sustainability, ethics, environmental impact, animal welfare) (Cardello, 1995; Acebron & Dopico, 2000; Napolitano *et al*., 2007). Juiciness, flavour and the texture (tenderness) of meat is considered as one of the main intrinsic factors influencing meat palatability and consumer acceptability (Bello & Calvo, 2000; Brewer & Novakofski, 2008). The visual appearance of meat is also an important quality attribute, which is mainly associated with freshness of the product (Kerry *et al*., 2000). A high level of visible fat discourages health conscious consumers from purchasing red meat because the high-saturated fatty acid content and unfavourable omega 6 to omega 3 polyunsaturated fatty acid ratio increases the consumer's risk to cancer and cardiovascular diseases (Steenkamp & van Trijp, 1996; Enser *et al*., 2001).

The global trend in animal production is a systematic transition from small-scale extensive production to large-scale intensive production systems due to various challenges (livestock theft, seasonal draughts, unpredictable weather patterns, diminishing land resources, fluctuating meat prices) (FAO, 2006). This transition increases the efficiency of livestock production and subsequently productivity and profitability (FAO, 2006; Coetzee & Malan, 2007).

It is essential to investigate the full impact of a production system on the various meat quality characteristics to insure that consumer expectation are met, and to increase purchase willingness and consumption of the product (Santa-Silva *et al*., 2002; Troy & Kerry, 2010). The objective of this study was to investigate the impact of an extensive (free-range) and intensive (feedlot) production system on the chemical composition and fatty acid profile of the *Biceps femoris*, *Longissimus dorsi* and *Semimembranosus* muscles of Dohne Merino lambs. This study did not include the quantification of the effect of gender (ram, ewe, castrated) on the sensory quality characteristics and instrumental tenderness of Dohne Merino lambs.

MATERIALS AND METHODS

LAMB MANAGEMENT, HANDLING AND SLAUGHTER PROCEDURE

The Dohne Merino lambs were born in March 2008 on Mariendahl (33° 51' 0 S; 18° 49' 60 E) Agricultural Experimental Farm, situated in the Western Cape, South Africa. Mariendahl is located in a winter rainfall region. All lambs were born from parents bred and raised under free-range/free roaming condition. At birth lambs were randomly assigned to two production systems, extensive (free range; n = 7) or intensive (feedlot; n = 7). The average birth weight of the lambs from both production systems was 4.0 kg ± 1.5 kg. Lambs were nursed by their biological mothers and received *ad libitum* colostrums during the first 24 hours after birth. Lambs were vaccinated against Pulpy kidney (3 months old), Pasteurella (3 months old) and Blue tongue (6 month old).

Extensive production system

After birth, the lambs roamed together with their dams in a free range system on a 10 ha plot at Mariendahl Agricultural Experimental Farm, with a herd density of 8 lambs / sheep per hectare. The foliage on the plot was abundant and consisted mainly of Subterranean clover (*Trifolium subterraneum*), Musk storksbill (*Erodium moschatum*), Medic clovers (*Medicago spp.*) and Ryegrass (*Lolium spp*.). The lambs received 500 g Veekos stud feed™ (Table 1 indicating the fatty acid profile of the feed) as suppementation (daily) and had *ad libitum* access to fresh water. Refer to Chapter 3 for the feed composition, of these feedstuffs. The plot contained no steep, uneven or elevated areas, which could have led to excessive or strenuous exercise. Lambs in this production system were not confined in any manner and received unlimited/unrestricted natural exercise (physical activity) through grazing. The lambs were weaned 100 days after birth.

Intensive production system

Lambs were weaned from their biological mothers, at an age of 4 days. After weaning the lambs were moved to an indoor holding pen (1.6 m x 1.6 m) with a surrogate mother (Saanen goat - *Capra hircus*) and two other newborn lambs. The indoor pen had sufficient bedding and the design of the holding facilities were in compliance with South African Feedlot Association (SAFA, 2008), the National Environmental Guidelines for Feedlots (SAFA, 2005) and Animal Protection Act (Act No. 71 of 1962) (Anon., 1962). Lambs were nursed by the Saanen goats and were also weaned at an age of 100 days. After weaning the lambs were individually confined to 1 x 2 m indoor stalls and fed Veekos Stud Feed™ pellets, with a metabolisable energy of 9.8 MJ kg^{-1} and lucerne. Lambs had *ad libitum* access to lucerne, Veekos Stud Feed™ pellets and fresh water.

Slaughtering

Dohne Merino lambs from both production systems were slaughtered at an age of 8 months, using standard South African slaughtering methods (Cloete *et al.*, 2004). The slaughter weight of the lambs was recorded 24 hours prior to slaughtering. The lambs were transported approximately 60 km to a commercial abattoir in Malmesbury (33° 27' 0 S; 18° 41' 60 E) on a day with a maximum temperature of 25°C. The lambs were off-loaded at the abattoir, grouped together and housed in lairage overnight. The lambs had *ad libitum* access to fresh water and received no feed. The next morning the lambs were electrically stunned (4 s at 200 V), hang by the Achilles tendon and the jugular vein severed (Cloete *et al.*, 2004). After exsanguination the carcasses were skinned, dressed and stored at 4°C for 24 hours. After 24 hours the carcasses were transported approximately 60 km in a refrigerated truck (4 - 7°C) to the Meat Science Laboratory at Stellenbosch University. The carcasses were offloaded and stored in the deboning area (6 - 8°C) of the laboratory for another 24 hours.

Table 1 Fatty acid profile (mg/g) of feed, consumed by lambs in the intensive (Veekos Stud Feed™) and extensive (Musk storksbill, Ryegrass, Medic clover, Subterranean clover) production systems

Fatty acid (mg/g feed)	Veekos stud	Musk storkbill	Ryegrass	Medic clover	Subterranean clover
SFA					
C14:0	0.02	ND	0.10	0.01	0.01
C15:0	0.02	0.09	0.15	0.07	0.02
C16:0	2.88	1.56	2.15	1.12	1.07
C18:0	0.69	0.32	0.50	0.35	0.43
MUFA					
C18: 1n9c	6.23	0.44	0.57	0.24	0.17
PUFA					
C18: 2n6c	59.52	2.04	2.48	2.30	0.77
C18: 3n3	0.08	0.05	0.07	0.02	0.01
C20: 3n6	0.01	0.02	0.10	ND	0.02
C20: 5n3	0.05	0.05	0.06	0.08	0.05
C22: 5n3	0.01	0.02	0.01	ND	ND
C22: 6n3	ND	ND	0.10	ND	ND
SFA	3.65	2.03	2.98	1.58	2.26
MUFA	6.35	0.74	1.05	0.34	0.43
PUFA	61.12	10.33	59.89	9.44	2.16
TUFA	67.47	11.07	60.93	9.79	2.59
P:S	16.76	5.09	20.07	5.97	0.95
n6	60.89	10.13	59.63	9.23	2.01
n3	0.19	0.16	0.22	0.17	0.11
n6:n3	322.45	62.24	274.22	55.43	18.43

SFA (saturated fatty acids); **MUFA** (mono unsaturated fatty acids); **PUFA** (polyunsaturated fatty acids); **TUFA** (total unsaturated fatty acids); **P:S** (polyunsaturated to saturated fatty acid ratio); **n6** (omega 6); **n3** (omega 3); **n6:n3** (omega 6 to omega 3 ratio); **EPA** (Eicosapentaenoic acid); **DPA** (Docosapentaenoic acid); **DHA** (Docosahexaenoic acid); **ND** (non detected)

Experimental units

Whole skeletal muscles (*Biceps femoris*, *Longissimus dorsi* and *Semimembranosus*) were chosen as experimental units instead of retail cuts. This decision was made based upon the fact that retail cuts consist mainly out of two or more muscles, each with different endogenous metabolic systems, and functions, and may also contain bones, tendons or excessive connective tissue. The latter will act as unnecessary variables during analyses, thus masking the effect of the treatment being investigated.

The *Biceps femoris* is situated at the extensor of the hip, stifle, and hock joints and flexes the stifle when the hind foot is lifted off the ground (Nickel *et al*., 1986; Frandson *et al*., 2003). The whole *Biceps femoris* muscle was excised from the left side of the carcass 48 hours post mortem.

The *Longissimus dorsi* acts as an extensor of the back and loin and flexes the spine laterally (Nickel *et al*., 1986; Frandson *et al*., 2003). A portion (1^{st} - 8^{th} rib) of the *Longissimus dorsi* muscles was excised (48 hours post mortem) from the left side of the carcass for chemical analyses. The *Semimembranosus* muscle acts as the extensor of the hip joints and flexor of the stifle (Nickel *et al*., 1986; Frandson *et al*., 2003). The whole *Semimembranosus* muscle was excised from the left side of the carcass 48 hours post mortem.

Chemical analyses

Sample preparation

After the completion of the physical measurements (Chapter 3) the remainder of the muscle was homogenised in a bowl cutter at low temperature (5°C). The homogenised sample was placed in a labelled polyethylene bag, vacuum sealed and frozen (-18°C) for approximately 5 weeks until analyses commenced. Before each analysis, samples were removed from the freezer (-18°C) and thawed at room temperature for 4 hours. All analyses were performed in duplicate.

Proximate analyses

The moisture content (%) (100°C, 24 hours) of 2.5 g homogenised meat sample was determined according to the official AOAC method 934.01 (AOAC, 2002a) and the ash content (%) (500°C, 6 hours) of the moisture free sample according to the official AOAC method 942.05 (AOAC, 2002b). The total lipid (%) (intramuscular fat) concentration of a 5 g homogenised meat sample was determined by using the chloroform/methanol (2:1 v/v) extraction method described by Lee *et al*. (1996). The total crude protein content (%) of a 0.1 mg dried defatted finely ground sample was determined by encapsulating the sample in a Leco™ foil sheet and analysed in a Leco Nitrogen/Protein Analyzer (FP – 528, Leco Corporation). The Dumas combustion method 992.15 (AOAC, 2002c) was used and results were expressed in % Nitrogen (N). The total crude protein (%) was determined by multiplying the nitrogen (%) present in the sample with a conversion factor of 6.25.

Myoglobin

The total myoglobin concentration (mg/ml) of each homogenised sample (5 g) was determined by using the official AOAC extraction method 941.17 (AOAC, 2002d). The following formula was used to calculated the total myoglobin (mg/ml) concentration of each sample: Myoglobin (mg/ml) = (Absorbance reading at 525 nm - Absorbance reading at 700 nm) x 2.303 x 6.

Collagen

The total soluble and insoluble collagen content (mg/g) of each sample was calculated by determining the hydroxyproline content (Hill, 1966; Bergman & Loxley, 1963; Cross *et al*., 1973). Approximately 8 g of the sample was placed in a 50 ml polypropylene centrifuge tube (Falcon tube™) containing 12 ml NaCl (1%) solution. The sample was heated in a water bath (78°C) for 60 minitues. After a cooling period of 15 minutes, the sample was centrifuged (6 000 RCF) for 10 minutes. The supernatant of the sample was decanted into a 50 ml polypropylene centrifuge tube labelled “soluble” and the residue (pellet) was placed in a tube labelled “insoluble”. The “soluble” and “insoluble” samples were individually hydrolysed with 30 ml HCL (6 N) for 16 hours at 110°C. The hydroxyproline in the samples were oxidised by chloramines-T and subsequently reacted with paradimethylaminobenzaldede to develop a pink colour. The pink solution was transferred to a micro-cuvette and the absorbance of each sample was read at wavelength of 560 nm, on a spectrophotometer. The collagen content of the sample was calculated as described by Hill (1966), Bergman and Loxley (1963) and Cross *et al*. (1973).

Fatty acid

The fatty acid profile of 2 g samples was determined by using the fatty acid methyl esters (FAME) extraction method as described by Folch *et al*. (1957). The FAME was analysed with a Thermo Finnigan Focus gas-chromatograph (Thermo Electron S.p.A, Strada Rivoltana, 20090 Rodana, Milan, Italy) equipped with a 60 m BPX70 capillary column with an internal diameter of 0.25 mm and 0.25 µm film (SGE International Pty Ltd, 7 Argent Place, Ringwood, Victoria 3134, Australia). The gas flow rate of hydrogen was 25 ml/min and 2-4 ml/min for the hydrogen carrier gas. The temperature programme was linear at 3.4°C/min with the temperature settings as follows: initial temperature of 60°C, injector (220°C), detector (260°C) and the final temperature at 160°C. The injection volume was 1 µL and the run time was approximately 45 minutes. The FAME of the samples was identified by comparing it with the retention times of a standard FAME mixture (Supelco™ 37 Component FAME mix, 10 mg/ml in CH_2Cl_2, Cat no. 47885-U. Supelco™, North Harrison Rd, Bellefonte, PA 16823-0048, USA) and values were recorded as mg/g meat sample.

Statistical analysis of data

A random split-plot design, with two production systems (extensive and intensive) as the main-plot, was used as the experimental design in this study. Seven carcasses were randomly drawn from each main-plot and the sub-plot factor consisted of three muscles (*Biceps femoris*, *Longissimus dorsi* and *Semimembranosus*). A random split-plot analysis of variance (ANOVA) was performed on the recorded physical attributes and chemical characteristics. The studentized residuals were calculated for all the variables and tested for deviations from normality using Shapiro-Wilk's test (Shapiro & Wilk, 1965). Outliers were identified and removed before the final ANOVA's were performed (Snedecor, 1967). Means of significant effects were compared using Student's t-LSD (Least Significant Difference) at a 5% level of significance.

Pearson's correlation coefficients were calculated for comparison between chemical (Chapter 4), physical (Chapter 3), sensory attributes (Chapter 5), instrumental tenderness (Chapter 5) and histochemical characteristics (Chapter 6) variables. All above procedures were analyse using SAS™ statistical software (Statistical Analysis System, Version 9.2).

RESULTS & DISCUSSION

Proximate analysis

Moisture

The *Longissimus dorsi* muscle from lambs from the extensive production system contained more moisture ($p = 0.009$) than intensively reared lambs (Table 2). Although no difference were detected between the moisture content (%) of the *Biceps femoris* ($p = 0.097$) and *Semimembranosus* ($p = 0.062$) from both production systems (extensive and intensive), a tendency was observed (Table 2), that the muscles of extensively reared lambs contained slightly more moisture (%). The p values of the *Biceps femoris* and *Semimembranosus* are relatively close to the significance level ($p < 0.050$) therefore it could be argued that a bigger sample set ($n > 7$ lambs) could have resulted in a clearer difference between the two production systems.

