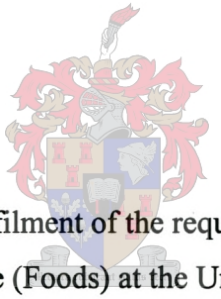
Effect of crossbreeding and reproduction rate on sensory, physical and chemical quality of lamb and mutton

Dewcille Schmidt



Thesis presented in partial fulfilment of the requirements for the degree of
Master of Consumer Science (Foods) at the University of Stellenbosch

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Co-study leaders: **Ms M. Muller**
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Declaration

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

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SUMMARY

The objective of this investigation was to determine the effect of crossbreeding and reproduction fitness on the sensory, physical and chemical quality of lamb and mutton.

This investigation was conducted by means of two experiments. Firstly an investigation was undertaken to determine whether breed combinations in a terminal crossbreeding system have an effect on lamb quality (Experiment 1). Secondly, progeny from a divergent selection experiment for ewe multiple-rearing ability was assessed in terms of mutton quality (Experiment 2).

In both experiments ratings of sensory attributes on the *M. semimembranosus* were obtained from a trained taste panel and related to data obtained from the *M. longissimus dorsi* on physical and from the *M. semimembranosus* on chemical composition. The moisture, lipid, protein, ash, mineral and fatty acid composition of the *M. semimembranosus* were obtained. Physical parameters measured on the *M. longissimus dorsi* were: ultimate pH (pH_{48}), drip loss, cooking loss and Warner-Bratzler shear force (WBS).

***Experiment 1*: The effect of breed on the sensory, physical and chemical meat quality characteristics of lamb derived from six terminal sheep breed combinations.**

Lamb carcasses representing six breed combinations (n=6 ewes per breed) were obtained from Langgewens Experimental Farm, Western Cape, South Africa. The lambs were sired by Dormer (D) and Suffolk (S) rams and born to Merino (M), Dohne Merino (DM) and SA Meat Merino (SAMM) ewes. This outlay resulted in six distinct breed combinations (DxM, DxDM, DxSAMM, SxM, SxDM, SxSAMM). The lambs were grown to commercial slaughter weight (± 38 kg) and slaughtered using standard South African techniques and conditions.

Significant differences were detected between the lamb breed combinations for the sensory attribute of initial juiciness ($p \leq 0.05$), whereas the taste panel did not identify breed differences for the attributes of tenderness, flavour, aroma, sustained juiciness and residue ($p > 0.05$). Although pH_{48} and WBS differed significantly between the breed combinations ($p \leq 0.05$), neither of these two parameters predicted the eating quality attributes accurately. No significant differences were detected between breed combinations for cooking or drip loss

significant differences were detected between breed combinations for cooking or drip loss ($p>0.05$). Differences existed between breed combinations pertaining to the mineral composition and the percentage content of individual fatty acids. There was a tendency for the DxSAMM group to have the highest mineral content and the SxDM group the lowest. Total saturated fatty acids (SFA) and total mono-unsaturated fatty acids (MUFA) were significantly influenced ($p\leq0.05$) by breed with the DxM group having the highest (±61%) and the DxDM having the lowest (±50%) total SFA. The DxM group had the lowest total MUFA (±33%) and the DxDM group the highest (±44%). Percentage concentration of individual fatty acids were affected ($p\leq0.05$) by breed. The polyunsaturated/saturated fatty acid ratio of all the breeds in this investigation was low and below the recommended human consumption value of 0.45. Although the taste panel could not detect any breed differences, differences were noted pertaining to the effect of breed on the nutritional value of the meat.

Experiment 2: **Sensory, physical and chemical mutton quality characteristics of South African Merino selected for and against reproductive fitness.**

The effect of divergent selection for ewe multiple rearing-ability on mutton quality was examined on the *M. longissimus dorsi* and *M. semimembranosus* of entire ram (R) and ewe (E) sheep derived from two Merino lines. The selection of these two lines was based on maternal ranking values for multiple rearing ability in a positive (P) and negative (N) line. In the negative line the replacements were based on the progeny of ewes that rear less than one lamb per joining, or lambing opportunity (i.e. failed to lamb or lost all progeny born at least once). Progeny of ewes that reared more than one lamb per joining (i.e. reared twins at least once) were selected for the positive line. Ten mature animals (equal sex ratio) from the P and ten from the N reproduction line (of the 5^{th} generation) were randomly selected to test for the effect of reproductivity and sex on the sensory, physical and chemical quality of the mutton.

The influence of selection line on sensory meat quality was in most instances negligible, with the exception of the sensory attribute of first bite ($p\leq0.05$), where meat derived from the positive line was rated to be less tender than that of the negative line contemporaries. Chemically the meat derived from the four different groups differed significantly ($p\leq0.05$) in moisture and lipid content. The positive ram group had the highest moisture (±76%) and the lowest lipid (±7%) content, whereas the negative ewe group the lowest moisture (±70%) and the highest lipid (±10%) content. No significant differences ($p>0.05$) were detected in the proximate chemical composition between the pooled positive and negative lines. The pH_{48}

and WBS values showed significant differences ($p \leq 0.05$) between the four groups. The NR group had the highest pH_{48} and the lowest WBS value. Results indicated a line effect on WBS tenderness. Meat derived from the positive line was less tender compared to the meat from the negative line. Results indicated that differences exist between the reproductive lines pertaining to the mineral composition and the percentage content of individual fatty acids. A general tendency was noted for the positive ewes to have the highest and the negative ewes to have the lowest mineral content. Significant differences ($p \leq 0.05$) were detected between the four groups in some individual fatty acids. The PR group had the highest total PUFA (polyunsaturated fatty acids) content (±8%) and the NR the lowest PUFA content (±6%). Significant difference ($p \leq 0.05$) in the total PUFA composition was also detected between lines, with the positive line showing a higher content (±7%) compared to the negative line (±6%).