The moisture content of meat is inversely correlated with the intramuscular fat content (Sales, 1995; Young *et al*., 2001). A negative correlation ($r = -0.539$; $p = 0.047$) was observed between the moisture and intramuscular fat content of the *Longissimus dorsi* muscle in this study. Meat from extensively raised animals have a significantly higher moisture content (%) than intensively produced animals (Summer *et al*., 1978 - lamb; Williams *et al*., 1983 - cattle; Rowe *et al*., 1999 - lambs; French *et al*., 2001 - cattle) which coincide with the fact that intensive production systems (high energy diets) produce carcasses with higher fat levels compared to extensively reared animals (Diaz *et al*., 2002; Santos-Silva *et al*., 2002). An increase in the moisture content (%) of meat could also be ascribed to an increase of muscle protein, because myofibrillars (protein structure) are responsible for the binding of intramuscular water (Goll *et al*., 1977). The protein

content (Table 2) of the *Biceps femoris* and *Semimembranosus* of extensively produced lambs supports Goll *et al*.'s (1977) findings.

The moisture content of meat contributes to various meat palatability traits (juiciness and tenderness) and could have a negative effect on the flavour of meat because most flavour carrying components are hydrophobic (Lawrie, 1998; Priolo et *al*., 2001; Jeremiah *et al*., 2003). The intensive production system had a significant effect on the moisture content of the *Longissimus dorsi* but no significant correlations were observed between moisture and the sensory attributes reported in Chapter 5.

Crude protein

The crude protein content of the *Biceps femoris* ($p = 0.097$) and *Semimembranosus* ($p = 0.289$) muscles, was unaffected by production system (Table 2) and similar results have been reported (Keane & Allen,1998 - cattle; Rowe *et al*., 1999 - lambs; French *et al*., 2000 - cattle; French *et al*., 2001 - cattle; Hoffman *et al*., 2003 – pigs; Pompa-Roborzynski & Kedzior, 2006). Diaz *et al*. (2002) proposed that the extensive production system alters the metabolism of the animals, metabolising the lipid reserves to produce muscular tissue. Norton *et al*. (1970) suggested that an increase in the crude protein content of a muscle is related to an increase in dietary protein. The crude protein content (14.8%; Chapter 3) of the feed from the extensive production system contains more protein than Veekos Stud Feed™ fed to the intensively reared lambs. The higher protein content of the feed (Chapter 3) from the extensive production system could explain the tendency observed in Table 2, that the *Biceps femoris* and *Semimembranosus* muscles from the extensive production system contains a higher concentration crude protein compared to lambs from the intensive production system.

Longissimus dorsi muscle from intensively reared lambs contained more ($p = 0.016$) protein (%) than lambs from the extensive production system (Table 2) and the latter result contradicts Theriez *et al.* (1981) findings. This might be ascribed to the higher protein turnover rate of intensively reared animals (Jones *et al*., 1990; Olsson and Pickova, 2005).

Table 2 The mean (±SD) for proximate analysis (lipid, ash, moisture and protein), myoglobin and collagen (soluble and insoluble) content of the *Biceps femoris*, *Longissimus dorsi* and *Semimembranosus* muscles of Dohne Merino lambs from two production systems (extensive and intensive)

	Biceps femoris			***Longissimus dorsi***			***Semimembranosus***		
	Extensive	**Intensive**	**p-Value**	**Extensive**	**Intensive**	**p-Value**	**Extensive**	**Intensive**	**p-Value**
Moisture (%)	74.09 ±1.12	72.84 ±1.32	0.097	73.71 ±0.98	72.03 ±1.05	**0.009**	73.76 ±0.66	73.15 ±0.38	0.062
Protein (%)	19.91 ±1.02	19.34 ±2.23	0.097	19.91 ±1.17	21.44 ±0.83	**0.016**	19.60 ±1.03	18.88 ±1.27	0.289
Lipid (%)	1.60 ±0.33	2.52 ±0.54	**0.002**	1.92 ±0.60	1.95 ±0.67	0.935	1.97 ±0.64	2.22 ±0.58	0.463
Ash (%)	1.14 ±0.13	1.16 ±0.03	0.711	1.23 ±0.12	1.18 ±0.07	0.426	1.11 ±0.10	1.11 ±0.03	1.000
Myoglobin (mg/ml)	8.29 ±0.93	7.06 ±0.91	**0.027**	6.75 ±0.50	5.50 ±0.89	**0.007**	7.90 ±0.92	6.63 ±0.76	**0.017**
S. collagen (mg/g)	0.18 ±0.04	0.18 ±0.03	0.997	0.18 ±0.02	0.18 ±0.04	0.931	0.18 ±0.06	0.17 ±0.01	0.713
I. collagen (mg/g)	4.23 ±0.91	3.29 ±0.35	**0.026**	2.47 ±0.52	2.74 ±0.86	0.486	4.07 ±1.32	3.46 ±0.62	0.288

SD (Standard Deviation); S. collagen (Soluble collagen); I. collagen (Insoluble collagen)

Total lipid – intramuscular fat

No differences were detected between the total lipid content (%) of extensively and intensively produced lambs for the *Longissimus dorsi* (p = 0.935) and *Semimembranosus* (p = 0.463) muscles (Table 2). However, the *Biceps femoris* muscle from the intensively produced lambs contained more (p = 0.002) intramuscular fat (%) than that from the extensively reared lambs. Various authors have concluded that intensive production systems produce livestock with a higher percentage of intramuscular fat (%) when compared to extensive production systems (Rowe *et al*., 1999 – lambs; Vestergaard *et al*., 2000a - cattle; French *et al*., 2001 - cattle; Priolo *et al*., 2002 - lambs; Pompa-Roborzynski & Kędzior, 2006 - lambs). This could be ascribed to the high energy diets, high plane of nutrition or limited exercise associated with intensive production systems (Priolo *et al*., 2002).

It could be speculated that the significantly low intramuscular fat content (%) of the *Biceps femoris* from extensively produced lambs (Table 2) could be attributed to the fact that this muscle is primarily used during locomotion (walking and grazing) and would be more active in animals in an extensive production system compared to animals in an intensive production system (Nickel *et al*., 1986; Frandson *et al*., 2003). Diaz *et al*. (2002) proposed that extensive production systems alter the metabolism of the animals, metabolising the lipid reserves to produce muscular tissue.

Ash

Production system (extensive and intensive) had no effect on the ash content (%) of the *Biceps femoris* (p = 0.711), *Longissimus dorsi* (p = 0.426) and *Semimembranosus* (p = 1.000) muscles of Dohne Merino lambs (Table 2). Similar results have been obtained by others (Enfält *et al*., 1997 - pigs; Rowe *et al*., 1999 – lambs; French *et al*., 2001 - cattle; Hoffman *et al*., 2003 - pigs).

Myoglobin

Muscles from extensively reared lambs contained significantly more myoglobin (mg/ml) than intensively produced lambs in all three muscles (Table 2). The *Biceps femoris* (active during locomotion) of the extensive production system contained the highest myoglobin content (8.29 mg/ml) and the *Longissimus dorsi* (postural muscle) of intensively reared lambs the lowest (5.50 mg/ml). Myoglobin is an oxygen carrying molecule and these findings are in concurrence with literature which states that active muscles which have a higher demand for oxygen, contain more myoglobin and are therefore significantly darker compared to less active muscles (Honikel, 1998; Lawrie, 1998; Young & West 2001). Various authors also concluded that extensively reared animals produce darker meat due to high levels of activity associated with the production system (Bidner *et al*., 1986; Vestergaard *et al*., 2000b; Varnam & Sutherland, 1995; Diaz *et al*., 2002; Priolo *et al*., 2002).

In this study negative correlations were observed between the myoglobin content of the *Semimembranosus* (r = -0.555; p = 0.0391) and *Longissimus dorsi* (r = -0.765; p = 0.0014) and the CIELab L* value (Chapter 3) which indicates that as the myoglobin content of these muscles increased, the meat became significantly darker (low L* value). This coincides with the findings that animals from extensive (free-range) production systems, produces meat with a lower L* value (darker) when compared to intensively (feedlot) raised animals, which could be attributed to the higher myoglobin content of these animals (Dufranse *et al*, 1995 - cattle; Vestergaard *et al*, 2000b - cattle; Priolo *et al*, 2001 - lambs; Priolo *et al*, 2002 – lambs; Raes *et al*., 2003 - cattle; Nuernberg *et al*, 2005 - cattle).

Active animals contains high concentration of oxidative type I muscle fibers, which are rich in myoglobin and contributes to a higher muscular myoglobin content. Continuous physical exercise, associated with extensive (free-range) rearing systems, induces the transition of fast twitch fibers (type II) to slow twitch fibers (type I) (Aalhus & Price, 1991, Lefaucheur & Gerrard, 1998; Petersen *et al*., 1998; Pette & Staron, 2000; Vestergaard *et al*., 2000b; Pette & Staron, 2001; Gentry *et al*., 2004, Abreu *et al*., 2006). Postural muscles (e.g. *Longissimus dorsi*) are more oxidative (type I) when compared to muscles involved in locomotion (e.g. *Biceps femoris* and *Semimembranosus*) (Totland & Kryvi, 1991; Ono *et al*., 1995; Chang *et al*., 2003). From the positive correlation between the *Biceps femoris* muscle's fiber type I (Chapter 6) and myoglobin (r = 0.625, p = 0.017) content, it is evident that oxidative type I muscle fibers are rich in myoglobin and that active muscles contain a larger concentration of type I fibers.

The visual appearance of fresh meat is one of the primary factors influencing consumer purchase behaviour and acceptance (Carpenter, 1966; Grunert, 2006). Consumers prefer meat with a bright red colour and associate it with high quality and freshness (Jeremiah *et al*., 1972). Consumers steer clear of meat that appears too dark/brown or too pale because they perceive the product as being of inferior quality (Issanchou, 1996; Berg, 2000; Viljoen *et al*., 2002).

Collagen

No significant difference was detected between the soluble collagen content (mg/g) of lambs from both production systems within the muscles (Table 2). Similar findings were obtained by Hawrysh *et al*. (1974) who concluded that physical activity had no significant effect on the insoluble, soluble and total collagen content of the *Longissimus dorsi* and *Biceps femoris*. However, the *Biceps femoris* from extensively produced lambs, contained more (p = 0.026) insoluble collagen compared to lambs from intensive production system. Production system had no effect on the insoluble collagen content (mg/g) of the *Longissimus dorsi* (p = 0.486) and *Semimembranosus* (p = 0.288) muscles. A tendency was observed from Table 2, that the muscles active during locomotion (*Biceps femoris* and *Semimembranosus*) contained more insoluble collagen (mg/g) compared to the postural muscle (*Longissimus dorsi*), which is similar to the results obtained by Zimmerman *et*

al. (1993). Petersen *et al*. (1997) also concluded that physical activity increased the insoluble content of the *Biceps femoris* muscle.

King (1987) concluded that the *Semimembranosus* muscle of lambs (5 months) contained the lowest concentration of soluble collagen and has the most mature (cross-linked) intramuscular collagen structure when compared to the *Semitendinosus* (ST), *Biceps femoris* (BF), *Longissimus dorsi* (LD) and *Psoas major* (PM). King (1987) summarised the collagen structure maturity of these muscles (SM > ST > BF > LD > PM) according to the thermal transition temperatures of the collagen and concluded that the collagen solubility of the *Semimembranosus* muscle will not change significantly with an increase in animal age. The insoluble collagen content (mg/g) of the intensively produced lambs in this study coincide with King's (1987) maturity theory (SM > BF > LD; Table 2).

Insoluble collagen has a negative effect on meat tenderness, which is regarded by consumers as the primary determinant of quality (Boleman *et al.*, 1997; Martin & Rodger, 2004). A negative correlation was observed between the insoluble collagen content and the first bite sensory score (sensory tenderness – Chapter 5) of the *Biceps femoris* ($r = -0.664$; $p = 0.009$) muscle. Miller *et al*. (1995) found that consumers could easily distinguish between different meat tenderness levels and indicated that they are prepared to pay premiums for certified tender meat (Boleman *et al*., 1997; Shackelford *et al.*, 2001). The *Biceps femoris* muscle has a high retail value therefore the significantly higher insoluble collagen content of the *Biceps femoris* from extensively produced lambs could have a negative impact on consumer acceptability of free-range meat (extensively produced).

Fatty acids

Myristic & Palmitic acids

The production systems had no effect on the Myristic (C14:0) (*Biceps femoris*: $p = 0.349$; *Longissimus dorsi*: $p = 0.281$; *Semimembranosus*: $p = 0.699$) and Palmitic (C16:0) (*Longissimus dorsi*: $p = 0.349$; *Semimembranosus*: $p = 0.431$) fatty acid composition of lambs used in this study. However, the *Biceps femoris* from intensively produced lambs contained a higher level ($p = 0.036$) of Palmitic acid (C16:0) (Table 3).

The feed from the intensive production system contained the highest concentration of C14:0 (0.02mg/g), C16: (2.8 mg/g), MUFA (monounsaturated fatty acids; 6.35 mg/g) and PUFA (polyunsaturated fatty acids; 61.12mg/g) compared to the forage based diet of the extensive production system (Table 1). This feed composition (Table 1) could explain the tendency observed in Table 3, that the Myristic and Palmitic acid content of intensively reared lambs were slightly higher. Results obtained and the tendency observed in this study are similar to the findings of Rowe *et al*. (1999), Varela *et al*. (2004), Realini *et al*. (2004) and Nuernberg *et al*. (2005).

Stearic acid

No differences were detected between the Stearic (C18:0) fatty acid content of lambs from both production systems (extensive and intensive) (Table 3). Various authors have reported that the C18:0 fatty acid content of extensively reared animals is significantly higher compared to lambs form intensive production systems (Rowe *et al*., 1999; Realini *et al*., 2004; Nuernberg *et al*., 2005).

Oleic acid

The *Biceps femoris* from the intensive production system had a higher ($p = 0.002$) higher Oleic (C18:1n9c) fatty acid content compared to lambs from extensive production system (Table 3). The production systems had no effect on the Oleic fatty acid content of the *Longissimus dorsi* ($p = 0.742$) and *Semimembranosus* ($p = 0.084$) muscle although a trend was observed that the muscles from the intensive production contains a higher Oleic acid content. Similar results were obtained by Rowe *et al*. (1999).

Desaturase enzymes initiate the synthesising of saturated fatty acids to monounsaturated-*cis* fatty acids, in meat (Wood *et al*., 2008). The feed from the intensive production system contained a higher concentration saturated fatty acids (3.65 mg/g feed) compared to the forage based diets of extensively reared lambs (Table 1) which could explain the significant difference (*Biceps femoris*) and tendency observed in Table 3. The higher Oleic acid content of meat (especially in the *Biceps* femoris) from intensively reared lambs would be beneficial to the consumers health.

Linoleic acid

No differences were detected (Table 3) between the Linoleic acid (C18:2n6c) content of extensively and intensively produced lambs. However a trend was observed that the muscles of intensively reared lambs contained higher concentrations of Linoleic acid compared to lambs from the extensive production system (Table 3). This trend is consistent with the findings of Rowe *et al*. (1999) and Varela *et a*l. (2004) but is in contrast with Realini *et al*. (2004), who concluded that pasture fed animals (extensive production system) contained significantly more Linoleic acid compared to concentrate fed animals (intensive production system).

Veekos Stud Feed™, fed to intensively reared lambs, contained 59.52 mg/g feed Linoleic acid compared to an average of 1.90 mg/g for the forage based diet of extensively reared lambs (Table 1). This high concentration of Linoleic acid content in the feed of intensively produced lambs could explain the trends observed in Table 3.

α-Linolenic acid

The *Longissimus dorsi* ($p = 0.050$) muscle from intensively reared lambs contained a slightly higher α-Linolenic acid (C18:3n3) concentration compared to lambs from extensive production system (Table 3). No difference were detected between the α-Linolenic acid content of the *Biceps femoris*

and *Semimembranosus* muscle from both production systems although a tendency was observed that muscles from intensively produced lambs had a higher α-Linolenic acid content (Table 3). Results obtained are inconsistent with the findings of Rowe *et al*. (1999), Varela *et al*. (2004), Realini *et al*. (2004) and Nuernberg *et al*. (2005) that pasture fed (extensive production system) animals contains more α-Linolenic acid.

Although not significant, the slightly higher α-Linolenic acid of the *Longissimus dorsi* could be due to the higher α-Linolenic acid content of the feed from the intensive production system (Table 1). α-Linolenic acid reduces the risk of cardiovascular diseases.

Homo-g-linolenic, Eicosapentaenoic, Docosapentaenoic and Docosahexaenoic acid

Differences were detected (Table 3) between the Homo-g-linolenic (C20:3n6) (*Biceps femoris*: p = 0.007; *Longissimus dorsi*: p = 0.027; *Semimembranosus*: p = 0.003) and Eicosapentaenoic acid (C20:5n3; EPA) (*Biceps femoris*: p = 0.016; *Longissimus dorsi*: p = 0.006; *Semimembranosus*: p = 0.734) content of lambs from both production systems. Extensively reared lambs contained significantly higher levels of EPA and lambs from the intensive production system contained significantly more homo-g-linolenic acid (Table 3). Similar results were obtained by Nuernberg *et al*. (2005) and Realini *et al*. (2004) for EPA and the Homo-g-linolenic acid results in this study are similar to the findings of Varela *et al*. (2004).

Production system had no effect on the Docosahexaenoic acid (DHA) content of lambs, although a tendency was observed (Table 3) that lambs from extensive production systems contained higher concentration DHA compared to lambs from the intensive production system. Nuernberg *et al*. (2005) obtained similar results.

Extensively reared lambs contained more Docosapentaenoic acid (DPA; C22:5n3) (*Biceps femoris*: p = 0.001; *Longissimus dorsi*: p = 0.007; *Semimembranosus*: p = 0.339) compared to lambs from the intensive production system (Table 3). Nuernberg *et al*. (2005) obtained similar results.

It was suspected that intensively reared lambs would contain a higher EPA and DHA concentration than extensively reared lambs as Veekos Stud Feed™ contains a higher α-Linolenic acid (C18:3n3) concentration (Table 1). This unexpected result could be explained by the high levels of Linoleic acid (C18:2n6) present in the feed (Table 1) and meat (Table 3) of intensive produced lambs which prevents the synthesis of α-linolenic (C18:3n3) to Eicosapentaenoic (EPA; C20:5n3) and Docosahexaenoic acids (C22:6n3) (Wood *et al*., 2008; Warriss, 2010). Meat from extensively produced lambs contains higher levels of EPA and DHA, which is beneficial to the consumer's health.

Table 3 The mean (±SD) fatty acid profile (mg/g muscle) the *Biceps femoris*, *Longissimus dorsi* and *Semimembranosus* muscles of Dohne Merino lambs reared in an extensive (n = 7) or intensive (n = 7) production system

Fatty acid	***Biceps femoris***			***Longissimus dorsi***			***Semimembranosus***		
(mg/ g muscle)	Extensive	Intensive	p-Value	Extensive	Intensive	p-value	Extensive	Intensive	p-Value
SFA									
C14:0	0.19 ±0.11	0.27 ±0.17	0.349	0.22 ±0.14	0.39 ±0.37	0.281	0.24 ±0.16	0.27 ±0.11	0.699
C16:0	4.66 ±1.32	7.17 ±2.48	**0.036**	5.76 ±2.36	7.52 ±4.16	0.349	5.96 ±1.06	6.50 ±1.39	0.431
C18:0	5.78 ±1.46	6.91 ±1.83	0.226	7.13 ±2.79	8.55 ±3.91	0.449	6.79 ±2.16	6.04 ±1.20	0.440
MUFA									
C18:1n9c	8.57±2.69	14.95 ±3.46	**0.002**	10.48 ±4.18	11.08 ±2.08	0.742	9.52 ±3.05	12.18 ±2.16	0.084
PUFA									
C18:2n6c	1.37 ±0.37	1.75 ±0.34	0.072	1.20 ±0.25	1.48 ±0.42	0.158	1.36 ±0.27	1.58 ±0.26	0.155
C18:3n3	0.03 ±0.01	0.04 ±0.00	0.143	0.03 ±0.01	0.05 ±0.03	**0.050**	0.03 ±0.01	0.03 ±0.01	0.377
C20:3n6	0.46 ±0.12	0.71 ±0.18	**0.007**	0.38 ±0.07	0.53 ±0.15	**0.027**	0.40 ±0.07	0.60 ±0.12	**0.003**
C20:5n3	0.03 ±0.01	0.04 ±0.01	**0.016**	0.01 ±0.00	0.02 ±0.01	**0.006**	0.03 ±0.00	0.04 ±0.01	**0.010**
C22:5n3	0.25 ±0.06	0.13 ±0.03	**0.001**	0.20 ±0.06	0.11 ±0.03	**0.007**	0.21 ±0.03	0.11 ±0.02	**<0.0001**
C22:6n3	0.12 ±0.04	0.10 ±0.03	0.442	0.10 ±0.03	0.08 ±0.03	0.296	0.10 ±0.02	0.09 ±0.02	0.339
SFA	10.97 ±2.88	14.72 ±4.33	0.080	13.43 ±5.27	16.81 ±8.28	0.381	13.39 ±3.33	13.19 ±2.62	0.904
MUFA	8.81 ±2.77	15.32 ±3.58	**0.003**	10.78 ±4.29	11.49 ±2.19	0.701	9.82 ±3.13	12.56 ±2.22	0.083
PUFA	2.88 ±0.68	3.17 ±0.53	0.400	2.47 ±0.53	2.66 ±0.65	0.559	2.69 ±0.50	2.78 ±0.45	0.738
TUFA	11.70 ±3.35	18.49 ±3.77	**0.004**	13.25 ±4.69	14.16 ±2.51	0.661	12.59 ±3.59	15.35 ±2.19	0.109
P:S	0.27 ±0.05	0.23 ±0.09	0.390	0.20 ±0.06	0.18 ±0.07	0.583	0.21 ±0.04	0.22 ±0.06	0.806
n6	2.39 ±0.56	2.80 ±0.46	0.106	2.08 ±0.45	2.33 ±0.58	0.382	2.33 ±0.45	2.45 ±0.40	0.593
n3	0.44 ±0.12	0.32 ±0.07	**0.037**	0.35 ±0.09	0.29 ±0.08	0.187	0.38 ±0.05	0.38 ±0.05	**0.004**
n6:n3	5.48 ±0.52	8.95 ±0.88	**<.0001**	5.57 ±0.73	8.80 ±1.34	**0.0004**	5.83 ±0.96	8.68 ±0.69	**<.0001**

SD (Standard Deviation); **SFA** (saturated fatty acids); **MUFA** (mono unsaturated fatty acids); **PUFA** (polyunsaturated fatty acids); **TUFA** (total unsaturated fatty acids); **P:S** (polyunsaturated to saturated fatty acid ratio); **n6** (omega 6); **n3** (omega 3); **n6:n3** (omega 6 to omega 3 ratio)

SFA, MUFA, PUFA, P:S, omega 6, omega 3 and n6:n3 ratio

The production systems (extensive and intensive) had no effect on the total saturated fatty acids (SFA), monounsaturated fatty acids (MUFA) (*Longissimus dorsi*: p = 0.701; *Semimembranosus*: p = 0.083), polyunsaturated fatty acids (PFA), polyunsaturated to saturated fatty acid ratio (P:S) and omega 6 (n6) content of the lambs used in this study (Table 3). A tendency was observed in Table 3, the *Biceps femoris* of intensively reared lambs tend to contain more SFA than extensively reared lambs. SFA can result in an increase in blood serum low-density lipoprotein (LDL) cholesterol levels which increases the consumers risk to cardiovascular heart diseases. The higher SFA concentration in intensively produced meat could have a negative effect on the consumer health. The slightly higher PUFA and MUFA content of intensively produced lambs on the other hand, can have the complete opposite effect promoting the reduction of LDL cholesterol in blood, which reduces the risk of cardiovascular heart diseases. The P:S ratio is predominantly (excluding the *Semimembranosus* muscle) higher in extensively reared lambs and adheres to the health guidelines of 0.45, to promote health and minimise the risk of cardiovascular diseases (Warriss, 2010).

The meat from extensively reared lambs contains more omega 3 fatty acids (n3) (*Biceps femoris*: p = 0.037; *Semimembranosus*: p = 0.004) compared to lambs from the intensive production system (Table 3). Meat from extensively reared lambs would promote consumer health and reduce the risk of cardiovascular heart diseases. However, an increase in the n3 PUFA ratio decreases the meat's oxidative stability, promoting the development of rancidity (Wood *et al*., 2003). Rancid meat has a short shelf life, unpleasant taste and is rejected by the consumer (Wood *et al*., 2003).

Intensive reared lambs contained a higher n6:n3 ratio (*Biceps femoris*: p < 0.0001; *Longissimus dorsi*: p = 0.0004; *Semimembranosus*: p < 0.0001). The omega 6 to omega 3 fatty acid ratio of intensively reared lambs exceeds the health guidelines of approximately 5:1 (Wood *et al*., 2008; Warriss, 2010). The significantly higher Homo-g-Linolenic acid made a contribution (*Biceps femoris*: p = 0.007; *Longissimus dorsi*: p = 0.027; *Semimembranosus*: p = 0.003) to the overall higher n6:n3 ratio of meat from intensively reared lambs (Table 3).

CONCLUSION

The aim of this study was to investigate the impact of an extensive (free-range) and intensive (feedlot) production system on the chemical composition and the fatty acid profile of the *Biceps femoris*, *Longissimus dorsi* and *Semimembranosus* muscles of Dohne Merino lambs. The effect of the production system depends on the intensity and exposure period of the animals to physical activity as well as the feed composition of each production system.

The production systems had a significant effect on the protein and moisture content of the *Longissimus dorsi* muscle with that from the extensive system containing more moisture and correspondingly less protein. Production system had no effect on these two chemical constituents for the other two muscles. On the other hand, the *Biceps femoris* muscle from intensively produced lambs contained more intramuscular fat (lipid) compared to lambs from the extensive production system. Results indicated that the physical activity, induced or suppressed, by the production systems had a significant effect on the myoglobin content of the meat. Therefore the meat from the extensive production systems contained significantly more myoglobin and thus being slightly darker. Consumers dislike meat with too dark/brown colour because they perceive the product as being of a substandard quality.

Production system had a significant effect on the tenderness of the *Biceps femoris* muscle. The *Biceps femoris* from intensively reared lambs contained significantly more intramuscular fat, which promotes tenderness whereas the *Biceps femoris* from extensively reared lambs contained a higher percentage of insoluble collagen, which has a negative effect on meat tenderness. It could be speculated that the meat from extensively reared lambs, especially the *Biceps femoris* muscle (high retail value), would have a negative effect on consumer acceptability and purchase behaviors.

An increase in the n3 PUFA ratio decreases the meat's oxidative stability, promoting the development of rancidity. The significantly higher n3 PUFA content of extensively reared lambs could therefore have a negative effect on the sensory properties (flavour and aroma) of meat produced in this study. The higher oleic, linoleic, α-linolenic, polyunsaturated and monounsaturated fatty acid content of meat from intensively reared lambs would be beneficial to the consumer health. However, the significantly higher omega 6 to omega 3 fatty acid ratio of meat from intensively reared lambs could have a negative effect on consumer health. Meat from extensively produced lambs contained higher levels of EPA, DHA, omega 3 fatty acids as well as a higher P:S ratio which will promote consumer health.

Regarding the health aspect of intensively produced lambs, it is suggested that the n6:n3 ratio of feed be adjusted (by the possible inclusion of non degradable lipid sources) to produce meat with a more favorable and healthy essential fatty acid content.

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Chapter 5

The effect of extensive and intensive production systems on the sensory quality characteristics and instrumental tenderness of Dohne Merino lambs

ABSTRACT

The main objective of this study was to investigate the impact of an extensive (n = 7) and intensive (n = 7) production system on the sensory meat quality characteristics (flavour, aroma, initial & sustained juiciness, first bite, residue) and instrumental tenderness of Dohne Merino lambs. The Biceps femoris, Longissimus dorsi and Semimembranosus muscle of each lamb were used for descriptive sensory analysis, Warner Bratzler Shear Force (WBSF) test and Texture Profile Analysis (TPA). Extensive production system produced slightly tougher meat with a more intense lamb flavour and aroma, especially with regards to the Biceps femoris. No significant differences in tenderness were detected between the two production systems using the WBSF test. The Longissimus dorsi and Semimembranosus from extensively reared lambs required a significantly higher compression force during TPA. The results of this study indicated that the application of intensive production systems will positively increase the sensory properties, especially tenderness, of the Biceps femoris of Dohne Merino lambs.

Keywords: Descriptive sensory analysis; Warner Bratzler shear force test; Texture profile analysis; Lamb flavour and tenderness; Free-range; Feedlot

INTRODUCTION

The red meat industry is constantly facing new challenges, not only influenced by economic factors and environmental changes, but mainly driven by consumer concerns and preferences (Woodford, 2010). Consumer preferences are very complex and are driven by various intrinsic and extrinsic cues (Acebron & Dopico, 2000). Juiciness, flavour and the tenderness of meat are considered as the main intrinsic factors influencing meat palatability and consumer acceptability (Bello & Calvo, 2000; Brewer & Novakofski, 2008). Beilken *et al*. (1990) concluded that consumers prefer meat that is tender and juicy, and that juiciness as well as flavour contributes to overall acceptability of the meat (Risvik *et al*., 1994). On the other hand many consumers regard tenderness as the primary determinant of meat quality and consider it as the most important quality attribute of meat (Boleman *et al*., 1997; Martin & Rodger, 2004). Miller *et al*. (1995) found that consumers could easily distinguish between different meat tenderness levels and indicated that they are prepared to pay premiums for certified tender meat (Boleman *et al*., 1997; Shackelford *et al*., 2001).

Seasonal droughts, unpredictable weather patterns, diminishing land resources, an unstable economy with fluctuating meat prices, decline in wool prices and environmental degradation has forced farmers to reformulate and restructure their farming methods (Woodford, 2010). The South African Department of Agriculture, Forestry and Fisheries reported that the majority of sheep farming in South Africa is extensive (DAFF, 2009), however, production systems are gradually shifting to more intensive farming systems to increase productivity and profitability (Coetzee & Malan, 2007). In order for the South African red meat industry to successfully implement a predominantly intensive production system, they need to investigate the full impact of the latter system on various meat characteristics, so as to insure that the quality of the product is maintained and that consumer expectations are met (Santa-Silva *et al*., 2002). Similar research has been done by Claasen (2008), on the effect of production systems (free-range or feedlot) on the sensory quality characteristics of the *Longissimus dorsi* muscle of Dorper lambs raised in South Africa. Lambs raised in the feedlot system, scored significantly ($p < 0.050$) higher for the sensory attributes of tenderness and sustained juiciness. Claasen (2008) concluded that the higher lipid content of meat form feedlot lambs attributed to these significant differences. No significant differences were observed between lambs from the feedlot and free-range production systems, for the sensory attributes aroma, flavour and initial juiciness. The production systems had no effect on the meat tenderness as indicated by the Warner-Bratzler shear force test (Claasen, 2008).

According to literature the type of livestock production system (diet, exercise and growth rate) implemented, could have an adverse or favourable impact on lamb's meat (Rousset-Atkin *et al.*, 1997; Priolo *et al*., 2001; Santa-Silva *et al*., 2002; Priolo *et al.*, 2002; Young *et al*., 2003; Aurousseau *et al*., 2007; Angood *et al.*, 2008; Fonti *et al.*, 2009). The firmness, toughness and mechanical properties of meat are affected by the quantity and thermal stability of collagen (Purslow, 1999; Lepetit *et al*., 2000). Spontaneous exercise associated with outdoor rearing systems results in a slightly higher collagen content and a slight to no modification in the heat stability of collagen (Berge *et al*., 1991; Combes *et al*., 2003).

The main objective of this study was to investigate the impact of a production system (extensive or intensive) on various meat sensory quality characteristics (flavour, aroma, initial juiciness, sustained juiciness, first bite and residue) and instrumental tenderness (Warner Bratzler Shear Force test and Texture Profile Analysis) of Dohne Merino lambs. This study did not include the quantification of the effect of gender (ram, ewe, castrate) on the sensory quality characteristics and instrumental tenderness of Dohne Merino lambs.

MATERIALS & METHODS

Lamb management, handling and slaughter procedure

The Dohne Merino lambs were born in March 2008 on Mariendahl (33° 51' 0 S; 18° 49' 60 E) Agricultural Experimental Farm, situated in the Western Cape, South Africa. Mariendahl is located in a winter rainfall region. All lambs were born from parents bred and raised under free-range/free roaming condition. At birth lambs were randomly assigned to two production systems, extensive (free range; n = 7) or intensive (feedlot; n = 7). The average birth weight of the lambs from both production systems was 4.0 kg ± 1.5 kg. Lambs were nursed by their biological mothers and received *ad libitum* colostrums during the first 24 hours after birth.

Extensive production system

After birth, the lambs roamed together with their dams in a free range system on a 10 ha plot at Mariendahl Agricultural Experimental Farm, with a herd density of 8 lambs / sheep per hectare. The foliage on the plot was abundant and consisted mainly of Subterranean clover (*Trifolium subterraneum*), Musk storksbill (*Erodium moschatum*), Medic clovers (*Medicago spp.*) and Ryegrass (*Lolium spp*.). The lambs received 500 g Veekos stud feed™ as supplementation (daily) and had *ad libitum* access to fresh water. Refer to Chapter 3 for the feed composition and Chapter 4 for the fatty acid profile, of these feedstuffs. The plot contained no steep, uneven or elevated areas, which could have led to excessive or strenuous exercise. Lambs in this production system were not confined in any manner and received unlimited/unrestricted natural exercise (physical activity) through grazing. The lambs were weaned 100 days after birth.

Intensive production system

Lambs were weaned from their biological mothers, at an age of 4 days. After weaning the lambs were moved to an indoor holding pen (1.6 m x 1.6 m) with a surrogate mother (Saanen goat - *Capra hircus*) and two other newborn lambs. The indoor pen had sufficient bedding and the design of the holding facilities was in compliance with South African Feedlot Association (SAFA, 2008), the National Environmental Guidelines for Feedlots (SAFA, 2005) and Animal Protection Act (Act No. 71 of 1962) (Anon., 1962). Lambs were nursed by the Saanen goats and were also weaned at an age of 100 days. After weaning the lambs were individually confined to 1 x 2 m indoor stalls and fed Veekos Stud Feed™ pellets, with a metabolisable energy of 9.8 MJ kg^{-1} and lucerne. Lambs had *ad libitum* access to lucerne, Veekos Stud Feed™ pellets and fresh water.

Slaughtering

Dohne Merino lambs from both production systems were slaughtered at an age of 8 months, using standard South African slaughtering methods (Cloete *et al.*, 2004). The slaughter weight of the

lambs was recorded 24 hours prior to slaughtering. The lambs were transported approximately 60 km to a commercial abattoir in Malmesbury (33° 27' 0 S; 18° 41' 60 E) on a day with a maximum temperature of 25°C. The lambs were off-loaded at the abattoir, grouped together and housed in lairage overnight. The lambs had *ad libitum* access to fresh water and received no feed. The next morning the lambs were electrically stunned (4 s at 200 V), hang by the Achilles tendon and the jugular vein severed (Cloete *et al.*, 2004). After exsanguination the carcasses were deskined, dressed and stored at 4°C for 24 hours. After 24 hours the carcasses were transported approximately 60 km in a refrigerated truck (4 - 7°C) to the Meat Science Laboratory at Stellenbosch University. The carcasses were offloaded and stored in the deboning area (6 - 8°C) of the laboratory for another 24 hours.

Experimental units

Whole skeletal muscles (*Biceps femoris*, *Longissimus dorsi* and *Semimembranosus*) were chosen as experimental units instead of retail cuts. This decision was made based upon the fact that retail cuts consist mainly out of two or more muscles, each with different endogenous metabolic systems and functions, and may also contain bones, tendons or excessive connective tissue. The latter will act as unnecessary variables during analyses, thus masking the effect of the treatment being investigated.

The *Biceps femoris* is situated at the extensor of the hip, stifle, and hock joints and flexes the stifle when the hind foot is lifted off the ground (Nickel *et al*., 1986; Frandson *et al*., 2003). The *Biceps femoris* muscle was removed 48 hours post mortem, from the right side of each carcass.

The *Longissimus dorsi* acts as an extensor of the back and loin and flexes the spine laterally (Nickel *et al*., 1986; Frandson *et al*., 2003). The *Longissimus dorsi* muscle (3^{th} rib to 4^{th} lumbar vetebrae) from the right side of each carcass was excised 48 hours post mortem.

The *Semimembranosus* muscle acts as the extensor of the hip joints and flexor of the stifle (Nickel *et al*., 1986; Frandson *et al.*, 2003). The *Semimembranosus* muscle was removed 48 hours post mortem, from the right side of each carcass. All three muscles were individually vacuum sealed in labelled plastic bags and placed in a freezer (-18°C) for approximately 5 weeks until analyses commenced.

Descriptive sensory analysis

Sample preparation

A lamb from each production system (extensive and intensive) was randomly selected for each replication (n = 7). The frozen muscle samples (*Biceps femoris*, *Longissimus dorsi* and *Semimembranosus)*, from each animal, was removed from the freezer (-18°C) and defrosted in a refrigerator (4°C) for 48 hours prior to each sensory analysis session. The vacuum packed defrosted samples were removed from the packaging and placed in separate coded oven roasting

bags (GLAD™). The roasting bag containing the sample was then placed on a metallic mesh grid enclosed with aluminium foil. A thermocouple probe, connected to a hand-held electronic temperature monitor (Hanna Instruments, South Africa), was inserted into the core of each sample (American Meat Science Association - AMSA, 1995), where after the roasting bag was closed with a metal tie. Two conventional ovens (Defy, Model 835), connected to a temperature control and montiring system (Viljoen *et al*., 2001), were preheated to 160°C (AMSA, 1995). The samples were placed in the preheated ovens and roasted until a core temperature of 72°C was recorded by the thermocouple probe (AMSA, 1995), where after the samples were removed from the ovens and roasting bags. The meat samples were cooled for 10 min and any excess subcutaneous fat, connective tissue or heat damaged (dry or burned) areas were trimmed off. Each meat sample was individually cut into 1.5 cm x 1.5 cm sample cubes (approximately 5 g per cube), perpendicular to the muscle fibers and with a single stroke of a sharp knife, to prevent excess moisture loss and muscle fibre disruption. The meat cubes were wrapped (individually) in aluminium foil squares, and placed in three digit coded ramekins. The coded ramekins containing the wrapped meat samples were placed in a preheated oven (100°C) and reheated for 10 minutes before the sensory analysis commenced (Hoffman *et.al,* 2003; Hoffman *et al.,* 2006).

Eight judges, with experience in sensory analysis of various meat attributes, were selected for the sensory panel. The panellists were trained in descriptive sensory analysis using the consensus method, as described by Lawless and Heymann (1998) and the AMSA guidelines (1995). The panellists were subjected to four training sessions. During each training session the panellist were provided with three cooked reference standards and a cooked sample (1.5 cm x 1.5 cm cube) of the *Biceps femoris*, *Longissimus dorsi* and *Semimembranosus* muscles from lambs of each production system (extensive and intensive). Reference standards were used to assist the panellist in distinguishing between tough and tender meat. The reference standards used were: the *Longissimus dorsi* of a commercial A2 lamb; *Longissimus dorsi* of a commercial C grade sheep (mutton) and a commercial beef fillet. In South Africa commercial C grade mutton is regarded as being the toughest and beef fillet the most tender cut. Grade A2 commercial lamb has intermediate to tender meat. The experimental samples were analysed on a 100 mm unstructured line scale adapted from the AMSA guidelines (1995). The line scale is anchored by a zero (low intensity) on the left-hand side and a 100 (high intensity) on the right-hand side. Six sensory attributes were consensually chosen by the panellist for the sensory analysis of the lamb samples: aroma; flavour; initial juiciness; sustained juiciness; first bite and residue. Refer to Table 1 for the definition and scale anchor points for each sensory attribute (AMSA, 1995; Hoffman *et al*., 2003, 2006).

Each treatment was repeated seven times (replications), using the ANOVA test-retest method. Each panellist received six samples to analyse during each session. The six samples comprised out of three lamb muscles (*Biceps femoris*, *Longissimus dorsi* and *Semimembranosus*)

from two production systems (extensive and intensive). Panel members were seated at individual sensory booths in a room with a controlled temperature (21°C) and artificial light. As described, samples were individually wrapped in aluminium foil, placed in coded ramekins and reheated for 10 minutes at 100°C. Samples were presented to each panellist in a completely randomised order. Thereafter the meat samples were analysed on the questionnaire compiled and standardised during the training sessions. Each panellist was provided with distilled water (21°C) and freshly sliced apple quarters to cleanse their palates between each sample evaluation.

Table 1 Definition and scale anchor points for each sensory attribute

SENSORY ATTRIBUTE	DEFINITION	SCALE
Lamb aroma	Aroma associated with lamb	0 = Extremely bland 100 = Extremely intense
Lamb flavour	Flavour associated with lamb whilst swallowing	0 = Extremely bland 100 = Extremely intense
Initial juiciness	The amount of fluid exuded on the cut surface when pressed between your thumb and forefinger	0 = Extremely dry 100 = Extremely juicy
Sustained juiciness	The degree of juiciness perceived after the first two chews using the molar teeth	0 = Extremely dry 100 = Extremely juicy
First bite	Impression of tenderness after the first two chews using the molar teeth	0 = Extremely tough 100 = Extremely tender
Residue	The amount of residue left in the mouth after the first ten chews	0 = Abundant 100 = None

Warner Bratzler shear force

The instrumental tenderness of the samples was analysed by using the Warner Bratzler shear force (WBSF) test as described by Honikel (1998). Three muscles (*Biceps femoris*, *Longissimus dorsi* and *Semimembranosus*) of each lamb (n = 7) from both production systems (extensive and intensive) were used for the WBSF test. A muscle slice (1.5 cm thick) was cut from each whole muscle, 48 hours post mortem at 4°C. The slices were cut perpendicular to the muscle fibre direction and all visible subcutaneous fat and connective tissue was trimmed off. The muscle slices were subsequently cooked in sealed plastic bags at 80°C for 60 minutes in a water bath (Honikel, 1998). Excess fluid was drained from the plastic bags and the samples were stored for 24 hours at 4°C. Seven cylindrical cores were randomly cut from the centre of each cooked sample with a metal core with a diameter of 12.7 mm, and stored at 4°C until testing commenced. An Instron Universal Testing Machine (Model 4444, Apollo Scientific, South Africa) was fitted with a Warner Bratzler blade, 1.2 mm thick with a triangular opening (13 mm at the widest point and 15 mm high), to determine the force (Newton) needed to shear a cooked cylindrical core of the sample, perpendicular to the muscle fiber direction. The Instron Universal testing machine was fitted with a 2 kN load cell and the shear test was conducted at a crosshead speed of 100 mm min^{-}

[1]. Shear force values for each sample was recorded in Newton (N) and a high value is indicative of a tougher sample (Honikel, 1998; Hoffman *et al*., 2003, 2006).

Texture Profile Analysis (TPA)

Sub-samples of the *Biceps femoris*, *Longissimus dorsi* and *Semimembranosus* muscles of each lamb (n = 7) from both production systems (extensive and intensive) were used for the TPA (double-bite test). Firmness of the samples was recorded during the first cycle of compressing (first bite) by measuring the samples resistance (maximum force) against compression in Newton (N). Cooked samples were used and samples were prepared according to AMSA (1995) guidelines. Six cubes (1.5 cm x1.5 cm) were cut, perpendicular to the muscle fiber direction, from each muscle sample. An Instron Universal testing machine (Model 3344, Apollo Scientific, South Africa) was fitted with a compression plate (3.5 mm in diameter) and a 5 kN loading cell. The TPA was conducted at a crosshead speed of 100 mm/min. The cube samples were compressed perpendicular to the muscle fiber direction at a 80% compression. Blue Hill software (Version 2.4) was used to conduct the TPA and maximum force values were recorded in Newton (N). A high recorded force (N) value was indicative of a high resistance to compression and thus a tougher sample (AMSA, 1995; Honikel, 1998; Bourne, 1978; Huidobro *et al.*, 2005).

Statistical analysis of data

A random split-plot design, with two production systems (extensive and intensive) as the main-plot, was used as the experimental design in this study. Seven carcasses were randomly drawn from each main-plot and the sub-plot factor consisted of three muscles (*Biceps femoris*, *Longissimus dorsi* and *Semimembranosus*). A random split-plot analysis of variance (ANOVA) was performed to analyse the instrumental tenderness (WBSF and TPA). Each of the eight judges analysed all samples for sensory attributes (aroma, flavour, initial, juiciness, sustained juiciness, first bite and residue). An appropriate ANOVA was performed to test for panel reliability by means of internal consistency (Judge x Treatment Combinations) and temporal stability measured by Judge x Carcass interaction. For all analyses the studentised residuals were calculated and test for deviations from normality using Shapiro-Wilk's test (Shapiro & Wilk, 1965). Outliers were identified and removed before the finale ANOVA's were performed (Snedecor, 1967). Means of significant effects were compared using Student's t-LSD (Least Significant Difference) at a 5% level of significance. For the correlation between sensory attributes (Chapter 5), instrumental tenderness (Chapter 5) and chemical composition (Chapter 4), Pearson's correlation coefficients were calculated. All above procedures were analyse using SAS™ statistical software (Statistical Analysis System, Version 9.1).

RESULTS & DISCUSSION

Sensory attributes

The trained panel detected sensory differences (Table 2) between the two production systems for the sensory attributes of the *Biceps femoris*: aroma ($p = 0.001$); sustained juiciness ($p = 0.048$); first bite ($p = 0.031$) and residue ($p = 0.024$). According to the trained panel, the *Biceps femoris* from the extensive production system had a significantly more intense lamb aroma. The *Biceps femoris* from intensively reared lambs had a higher juiciness content for both the initial and sustained juiciness, although the former was not significant ($p > 0.050$). Lambs from the intensive production system also scored significantly higher for the sensory attributes first bite and residue, which indicates a more tender muscle.

No differences ($p > 0.050$) were detected (Table 2) between the *Longissimus dorsi* of extensively and intensively reared lambs, for all the sensory attributes analysed. The *Semimembranosus* from lambs from the extensive production system had a higher ($p = 0.037$) lamb aroma intensity. No sensory differences ($p > 0.050$) were detected (Table 2) between the two production systems for the remaining sensory attributes.

Rousset-Atkin *et al*. (1997) concluded that the diet of pasture fed sheep usually results in meat with an increased lamb aroma and in some instances the development of off-flavours. The subcutaneous fat of pasture fed animals contains relatively higher concentrations of linolenic acid than grain fed animals and the former contributes to an increase in cooked meat aroma and possibly also the development of off-flavours associated with pasture fed animals (Ray *et al*., 1975; Melton *et al*., 1982; Young *et al*., 1999; Wood *et al*., 2003; Diaz *et al*., 2005; Aurousseau *et al*., 2007; Popova *et al*., 2007; Neurenberg *et al*., 2008). Various authors (Wong *et al.*, 1975; Brennand & Lindsay, 1992; Priolo *et al.*, 2001) reported that the typical flavour and aroma associated with lamb's meat is due to the presence of branched-chain fatty acids (4-methyloctanoic acid), in the subcutaneous fat. However, according to Young *et al.* (2003) and Priolo *et al.* (2002), higher concentrations of branched-chain fatty acids were found in the fat of grain fed lambs when compared to grass fed lambs.

Although the trained panel, in this study, scored the samples from the extensive production system significantly higher for lamb aroma intensity (*Biceps femoris* and *Semimembranosus*), the mean values of all three muscles from the respective production systems were of the same magnitude. The flavour of the cooked meat samples of both production systems for all three muscles was also similar ($p > 0.050$). This illustrates that diet did not have a considerable effect on the general aroma or flavour of the samples. The flavour and aroma result of this study conflicts with the result obtained by Claasen (2008). Although no differences ($p > 0.050$) were detected, between the two production systems for aroma and flavour in Claasen's (2008) study, the taste panel scored intensively produced meat slightly higher with regards to these two sensory attributes. The feed composition of Claasen's (2008) study differed from the feed fed to the lambs

in this study and it could therefore be speculated that differences in feed composition attributed to the aroma and flavour difference between these two studies (discussed in literature review).

Priolo *et al*. (2002) reported that carcass fatness is positively correlated to sensory juiciness and that animals from intensive production systems produced carcasses with a higher fat content due to the consumption of a high energy diet. Although similar results were obtain in this study, no correlation was observed between sustained juiciness and intramuscular fat content (Chapter 4), for all three muscles (*Biceps femoris*: r = 0.147, p = 0.616; *Longissimus dorsi*: r = 0.308, p = 0.284; *Semimembranosus*: r = 0.147; p = 0.616). Offer and Trinick (1983) concluded that the initial juiciness of meat is positively correlated with the water holding capacity of meat, which is influenced by the muscles' ultimate pH post mortem. Santa-Silva *et al*. (2002) found that intensively produced animals have a higher ultimate pH and thus a higher water holding capacity, when compared to concentrate fed animals, due to their high susceptibility to ante mortem stress. In this study no correlation was observed between muscle pH (48 hour post mortem; Chapter 3) and initial juiciness (*Biceps femoris*: r = 0.357, p = 0.211; *Longissimus dorsi*: r = 0.172, p = 0.555; *Semimembranosus*: r = 0.250; p = 0. 388). It could be concluded that the production systems in this study had no stressful effect on the lambs therefore the muscle pH was not elevated and did not indirectly affect initial juiciness of the meat.

The lambs from the intensive production system scored slightly higher for sensory tenderness (first bite and residue) when compared to lambs raised under extensive conditions (Table 2). Claasen (2008) obtained similar results for the sensory tenderness (first bite and residue) of the *Longissimus dorsi* muscle of Dorper Lambs. According to literature marbling (intramuscular fat) tends to correlate positively with sensory tenderness (Smith *et al.*, 1976; Schönfeldt *et al*., 1993; Angood *et al*., 2008). In this study first bite (r = 0.653; p = 0.011) and residue (r = 0.666; p = 0.009) are both positively correlated with the average intramuscular fat content (Chapter 4) for all three muscles (*Biceps femoris*, *Longissimus dorsi* and *Semimembranosus*). Fishell *et al.* (1985) stated that a high energy diet has a positive effect on meat tenderness because the rapid weight gain decreases the intramuscular collagen (cross-linked) content. Data obtained in this study confirm the results of Fishell *et al*. (1985) because the mean first bite score over all three muscles (*Biceps femoris*, *Longissimus dorsi* and *Semimembranosus*) was negatively correlated (r = -0.536; p = 0.048) with the average insoluble collagen content (Chapter 4) of all three muscles. Smith and Carpenter (1970) concluded that muscles that are more active during locomotion are less tender due to an increase in intramuscular collagen. The *Biceps femoris* muscle and Semimembranosus is highly active during locomotion and when compared to the *Longissimus dorsi* muscle, obtained the lowest scores for sensory tenderness (first bite and residue). The sensory first bite score for the *Biceps femoris* muscle was negatively correlated (r = -0.664; p = 0.010) with the insoluble collagen content of the *Biceps femoris* (Chapter 4). No significant correlation was detected between the sensory first bite (r = -

0.034; p = 0.909) and residue (r = -0.034; p = 0.907) scores for the *Longissimus dorsi* and insoluble collagen content of this muscle (Chapter 4).

In this study an overall tendency was observed that extensively produced meat was less tender and juicy, with a slightly (p > 0.050) higher lamb aroma and flavour intensity. The intensive production systems had a significant positive effect on the sensory qualities (aroma, sustained juiciness, first bite and residue) of the *Biceps femoris*, which is a high priced cut.

Instrumental texture

The *Biceps femoris*, *Longissimus dorsi* and *Semimembranosus* muscles of Dohne Merino lambs from the two production systems (extensive and intensive) were subjected to two reference instrumental texture tests, WBSF and TPA. Table 3 illustrates the WBSF and TPA means and standard deviations (±SD). WBSF measures tenderness and TPA measures firmness, both these measurements were recorded in Newton (N).

No tenderness differences (p = 0.998) were detected between *Biceps femoris* from lambs from the two production systems after subjection to the WBSF test (Table 3). The p-value is relatively close to 1 therefore the Warner Bratzler readings for both the extensive and intensive production systems can be regarded as virtually the same. The *Biceps femoris* samples were also subjected to a TPA test. Again the means of the two production systems did not differ (p = 0.081), indication that the firmness (N) of the *Biceps femoris* was the same for the respective production systems.

After the *Longissimus dorsi* samples were subjected to the WBSF test, no differences (p = 0.160) were detected (Table 3) between the lambs from the two production systems. However, the *Longissimus dorsi* from the lambs raised under extensive conditions required a higher force (p = 0.014) during the first cycle of compression for the TPA, indicating an increased in muscle firmness for this production system.

No differences (p = 0.586) were detected (Table 3) between the *Semimembranosus* from the two production systems, during the WBSF test. However, highly significant differences were detected during the TPA test (p = 0.002). The *Semimembranosus* from the extensive production system (362.60 ± 27.62 N) required a higher force during the first cycle of compression than the *Semimembranosus* from the intensive production system (278.31 ± 49.27 N). The extensive production system thus resulted in a slightly firmer cooked sample texture.

Table 2 The score mean (±SD) for various sensory attributes of the *Biceps femoris*, *Longissimus dorsi* and *Semimembranosus* of Dohne Merino lambs reared in extensive (n = 7) and intensive (n = 7) production systems

	Biceps femoris			***Longissimus dorsi***			***Semimembranosus***		
	Extensive	**Intensive**	**p-Value**	**Extensive**	**Intensive**	**p-Value**	**Extensive**	**Intensive**	**p-Value**
Aroma[a]	60.25 ±1.70	54.96 ±2.74	**0.001**	59.68 ±1.71	57.68 ±3.02	0.153	61.39 ±1.48	58.18 ±3.31	**0.037**
Flavour[b]	60.55 ±1.91	58.77 ±2.59	0.168	59.04 ± 2.32	58.66 ±3.41	0.814	60.64 ± 2.32	59.25 ±2.84	0.335
Initial juiciness[c]	58.96 ±3.25	60.46 ±3.35	0.412	62.23 ±4.21	62.66 ±4.95	0.864	58.71 ± 2.71	60.64 ±3.78	0.295
Sustained juiciness[d]	58.64 ±2.14	62.05 ±3.49	**0.048**	63.46 ±3.88	64.50 ±5.43	0.689	59.43 ±3.25	61.04 ±3.61	0.399
First bite[e]	65.77 ±6.54	72.61 ±3.45	**0.031**	76.25 ±10.91	78.46 ±9.60	0.694	62.04 ±9.00	68.00 ±7.84	0.211
Residue[f]	65.64 ±6.44	72.84 ±3.60	**0.024**	71.82 ±9.53	73.36 ±8.89	0.761	61.07 ±7.68	65.52 ±8.59	0.328

[a-f]Lamb Aroma & Flavour: 0 = Extremely bland, 100 = Extremely intense Lamb Aroma & Flavour; Initial & Sustained Juiciness: 0 = Extremely Dry, 100 = Extremely Juicy; First Bite: 0 = Extremely tough, 100 = Extremely tender; Residue: 0 = Abundant, 100 = None. SD = Standard Deviation

Table 3 The mean (±SD) instrumental texture of the *Biceps femoris*, *Longissimus dorsi* and *Semimembranosus* of Dohne Merino lambs from two production systems (extensive and intensive), using two reference methods: the Warner Bratzler shear force (WBSF) for measuring tenderness and Texture Profile Analysis (TPA) measuring firmness

	Biceps femoris			***Longissimus dorsi***			***Semimembranosus***		
Newton	**Extensive**	**Intensive**	**p-Value**	**Extensive**	**Intensive**	**p-Value**	**Extensive**	**Intensive**	**p-Value**
WBSF	37.24 ±8.54	37.25 ±3.23	0.998	44.52 ±5.73	49.28 ±6.16	0.160	52.25 ±3.62	49.32 ±13.36	0.586
TPA	265.14 ±26.74	216.22 ±62.41	0.081	276.69 ±41.39	222.20 ±28.77	**0.014**	362.60 ±27.62	278.31 ±49.27	**0.002**

SD = Standard Deviation

As mentioned above, no significant differences were detected between the lambs from both production systems when the samples (*Biceps femoris*, *Longissimus dorsi* and *Semimembranosus*) were subjected to the WBSF test. These results are similar to the results obtained by Santa-Silva *et al*. (2002), who detected no significant difference between shear force values of extensive and intensively produced meat. According to literature, meat from intensively produced animals has a higher intramuscular fat content and a lower WBSF value, than extensively produced animals because intramuscular fat has a low resistance to shearing (Sañado *et al.*, 2003; Fonti *et al.*, 2009). Brewer and Calikin (2003) stated that animals raised on low energy diets (extensive production system) have a high connective tissue content which increases the meat's resistance to shearing thus contributing to the sensory toughness of the meat. No significant correlations (Table 4) were observed between WBSF values, chemical composition (Chapter 4), sensory attributes (Chapter 5) and TPA (Chapter 5).

Although no significant differences between the WBSF values in this study were recorded (Table 3) for the *Longissimus dorsi* muscle from both production systems, the *Longissimus dorsi* from the intensive production system had a slightly higher shear force value. This contradicts the results obtained by Claasen (2008), who concluded that extensively reared Dorper lambs had a slightly higher ($p > 0.050$) shear force value compared to lambs from the intensive production system. Brewer and Calkins (2003) stated that animals raised on a low energy diets (extensive production system) has a high connective tissue content which increases the meat's resistance to shearing thus contributing to the sensory toughness of the meat. In this study the *Longissimus dorsi* from intensively reared lambs contained slightly ($p > 0.050$) more insoluble collagen (Chapter 4), which is similar to the results obtained by Berg *et al*. (1989) on pigs. Berg *et al*. (1989) speculated that the higher collagen content could be ascribed to intensively produced animal being confined, which increase stress levels and static muscle activity compared to extensively reared animals.

However, Smith and Carpenter (1970) concluded that muscles that are more active during locomotion are less tender due to increase in (total) intramuscular collagen. The slightly higher ($p > 0.050$) shear force value of the *Semimembranosus* from extensively reared lambs could be ascribed to a higher activity level of the muscle during locomotion (grazing) and a subsequent increase ($p > 0.050$) in insoluble collagen content of the muscle (Chapter 4).

The *Longissimus dorsi* and *Semimembranosus* from the extensive production system required a significantly higher force during the first cycle of compression (TPA; firmness) when compared to muscles from the intensive production systems. Although no correlations were detected between TPA (firmness) and first bite (*Biceps femoris*: $r = -0.472$; $p = 0.089$; *Longissimus dorsi*: $r = -0.321$, $p = 0.264$; *Semimembranosus*: $r = -0.413$, $p = 0.142$) and residue (*Biceps femoris*: $r = -0.513$; $p = 0.061$; *Longissimus dorsi*: $r = -0.335$, $p = 0.242$; *Semimembranosus*: $r = -0.328$, $p = 0.253$), Huidobro *et al*. (2005) indicated that TPA could be used to accurately predict

sensory tenderness. The possibility exists that if the sample size of this experiment were bigger, more significant correlations may have been found.

CONCLUSION

The aim of this study was to determine whether a specific livestock production system could affect the sensory quality characteristics and instrumental tenderness and firmness of meat from Dohne Merino lambs.

The results of this investigation indicate that intensive production system produces meat with slightly more positive sensory quality characteristics when compared to extensive production systems. The intensive production system produces more juicy (initial and sustained) and tender (first bite and residue) meat. The latter two major attributes contribute positively to the overall quality of the meat. Extensive production systems tend to produce meat with a slightly more intense lamb aroma and flavour intensity, and slightly less tender meat. Of special interest is the fact that the intensive production systems had a significantly positive effect on the sensory qualities (aroma, sustained juiciness, first bite and residue) of the *Biceps femoris*, which is a high value muscle.

No correlations were found between instrumental tenderness and sensory tenderness, however TPA (firmness) results predicted more accurately the sensory tenderness of the samples when compared to WBSF (shear force) results. Other authors also observed this tendency and it could be suggested that TPA should be used instead of WBSF to determine instrumental firmness, however, this is an area that requires more research.

To thoroughly understand the full impact of a production system on the sensory quality and instrumental tenderness of lamb's meat, all edible muscles should be included in the study, as well as the quantification of the effect of gender (ram, ewe, castrated). Although the lambs in this study were all slaughtered at the same age (8 months), it could be speculated that older animals (> 8 months) could result in significantly larger differences between the two production groups, especially for the sensory attribute, tenderness.

Table 4 Pearson's correlation coefficients (r-Value) and p-Value (at 5% significance level) for comparisons between WBSF values and various chemical, sensory and TPA scores of the *Biceps femoris*, *Longissimus dorsi* and *Semimembranosus*

	Biceps femoris		***Longissimus dorsi***		***Semimembranosus***	
Correlation	**r-Value**	**p-Value**	**r-Value**	**p-Value**	**r-Value**	**p-Value**
Soluble collagen	-0.242	0.405	-0.545	0.440	0.028	0.924
Insoluble collagen	0.008	0.980	0.103	0.726	0.053	0.857
Intramuscular fat	-0.137	0.640	-0.121	0.681	-0.119	0.686
First bite	-0.304	0.291	-0.099	0.736	-0.116	0.692
Residue	-0.362	0.203	-0.151	0.606	-0.100	0.733
TPA	0.141	0.630	0.024	0.935	0.299	0.300

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Chapter 6

The effect of extensive and intensive production systems on the histochemical properties of Dohne Merino lamb muscles

ABSTRACT

The objective was to investigate the impact of an extensive (n = 7) and intensive (n = 7) production system on the histochemical properties of the Biceps femoris, Longissimus dorsi and Semimembranosus muscles of Dohne Merino lambs. The mATPase assay was used to classify the muscle fibers (I; IIA; IIB). The Biceps femoris muscle from extensively reared lambs contained more (p = 0.001) type I and less IIB (p < 0.001) muscle fibers compared to the Biceps femoris of intensively reared lambs. The Semimembranosus from extensively reared lambs contained more type I (p < 0.001) and IIA (p < 0.001) muscle fibers compared to the Semimembranosus of intensively reared lambs. Production systems had a significant effect on type IIA fiber size (diameter: p = 0.025 and area: p = 0.032) of the Semimembranosus, extensively reared had larger IIB fibers. No differences (p > 0.050) in sarcomere length were observed.

Keywords: Fiber typing; Sarcomere; Free-range; Feedlot; *m*ATPase staining; Meat quality

INTRODUCTION

An important driving force for consumer acceptance is product quality, which also influences overall consumer satisfaction and purchase behaviour. Quality has been defined as the total degree of satisfaction a consumer receives from a product (Jul and Zeuthen, 1981) and is used as a generic term to describe the positive properties of a product (Maltin *et al.,* 2003). Meat quality is initially perceived by the consumer through a visual impression (colour, visible fat, and purge) and confirmed during consumption of the product (texture, juiciness, flavour) (Acebron & Dipico, 2000).

One of the main goals of the meat industry is to provide consumers with products that are consistent in quality, which will subsequently increase the consumer's confidence in the product and encourage repurchasing (Maltin *et al*., 1997; Lefaucheur & Gerrard, 1998). Variation in meat quality is contributed by various intrinsic (species, breed, individual, sex, age, genetics) and extrinsic (feed, environmental conditions, production system, slaughter procedures) factors, most of which have been extensively researched to provide the meat industry with guidelines (breeding, production, processing) to ultimately minimise quality variation (Maltin *et al*., 1997; Sanudo *et al*., 1998; Klont *et al*., 1998; Karlsson *et al*., 1999). Although these guidelines provide the meat industry with valuable assistance, variability in meat quality is still a major issue (Maltin *et al*., 1997;

Lefaucheur & Gerrard, 1998; Maltin *et al*., 2003; Lefaucheur, 2010). Evidence in the literature suggest that the complex histochemical properties of skeletal muscles (e.g. muscle fiber type, fiber frequency, fiber dimensions and sarcomere length) are an important source of quality variation in meat and could be used as a predictor of meat quality especially for the most important palatability trait, tenderness (Tuma *et al*., 1962; Calkins *et al*., 1981; Valin *et al*., 1982; Whipple *et al*., 1990; Crouse *et al*., 1991; Maltin *et al*., 1997; Klont *et al*., 1998; Lefaucheur & Gerrard, 1998; Karlsson *et al*., 1999; Chang *et al*., 2003; Lefaucheur, 2010).

Various classification techniques and nomenclature has been developed for the classification of mammalian muscle fibers (Peinado *et al*., 2004) but in this study the most widely accepted classification technique, based on the contractile properties of the muscle fiber and the sensitivity of the myosin adenosine triphosphatase (*m*ATPase) enzyme activity to the pH of the pre-incubation solution (Brooke and Kaiser, 1970), was used.

The objective of this study was to investigate the impact of an extensive (free-range) and intensive (feedlot) production system on the histochemical properties of three muscles (*Biceps femoris*, *Longissimus dorsi*, *Semimembranosus*) of Dohne Merino lambs. The possible impact of these results on the physical (Chapter 3), chemical (Chapter 4) and sensory (Chapter 5) properties of the meat produced by extensively and intensively reared lambs, will also be discussed. This study did not include the quantification of the effect of gender (ram, ewe, castrate) on the histochemical properties.

MATERIALS & METHODS

Lamb management, handling and slaughter procedure

The Dohne Merino lambs were born in March 2008 on Mariendahl (33° 51' 0 S; 18° 49' 60 E) Agricultural Experimental Farm, situated in the Western Cape, South Africa. Mariendahl is located in a winter rainfall region. All lambs were born from parents bred and raised under free-range/free roaming condition. At birth lambs were randomly assigned to two production systems, extensive (free range; n = 7) or intensive (feedlot; n = 7). The average birth weight of the lambs from both production systems was 4.0 kg ± 1.5 kg. Lambs were nursed by their biological mothers and received *ad libitum* colostrums during the first 24 hours after birth. Lambs were vaccinated against Pulpy kidney (3 months old), Pasteurella (3 months old) and Blue tongue (6 month old).

Extensive production system

After birth, the lambs roamed together with their dams in a free range system on a 10 ha plot at Mariendahl Agricultural Experimental Farm, with a herd density of 8 lambs / sheep per hectare. The foliage on the plot was abundant and consisted mainly of Subterranean clover (*Trifolium subterraneum*), Musk storksbill (*Erodium moschatum*), Medic clovers (*Medicago spp.*) and

Ryegrass (*Lolium spp*.). The lambs received 500 g Veekos stud feed™ as supplementation (daily) and had *ad libitum* access to fresh water. Refer to Chapter 3 for the feed composition and Chapter 4 for the fatty acid profile, of these feedstuffs. The plot contained no steep, uneven or elevated areas, which could have led to excessive or strenuous exercise. Lambs in this production system were not confined in any manner and received unlimited/unrestricted natural exercise (physical activity) through grazing. The lambs were weaned 100 days after birth.

Intensive production system

Lambs were weaned from their biological mothers, at an age of 4 days. After weaning the lambs were moved to an indoor holding pen (1.6 m x 1.6 m) with a surrogate mother (Saanen goat - *Capra hircus*) and two other newborn lambs. The indoor pen had sufficient bedding and the design of the holding facilities were in compliance with South African Feedlot Association (SAFA, 2008), the National Environmental Guidelines for Feedlots (SAFA, 2005) and Animal Protection Act (Act No. 71 of 1962) (Anon., 1962). Lambs were nursed by the Saanen goats and were also weaned at an age of 100 days. After weaning the lambs were individually confined to 1 x 2 m indoor stalls and fed Veekos Stud Feed™ pellets, with a metabolisable energy of 9.8 MJ kg^{-1} and lucerne. Lambs had *ad libitum* access to lucerne, Veekos Stud Feed™ pellets and fresh water.

Slaughtering

Dohne Merino lambs from both production systems were slaughtered at an age of 8 months, using standard South African slaughtering methods (Cloete *et al.*, 2004). The slaughter weight of the lambs was recorded 24 hours prior to slaughtering. The lambs were transported approximately 60 km to a commercial abattoir in Malmesbury (33° 27' 0 S; 18° 41' 60 E) on a day with a maximum temperature of 25°C. The lambs were off-loaded at the abattoir, grouped together and housed in lairage overnight. The lambs had *ad libitum* access to fresh water and received no feed. The next morning the lambs were electrically stunned (4 s at 200 V), hang by the Achilles tendon and the jugular vein severed (Cloete *et al.*, 2004). After exsanguination the carcasses were dehided, dressed and stored at 4°C for 24 hours. After 24 hours the carcasses were transported approximately 60 km in a refrigerated truck (4 - 7°C) to the Meat Science Laboratory at Stellenbosch University. The carcasses were offloaded and stored in the deboning area (6 - 8°C) of the laboratory for another 24 hours.

Experimental units

Whole skeletal muscles (*Biceps femoris*, *Longissimus dorsi* and *Semimembranosus*) were chosen as experimental units instead of retail cuts. This decision was made based upon the fact that retail cuts consist mainly out of two or more muscles, each with different endogenous metabolic systems, and functions, and may also contain bones, tendons or excessive connective tissue. This

will act as unnecessary variables during analyses, thus masking the effect of the treatment being investigated.

The *Biceps femoris* is situated at the extensor of the hip, stifle, and hock joints and flexes the stifle when the hind foot is lifted off the ground. The *Longissimus dorsi* acts as an extensor of the back and loin and flexes the spine laterally and the *Semimembranosus* muscle acts as the extensor of the hip joints and flexor of the stifle (Nickel *et al*., 1986; Frandson *et al*., 2003).

Fiber Typing

Specimen collection and preparation

Superficial tissue specimens (5 mm) were collected from the medial region of each muscle (*Biceps femoris*, *Longissimus dorsi* - 12th rib and *Semimembranosus*) from the right side of the carcass of Dohne Merino lambs (n = 7) from both production systems (extensive and intensive), within 45 minutes post mortem. Each specimen from each muscle and carcass (right side) was individually mounted on a coded cardboard square (1.5 x 1.5 cm) with the muscle fiber orientation perpendicular to the cardboard surface. OCT Tissue Freezing Medium (Jung™) was used to fixate and mount the specimen on the cardboard square were after the mounted specimen was immediately submerged in iso-pentane cooled in liquid nitrogen. Whereafter the mounted samples were frozen in liquid nitrogen and stored at -80°C until further analysis. It is crucial to freeze the specimen in liquid nitrogen within the first hour post mortem to avoid morphological degradation of the specimen (Dubowitz & Brooke, 1973; Dubowitz, 1985).

Specimens were sectioned in a cryostat (Leica, CM1100) set at -23°C with 60% relative humidity. The specimens were left inside the cryostat chamber for 5 minutes to adjust to the cryostat's internal atmosphere (temperature and humidity). Three successive/serial transverse/cross sections (10 µm) were cut from each specimen, and each section was individually mounted on a separate labelled microscope slide (Lasec™).

During sectioning, if the internal temperature of the cryostat chamber rose above -20°C, sectioning was halted and the specimen was removed from the cryostat and placed back in storage (-80°C), to avoid morphological degradation of the specimen (Dubowitz & Brooke, 1973; Dubowitz, 1985). The lid of the cryostat was closed until the cryostat chamber reached the optimal/desired temperature of -23°C before sectioning was resumed. Mounted slides were investigated under a standard light microscope to insure the sectioned specimen's fiber orientation was perpendicular to the slide surface and that the specimen contained no artefacts, cell disruption or freeze damage (Dubowitz & Brooke, 1973; Dubowitz, 1985). Microscope slides, containing sectioned specimen, were carefully placed in a staining jar and stored at -20°C until *m*ATPase staining.

mATPase staining assay

The sectioned specimens were removed from storage (-80°C), left for 5 minutes to reach room temperature and stained for myosin adenosine triphosphatase (*m*ATPase) activity (Brooke and Kaiser, 1970). The specific pH used for *m*ATPase was adjusted specifically for Dohne Merino lamb muscle. After numerous trials on Dohne Merino lamb specimens, it was noted that the *m*ATPase activity of Dohne Merino lamb muscle fibers were inhibited at pH 4.0, 4.2 and 10.4 and therefore the pH's of the pre-incubation step of the *m*ATPase staining assay of Brooke and Kaiser (1970) was amended and adjusted to pH 4.0, 4.2 and 10.4. The stained sections were left to air dry where after a cover slip was mounted on the section, using Kaiser glycerine-gelatine.

Fiber typing and frequency

Photos of the pH ranges (4.0, 4.2 and 10.4) of each specimen were taken at the same location on each slide. Photos were taken at a 10x magnification using a digital camera (Nikon, DXM 1200, USA) linked to a light microscope (Nikon, Eclipse E400). Nikon ACT1 software (Version 2.63) was used to capture the digital images. The *m*ATPase activity at a specific pH has been determined by Brooke and Kaiser (1970), and muscle fibers were classified according to their colour transition from pH 4.0 to pH 10.4. Table 1 shows the criteria used to classify muscle fibers of each specimen into type I, IIA and IIB (adapted from Staron & Hikida 1992; Brooke & Kaiser, 1970). Accordingly, type I fibers will stain dark in acidic conditions (pH 4.0 and 4.2) and type II (pH10.4) will stain dark under alkaline conditions (Brooke & Kaiser, 1970). The muscle fiber type frequency/composition for each muscle (*Biceps femoris*, *Longissimus dorsi* and *Semimembranosus*) from the lambs from each production system (extensive and intensive) was determined by classifying each muscle fiber (Table 1) and subsequently counting each fiber type within the cross-sectional area of the specimen.

Table 1 Muscle fiber colour transition at various pH's after *m*ATPase staining

Fiber Type	pH 4.0*	pH 4.2*	pH 10.4*
I	Dark	Dark	Light
IIA	Light	Light	Dark
IIB	Light	Intermediate	Intermediate

*Adapted from Staron and Hikida (1992); Brooke and Kaiser, 1970

Fiber diameter and area

The 10x magnification photos taken for the muscle fiber typing was used to measure the fiber diameter and area. Simple PCI (Version 5.2.1, Compix Inc., USA) image analysing software was used to measure the muscle fiber diameter (µm) and area (µm^2) of each specimen. The fiber diameter (µm) and area (µm^2) were determined for all three muscles (*Biceps femoris*, *Longissimus*

dorsi and *Semimembranosus*) from the right side of the carcass of Dohne Merino lambs. The Simple PCI was set at x10 magnification and a closed polygon shape was used to draw on the outline of each muscle fiber (fiber type already identified as in previous section) to calculate mean fiber diameter (µm) and area (µm^2). All the muscle fibers within the cross-sectional area of each specimen were measured for each muscle fiber type (I, IIA and IIB).

Sarcomere length analysis

Tissue specimens of approximately 20 g were removed from the medial region of the *Biceps femoris*, *Longissimus dorsi* and *Semimembranosus*. All specimens were collected from the left side of the carcass, 48 hours post mortem (same conditions as chemical composition samples; Chapter 4). The specimens were vacuum sealed in labelled plastic bags and stored at -18°C for approximately 4 months until specimens were analysed. Before analysis of the specimens, the samples were thawed for 5 hours at room temperature (20°C) and divided into five cubes of approximately 4 g each. The sarcomere length (µm) of each specimen was determined by using the method as described by Botha *et al.* (2007). Mounted specimens were investigated under a light microscope (Nikon, Eclipse E400) at a 10x magnification. A digital camera (Nikon DXM 1200, USA) linked to a light microscope (Nikon, Eclipse E400) was used to take five digital images, per mounted specimen, of randomly selected individual intact muscle fibers. Nikon ACT 1 software (Version 2.63) was used to capture the digital images. Simple PCI (Version 5.2.1, Compix Inc., USA) image analysing software, was used to measure the length (µm) of ten consecutive sarcomeres on an individual muscle fiber, thereafter the length (µm) was divided by 10 to calculate the length (µm) of an individual sarcomere. The mean sarcomere length (µm) for each muscle (*Biceps femoris*, *Longissimus dorsi* and *Semimembranosus*) from a specific production system (extensive or intensive) was calculated from the average of 175 measurements (5 samples per muscle, 5 digital images per sample, and 7 carcasses per production system).

Statistical analysis of data

A random split-plot design, with two production systems (extensive and intensive) as the main-plot, was used as the experimental design in this study. Seven carcasses were randomly drawn from each main-plot and the sub-plot factor consisted of three muscles (*Biceps femoris*, *Longissimus dorsi* and *Semimembranosus*). A random split-plot analysis of variance (ANOVA) was performed on the recorded sarcomere length (µm), fiber type frequency, fiber diameter (µm) and area (µm^2) data. The studentised residuals were calculated for all the variables and tested for deviations from normality using Shapiro-Wilk's test (Shapiro & Wilk, 1965). Outliers were identified and removed before the final ANOVA's were performed (Snedecor, 1967). Means of significant effects were compared using Student's t-LSD (Least Significant Difference) at a 5% level of significance.

Pearson's correlation coefficients were calculated for comparison between histochemical characteristics (Chapter 6), physical (Chapter 3), chemical composition (Chapter 4), sensory attributes (Chapter 5) and instrumental tenderness (Chapter 5) variables. All above procedures were analyse using SAS™ statistical software (Statistical Analysis System, Version 9.2).

RESULTS & DISCUSSION

Fiber typing

The *Biceps femoris* muscle from extensively reared lamb (28.57%) contained more ($p = 0.001$) type I muscle fibers than intensively reared lambs (23.50%; Table 2). However, the *Biceps femoris* muscle of lambs subjected to the extensive production system (43.45%) contained less ($p < 0.001$) type IIB muscle fibers than lambs from the intensive production system (49.92%; Table 2). No significant differences were detected between the *Longissimus dorsi* of lambs from both production systems, for all the muscle fiber types investigated (Table 2). The *Semimembranosus* from extensively reared lambs contained more type I ($p < 0.001$) and type IIA ($p < 0.001$) muscle fibers, than the *Semimembranosus* from intensively reared lambs (Table 2). There was no difference ($p = 0.236$) between production systems for the type IIB fiber in this muscle.

Although no significant differences were detected, a trend was observed (Table 2) in which lambs from the extensive production system contained more type I and IIB muscle fibers, and less type IIA muscle fibers when compared with lambs from the intensive production system. The most abundant muscle fiber types present in the *Longissimus dorsi* and *Semimembranosus* from both production systems (extensive and intensive) are type IIA and IIB. These results are similar to those obtained by Peinado *et al*. (2004), Sazili *et al*. (2005) and Wank *et al.* (2006). Postural muscles (e.g. *Longissimus dorsi*) are more oxidative (Type I) compared to muscles involved in locomotion (e.g. *Biceps femoris* and *Semimembranosus*) (Aalhus & Price, 1991; Totland & Kryvi, 1991; Ono *et al*., 1995; Chang *et al*., 2003). The results shown in Table 2 are not consistent with literature. This could be attributed to the superficial location of sample collection on each muscle. Muscle fiber composition varies within a muscle, the superficial layers of a muscle contains more glycolytic fibers (type IIB) and the deeper layers more oxidative fibers (type I) (Armstrong *et al*., 1987; Philippi & Sillau, 1994). Future research should included samples from the superficial, medial and deeper layer of each muscle to insure that the fiber typing data is representative of the whole muscle. Results obtained in this study for the *Longissimus dorsi*, are similar to the findings of Peinado *et al*. (2004) for the *Longissimus thoracis* muscle in adult sheep.

The *Biceps femoris*, *Longissimus dorsi* and *Semimembranosus* muscles from the free roaming lambs (extensive production system) had a higher percentage of type I fibers than lambs from the intensive production system. Aalhus and Price (1991) found similar results when comparing endurance exercised sheep versus sheep that received no exercise. Other studies also

found induced exercise led to a transition from type IIB to IIA fibers (Aalhus & Price, 1991 - sheep; Essén-Gustavsson, 1993 – pigs; Mcallister *et al*., 1997- pigs; Lefaucheur & Gerrard, 1998 - mammalian skeletal muscles; Pette & Staron, 2001 - humans and rats). In this study, transition from IIB to IIA was only observed for the *Biceps femoris*. The extensively (exercised) raised lambs had a higher type IIA percentage while the intensively (unexercised) raised lambs had a higher type IIB percentage. The IIB to IIA fiber transition was only visible in the *Biceps femoris,* most probably as this muscle is one of the most active muscles during locomotion (grazing) (Nickel *et al.*, 1986).

Implication for meat quality

Overall, the extensively produced lambs contained more oxidative type I fibers and less glycolytic type IIB fibers, when compared to intensively produced lambs, except for the *Longissimus dorsi* muscle. Meat containing a high percentage of type I fibers, will be more susceptible to cold shortening (Davis, 1979; Ceña *et al*., 1992; Foegeding *et al*., 1996), contain more collagen (Kovanen *et al*., 1984; Kovanen, 1989; Berg, 2000; Dingboom & Weijs, 2004; Lefaucheur, 2010), exhibit decreased post mortem proteolysis (Calkins & Seideman, 1988; Whipple & Koohmaraie, 1992; Sazili *et al*., 2005) and contain myofibrils with thicker z-lines (Payne *et al*., 1975; Sjostrom & Squire, 1977; Eisenberg, 1983; Taylor, 1995; Maltin *et al*., 2003). All of these factors negatively influence the overall tenderness of meat. Typically meat containing a high concentration of type I fibers also has a high intramuscular fat content (Essén-Gustavsson *et al*; 1992; Essén-Gustavsson *et al*; 1994; Alasnier *et al*., 1996; Malenfant *et al*., 2001) which positively contributes to a pleasant meat flavour, juicier meat (Valin *et al*., 1982; Essén-Gustavsson & Fjelkner-Modig, 1985; reviewed by Lefaucheur, 2010) and an increase in meat tenderness (Calkins *et al*. 1981). However, the high polyunsaturated fat content of meat containing a high concentration of type I fibers, makes them more susceptible to post mortem fatty acid oxidation, resulting in meat with a rancid taste, which is an undesirable sensory attribute (reviewed by Lefaucheur, 2010).

Meat containing a large percentage of type I fibers could produce DFD (dry, firm and dark) meat if animals were stressed pre-slaughter (Warriss, 2010). DFD meat has a relatively high water holding capacity, which negatively influences the juiciness of meat as experienced by the consumer during mastication. Extensively produced free roaming lambs are frequently more susceptible to pre-slaughter stress, because these animals are not used to confinement (lairage) or being handled (herding, transporting and slaughtering) (Warriss *et al*., 1983; Barton-Gade & Blaabjerg, 1989).

Table 2 The mean (±SD) muscle fiber composition (%) of the *Biceps femoris*, *Longissimus dorsi* and *Semimembranosus* of Dohne Merino lambs reared in extensive (n = 7) and intensive (n = 7) production systems

	Biceps femoris			***Longissimus dorsi***			***Semimembranosus***		
Type	**Extensive**	**Intensive**	**p-Value**	**Extensive**	**Intensive**	**p-Value**	**Extensive**	**Intensive**	**p-Value**
I (%)	28.57 ±2.95	23.50 ±1.05	**0.001**	12.7 ±2.11	12.56 ±0.68	0.866	20.13 ±1.97	14.38 ±1.88	**< 0.001**
IIA (%)	27.98 ±2.76	26.58 ±0.73	0.218	30.23 ±1.93	31.42 ±1.17	0.186	27.94 ±1.39	32.69 ±1.45	**< 0.001**
IIB (%)	43.45 ±2.36	49.92 ±1.31	**< 0.001**	57.07 ±1.70	56.02 ±1.39	0.228	51.92 ±1.90	52.93 ±0.97	0.236

SD (Standard Deviation)

Meat containing a high percentage of type IIB fibers Meat containing a large percentage of type IIB fibers could produce PSE (pale, soft, exudative) meat if animals were stressed pre-slaughter (Warriss, 2010). However, intensively produced lambs are normally less susceptible to pre-slaughter stress, because these animals are accustomed to confinement and to being handled (Warriss *et al*., 1983; Barton-Gade & Blaabjerg, 1989).

Meat containing a high percentage of type IIB fibers, has a superior quality when compared to type I fibers. Type IIB fibers are less susceptible to cold shortening, contain less collagen (Dingboom & Weijs, 2004) and more proteolytic enzymes (Ouali & Talmant, 1990; Whipple & Koohmaraie, 1992), and contain myofibrils with thin z-lines (Payne *et al*., 1975; Sjostrom & Squire, 1977; Eisenberg, 1983; Taylor, 1995; Maltin *et al*., 2003). All of these factors positively contribute to the overall tenderness of meat. However, various authors have suggested that a high percentage of type I fibers are more favourable for meat quality (Ashmore, 1974; Valin *et al*., 1982; Gentry *et al*., 2002; Chang *et al*., 2003; Ryu & Kim, 2006). Since a single fiber type is not solely responsible for the overall meat quality, various authors has suggested that this area renders more research (Lefaucheur & Gerrard, 1998; Choi & Kim, 2009).

Correlations

A positive correlation ($r = 0.586$; $p = 0.028$) was observed between the type IIB fiber concentration of the *Biceps femoris* and the sensory tenderness (residue score discussed in Chapter 5) for the *Biceps femoris*. The sensory attribute residue, refers to the amount of residue left in the mouth after the first ten chews due to the presence of connective tissue. A high score is indicative of trace amounts or no residue left in the mouth therefore meat is classified as being tender. A positive correlation between type IIB concentration and the sensory tenderness score (residue) is consistent with literature which states that meat containing a high percentage of type IIB contains less collagen (Dingboom & Weijs, 2004). A strong positive correlation ($r = 0.668$; $p = 0.009$) existed between the type I fiber concentration of the *Biceps femoris* and the insoluble collagen content of the *Biceps femoris* (Chapter 4). The opposite was observed for the type IIB fiber concentration of the *Biceps femoris* ($r = 0.611$; $p = 0.020$) and insoluble collagen content, which confirms Dingboom & Weijs' (2004) statement. The *Biceps femoris* of the intensive production system contained a higher ($p < 0.001$) percentage of type IIB fibers (Table 2) and was significantly more tender (first bite $p = 0.031$; residue $p = 0.024$) than the *Biceps femoris* from extensively produced lambs (Chapter 5). A strong negative correlation existed between both sensory tenderness attributes first bite ($r = -0.718$; $p = 0.004$) and residue ($r = -0.746$; $p = 0.002$) of the *Biceps femoris* and the type I fiber concentration of the *Biceps femoris*. A positive correlation was found between the concentration of type I fibers and tenderness (Strydom *et al*., 2000; Renand *et al*., 2001; Choi & Kim, 2009). However, other authors found no correlation between fiber type and

tenderness (Vestergaard *et al*., 2000a), and a negative correlation between type I fibers and tenderness has previously been reported (Ozawa *et al*., 2000). In this study, no correlations were observed between the other two muscles (*Longissimus dorsi* and *Semimembranosus*) and sensory tenderness (first bite and residue). The IIB to IIA fiber transition was only visible in the *Biceps femoris* most probably because the *Biceps femoris* is one of the most active muscles during locomotion (grazing) (Nickel *et al*., 1986; Frandson *et al*., 2003).

The sensory aroma scores (Chapter 5) of the *Biceps femoris* was positively correlated ($r = 0.611$; $p = 0.020$) with the concentration of type I fibers of the *Biceps femoris* and negatively correlated ($r = -0.786$; $p = 0.001$) with the concentration of type IIB fibers of the *Biceps femoris*. A high aroma sensory score is indicative of intense lamb aroma (Chapter 5). The *Biceps femoris* of the extensively produced lamb contained a ($p = 0.001$) higher percentage of type I fibers (Table 2) and had an intenser lamb aroma ($p = 0.001$) than the *Biceps femoris* from extensively produced lambs (Chapter 5). Type I and IIA muscle fibers contain a higher concentration of intramuscular fat (phospholipids and triacylglycerols) compared to type IIB fibers (Essén-Gustavsson *et al*; 1992; Essén-Gustavsson *et al*; 1994; Alasnier *et al*., 1996; Malenfant *et al*., 2001). Meat with a high intramuscular fat (marbling) content is positively correlated with a pleasant meat flavour and aroma which could be ascribed to the high phospholipid content of the meat (Essén-Gustavsson & Fjelkner-Modig, 1985; as reviewed by Lefaucheur, 2010). No correlations were found in this study between the intramuscular fat content of all three muscles (*Biceps femoris*, *Longissimus dorsi* and *Semimembranosus*) (Chapter 4) and type I fibers as well as intramuscular fat (Chapter 4) and aroma or flavour intensity (Chapter 5).

Fiber diameter and area

The impact of an extensive and intensive production system on the muscle fiber diameter (μm) and area (μm^2) of the *Biceps femoris*, *Longissimus dorsi* and *Semimembranosus* muscle of Dohne Merino are presented according to muscle fiber type, in Table 3. No differences were detected between the muscle fiber diameter (μm) and area (μm^2), for the *Biceps femoris* and *Longissimus dorsi* from both production systems. No significant differences were observed between the muscle fiber diameter (μm) and area (μm^2) of type I and IIB muscle fibers of the *Semimembranosus* from both production systems. This coincides with other studies which concluded there is no significant difference between the fiber diameter of exercised and non-exercised sheep, which supports the results obtained in this study (Aalhus & Price 1991).

Contradicting to Aalhus and Price (1991), a clear difference was detected between the diameter (μm) ($p = 0.024$) and area (μm^2) ($p = 0.032$) of type IIA fibers of the *Semimembranosus* (Table 3). Extensively reared lambs had larger (62.02 μm; 3090 μm^2) type I fibers compared to intensively reared lambs (54.29 μm; 2371 μm^2).

An overall tendency was observed that the muscle fiber diameter (μm) and area (μm^2) of lambs from the extensive production system was larger than from the intensive production system (Table 3), with the exception of IIB (μm^2) fibers of the *Longissimus dorsi* muscle. In this study, Type IIA fibers had the largest fiber size (diameter and area), type I had an intermediate size and type IIB had the smallest fiber size of all three muscles regardless of the production system (Table 3). The fiber size findings in this study are not consistent with the findings of others who reported that oxidative type I fibers have the smallest fiber size (diameter and area), glycolytic type IIB fibers the largest and oxidative glycolytic type IIA fibers an intermediate fiber size (Cassens & Cooper, 1971; Rosser *et al*., 1992; Maltin, 1997; Lieber, 2002). In general cells that are predominantly depended on oxidative metabolism have smaller diameters to minimise the diffusion distance of the oxygen between the cell and mitochondria (Segal & Faulkner 1985; Wittenberg & Wittenberg 1989) which may explain the smaller fiber type I fibers found in this study (Table 3). Furthermore other studies have shown that in sheep specifically, the size of type I fibers are similar in size to type IIB fibers, and glycolytic fibers (type IIB) are not always larger than oxidative fibers (type I) (Suzuki & Tamate, 1988 – hip and thigh muscles; Suzuki, 1971a - *m. Semitendinosus*, *m*. *Longissimus dorsi*, *m*. *Psoas major*, *m*. *Latissimus dorsi* and *m*. *Gastrocnemius*; Suzuki, 1971b - *m*. *Serratus ventralis*, *m*. *Supraspinatus*, *m*. *Infraspinatus*, *m*. *Semimembranosus* and *m*. *Triceps brachii*; Suzuki & Cassens, 1983 – *Serratus ventralis thoracis* muscle).

The *Biceps femoris* from the extensively produced lambs had the largest overall fiber diameter (μm) and area (μm^2) (Table 3). Muscles responsible for locomotion such as the *Biceps femoris* and *Semimembranosu*s have larger muscle diameters and areas than muscles responsible for maintaining posture such as the *Longissimus dorsi* (Hammond, 1932).

It could be speculated that although the exercise (grazing) received by the extensively (free-range) raised lambs was sufficient to induce a fast to slow twitch muscle fiber transition in the *Biceps femoris* and *Semimembranosus* (Table 2), the intensity of the exercise and the period exposed to the exercise (8 months) was not enough to cause a significant increase in the muscle fiber diameter (μm) and area (μm^2).

Table 3 The mean (±SD) muscle fiber type diameter (μm), area (μm^2) and sarcomere length (μm) of the *Biceps femoris*, *Longissimus dorsi* and *Semimembranosus* of Dohne Merino lambs raised in extensive (n = 7) and intensive (n = 7) production systems

	Biceps femoris			***Longissimus dorsi***			***Semimembranosus***		
	Extensive	**Intensive**	**p-VALUE**	**Extensive**	**Intensive**	**p-VALUE**	**Extensive**	**Intensive**	**p-VALUE**
Type I (μm)	56.64 ±3.71	52.23 ±4.91	0.082	50.98 ±3.76	48.35 ±3.54	0.203	54.00 ±6.91	51.09 ±2.15	0.307
Type I (μm^2)	2563 ±336.52	2197 ±416.40	0.095	2087 ±302.97	1871 ±276.89	0.190	2361 ±606.51	2089 ±171.06	0.275
Type IIA (μm)	67.52 ±3.92	62.51 ±6.32	0.100	63.42 ±6.36	61.64 ±2.91	0.513	62.06 ±7.37	54.29 ±3.14	**0.025**
Type IIA (μm^2)	3620 ±426.58	3119 ±625.34	0.105	3213 ±632.45	3039 ±271.64	0.515	3090 ±738.45	2371 ±268.76	**0.032**
Type IIB (μm)	50.2 ±5.71	45.7 ±6.17	0.182	42.41 ±5.44	41.08 ±4.69	0.634	41.11 ±2.24	40.26 ±4.64	0.671
Type IIB (μm^2)	1967 ±502.02	1581 ±455.84	0.157	1454 ±375.90	1588 ±544.56	0.603	1401 ±237.74	1308 ±308.60	0.540
Length (μm)	1.89 ±0.07	1.99 ±0.15	0.130	1.75 ±0.07	1.78 ±0.08	0.512	1.89 ±0.16	1.84 ±0.09	0.434

SD (Standard Deviation)

Correlations

Prior to the onset of post mortem proteolysis, meat with larger muscle fibers tend to be less tender than meat with smaller fiber diameter (Crouse *et al*., 1991; Maltin *et al*., 1997). No significant correlations were observed in this study between tenderness (instrumental and sensory; refer to Chapter 5) and fiber size (diameter and area), for any of the three muscles (*Biceps femoris*, *Longissimus dorsi* and *Semimembranosus*) from either production systems (extensive or intensive).

Moody *et al*. (1980) and Spindler *et al*. (1980) reported a positive correlation between carcass weight and muscle fiber diameter (µm). Lambs from the extensive production system 48.29 ±2.14 kg in this study, had a higher slaughter weight ($p < 0.001$; Chapter 3) than intensively 39.76 ±3.08 kg produced lambs, at 8 months. Positive correlations were observed between the carcass weight (Chapter 3) of the lambs, and the fiber diameter ($r = 0.547$; $p = 0.034$) and area ($r = 0.545$; $p = 0.043$) of type I fibers (Table 3). Therefore the higher slaughter weight of the lambs from the extensive production system contributed to the larger fiber diameter (µm) and area (μm^2) of the extensively produced lambs.

Sarcomere length

No differences were detected between the sarcomere length (µm) of lambs from both production systems (Table 3): *Biceps femoris* ($p = 0.130$), *Longissimus dorsi* ($p = 0.512$) and *Semimembranosus* ($p = 0.434$).

The sarcomere length of a muscle fiber has been previously shown to be positively correlated with tenderness (Davis *et al*. 1979; Ceña *et al*. 1992). However, no correlations were found between the sarcomere length of all three muscles (*Biceps femoris*, *Longissimus dorsi* and *Semimembranosus*) from either production systems (extensive and intensive) and tenderness (sensory and instrumental tenderness discussed in Chapter 5).

The method of carcass suspension and anatomical position of each muscle has been shown to have adverse effects on the length of sarcomeres (Locker, 1960; Herring *et al*., 1965; McCrae *et al*., 1971; Hostetler *et al.*, 1972; Aalhus & Price, 1991). The lambs in this study were hung by the Achilles tendon. Aalhus and Price (1991) stated that muscles located near the vertebral column (e.g. *Longissimus dorsi*) and in the posterior lower hind limb (e.g. *Semimembranosus*), of carcasses hung by the Achilles tendon, are strained resulting in longer sarcomeres. Results in Table 3 indicate that the carcass suspension had no significant effect on the sarcomere length.

CONCLUSION

The objective of this study was to investigate the impact of an extensive (free-range) and intensive (feedlot) production system on the histochemical properties of three muscles (*Biceps femoris*, *Longissimus dorsi*, *Semimembranosus*) of Dohne Merino lambs, and the subsequent effect on various meat quality characteristics. All three muscles (*Biceps femoris*, *Longissimus dorsi* and *Semimembranosus*) from extensively produced lambs had a higher percentage of type I fibers compared to intensively produced lambs which had a higher percentage of type IIB fibers. According to literature, spontaneous physical exercise associated with extensive (free-range) rearing systems, induce the transitions of fast twitch fibers to slow twitch fibers. No clear evidence exists in the literature stating which specific fiber type is predominantly responsible for overall meat quality although various authors suggested that a high percentage of type IIB fibers promotes tenderness and a high percentage of type I fibers contributes to overall flavour, aroma and juiciness. In this study the *Biceps femoris* of intensively produced lambs (with a significantly higher type IIB fiber %) was significantly more tender compared to extensively reared lambs.

Meat containing larger muscle fibers tends to be less tender than meat with smaller fiber diameters. Although no significant fiber size (diameter and area) differences were detected in this study, between each of the three muscles (*Biceps femoris*, *Longissimus dorsi* and *Semimembranosus*) from both production systems (extensive and intensive), it was evident that fibers from the extensively produced lambs were larger than intensively produced lambs.

No correlations were found between the sarcomere length of all three muscles (*Biceps femoris*, *Longissimus dorsi* and *Semimembranosus*) from both production systems (extensive and intensive) and tenderness (sensory and instrumental). More research is required to investigate various external and internal factors that may contribute to the variation in sarcomere length and to further elucidate which muscle fiber type is predominantly responsible for the decrease in sarcomere length and subsequent decrease in tenderness.

In conclusion, an increase in exercise results in an increase in type I fibers and a subsequent decrease in tenderness. From this study recommendations could be made to the South African Red Meat Industry that the application of intensive production systems will significantly increase the most important palatability trait, tenderness of the *Biceps femoris* and to a lesser extent the *Longissimus dorsi* and *Semimembranosus* of Dohne Merino lambs.

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Chapter 7

Conclusion and Recommendations

The modern red meat consumer considers meat quality as the most important characteristic but also demands healthier products that are environmentally friendly, promote sustainability and comply with animal welfare guidelines.

The global red meat industry is constantly facing new challenges, not only driven by consumer concerns and preferences, but also influenced by economic factors and environmental changes. Various challenges facing livestock farmers (the increase in livestock theft, seasonal droughts, unpredictable weather patterns and diminishing land resources) has forced them to reformulate and restructure their farming methods. The global trend in animal production is a systematic transition from small-scale extensive production to large-scale intensive production systems which can lead to an increase in livestock production efficiency, productivity, profitability and insure that retail prices remain competitive compared to other cheaper sources of protein (poultry).

It is clear from literature that intensive production systems do not satisfy consumer preferences or needs regarding the extrinsic cues (health, animal welfare, environmental impact). The main objective of this study was to investigate the impact of an extensive (free-range) and intensive (feedlot) production system on the consumer's intrinsic preference cues (flavour, aroma, initial juiciness, sustained juiciness, first bite, residue, instrumental tenderness, physical attributes, proximate chemical composition, fatty acid profile) and secondly to investigate the affect of natural exercise (grazing, extensive production systems) or restrictive movement (intensive production systems), on the muscle fiber type composition of various muscles (*Biceps femoris*, *Longissimus dorsi*, *Semimembranosus*) of Dohne Merino lambs, and the effect thereof on various meat quality characteristics.

It is crucial to provide the consumer with a product that is consistent in quality to subsequently increase the consumer's confidence in the product and encourage repurchasing, therefore it is essential to investigate the full impact of both production systems (extensive and intensive) on various meat characteristics, so as to ensure that the quality is maintained and that consumer expectations are met.

Results of this study indicate that intensively reared lambs produced meat with a better eating quality compared to the extensive production system, as well as a significant increase in sensory tenderness for the *Biceps femoris* muscle. Intensively produced lambs, on the other hand, had a significantly thicker subcutaneous fat layer which could have a negative effect on consumer purchase behaviour as consumers prefer lean meat with less visible fat.

The production systems (extensive and intensive) had a significant effect on the myoglobin content of the meat with meat from extensively reared lambs containing significantly more myoglobin and thus being slightly darker. Consumers tend to steer clear of meat with a dark appearance as they assume that the product has expired and/or the quality is sub-standard.

The significantly higher PUFA n3 content of extensively reared lambs could have a negative effect on the sensory properties (flavour and aroma) of meat because an increase in the PUFA ratio decreases the meat's oxidative stability, promoting the development of rancidity. Then again, the significantly higher omega 6 to omega 3 fatty acid ratio of meat from intensively reared lambs may increase the consumer's risk to cardiovascular diseases. Meat from extensively produced lambs contained higher levels of EPA, DHA, omega 3 fatty acids as well as a higher P:S ratio which will appeal to health conscious consumers.

Extensively reared lambs had a higher type I muscle fiber content and intensively produced lambs had a higher percentage of type IIB fibers. No clear evidence exist in literature stating which specific fiber type is predominantly responsible for overall quality of meat, although various authors suggested that a high percentage of type IIB fibers promotes tenderness and a high percentage of type I fibers contributes to overall flavour, aroma and juiciness. A significant positive correlation observed between the type IIB fiber concentration of the *Biceps femoris* and the *Biceps femoris* sensory tenderness scores, confirms this statement. No significant fiber size (diameter and area) differences were detected in this study, but it was evident that fibers from the extensively produced lambs were larger than intensively produced lambs. No significant correlations were observed between tenderness and fiber size (diameter and area), for any of the three muscles (*Biceps femoris*, *Longissimus dorsi* and *Semimembranosus*) from either production systems (extensive or intensive).

From this study the following recommendation can be made to the South African red meat industry: application of intensive production systems will increase the sensory characteristics of these selected muscles from Dohne Merino lambs, especially the tenderness of the *Biceps femoris*, which has a high retail value. From a health point of view both production systems could have negative and positive implications on the consumer's health therefore it is suggested that the n6:n3 ratio of feed should be adjusted to produce meat with a more favourable and healthy essential fatty acid content.

However, to improve on this study and to thoroughly understand the full impact of a production system on the sensory, chemical, nutritional and instrumental quality characteristics of lamb's meat, it is recommended that all edible muscles should be included in an investigation, as well as the quantification of the effect of gender (ram, ewe, castrated). It is also suggested that a larger sample size and an extended period (> 8 months) of exposure to a production system be evaluated to see whether some of the trends noted in this investigation could become significant. An analysis of other sheep breeds (especially the indigenous breeds found in South Africa) may also be of value to the South African red meat industry.