SAMEVATTING

Die doel van hierdie ondersoek was om die invloed van kruisteëling en reproduksie vermoë op die sensoriese, fisiese en chemiese kwaliteitseienskappe van lamsvleis en skaapvleis te bepaal.

Hierdie ondersoek was uitgevoer deur middel van twee eksperimente. Eerstes was daar 'n ondersoek onderneem om te bepaal wat die effek van verskillende skaapras kombinasies, soos gebruik in 'n terminale kruisteling sisteem, op vleiskwaliteitseienskappe is (Eksperiment 1). Tweedens, is die skaapvleis kwaliteitseienskappe ondersoek in die nageslag van ooie wat geselekteer is vir en teen die vermoë om meerlinge te speen (Eksperiment 2).

In beide eksperimente was die sensoriese kwaliteitseienskappe, van die *M. semimembranosus,* bepaal met behulp van 'n opgeleide laboratorium paneel. Sensoriese data was vergelyk met die chemiese data verkry van die *M. semimembranosus* en die fisiese data wat verkry was van die *M. longissimus dorsi.* Die *M. semimembranosus* was ontleed om die vog, lipied, protein, as, mineraal en vetsuur samestelling van die vleis te bepaal. Die fisiese parameters van die *M. longissimus dorsi* wat gemeet is, was: eind pH (pH_{48}), drupverlies, kookverlies en Warner-Bratzler skeurkrag (WBS).

***Eksperiment 1*: Die effek van ras op die sensoriese, fisiese en chemiese vleis kwaliteitseinskappe van lammers verkry van ses terminale skaap ras kombinasies.**
Lamskarkasse verteenwoordigend van ses verskillende ras kombinasies (n=6 ooie per ras) was verkry vanaf Langgewens Ekperimentele Proefplaas, Wes-Kaap, Suid-Afrika. Die lammers was gevader deur Dormer (D) en Suffolk (S) ramme en gespeen deur Merino (M), Dohne Merino (DM) en SA Vleis Merino (SAMM) ooie. As resultaat was ses ras kombinasies (DxM, DxDM, DxSAMM, SxM, SxDM, SxSAMM) verkry. Die lammers was grootgemaak tot 'n komersiële slaggewig (±38 kg) en geslag deur gebruik te maak van standaard Suid-Afrikaanse tegnieke en toestande.

Betekenisvolle verskille het voorgekom tussen die verkillende ras kombinasies ten opsigte van die sensoriese eienskap van aanvanklike sappigheid ($p \leq 0.05$). Die proepaneel kon geen verdere verkille ($p > 0.05$) in sensoriese eienskappe tussen ras kombinasies identifiseer nie. Alhoewel die pH_{48} en WBS betekenisvol verskil het tussen die verskillende ras kombinasies

($p \leq 0.05$), was nie een van hierdie twee parameters 'n akkurate aanduiding van die sensoriese kwaliteitseienskappe nie. Geen betekenisvolle verskille het voorgekom tussen die ras kombinasies vir kook- en drupverlies nie ($p > 0.05$). Verskille het wel voorgekom tussen die ras kombinasies ten opsigte van mineraal samestelling en die persentasie samestelling van die individuele vetsure. Daar was 'n neiging waargeneem dat die DxSAMM groep die hoogste en die SxDM groep die laagste mineraal inhoud gehad het. Totale versadigde vetsuursamestelling (SFA) en die totale mono-onversadigde vetsuursamestelling (MUFA) was betekenisvol beinvloed ($p \leq 0.05$) deur ras kombinasies. Die DxM groep het die hoogste (±61%) en die DxDM die laagste (50.27%) totale versadigde vetsuur inhoud gehad. Die DxM groep het die laagste (±33%) en die DxDM groep het die hoogste totale mono-onversadigde vetsuur inhoud gehad (±44%). Ras kombinasies het die persentasie individuele vetsure beïnvloed ($p \leq 0.05$). Die poli-onversadigde/versadigde vetsuur verhouding van al die rasse in hierdie ondersoek was laag en laer as die aanbevole menslike konsumpsie waarde van 0.45. Alhoewel die proepaneel nie enige ras verskille kon identifiseer nie, was daar wel verskille identifiseerbaar ten opsigste van die nutriëntsamestelling van die vleis.

Eksperiment 2: **Sensoriese, fisiese en chemiese vleiskwaliteitseienskappe van Suid-Afrikaanse Merino skape geselekteer vir en teen reproduksie vermoë.**

Die effek van reproduksie vermoë op skaap vleiskwaliteitseienskappe was bepaal op die *M. longissimus dorsi* en *M. semimembranosus* van ramme (R) en ooie (E) verkry vanaf twee Merino lyne. Die seleksie van die twee lyne was gebaseer op meervoudige speenvermoë in 'n positiewe (P) en negatiewe (N) lyn. In die N lyn is die nageslag van ooie gekies wat minder as een lam per lamgeleentheid grootgemaak het. Die ooie het dus by minstens een geleentheid òf oorgeslaan, òf die lam(mers) wat hulle gehad het, verloor. Die nageslag van ooie wat meer lammers grootgemaak het, as wat hulle lamgeleenthede gehad het, was geselekteer vir die P lyn. Tien volwasse skape (gelyke geslag verhouding) van die P reproduksielyn en tien van die N reproduksie lyn (van die 5^{de} generasie) was ewekansig geselekteer om die effek van reproduksie vermoë en geslag op die sensoriese, fisiese en chemiese kwaliteitseienskappe van skaapvleis te bepaal.

Die invloed van seleksie lyn op die sensoriese vleiskwaliteitseienskappe was in meeste gevalle weglaatbaar met die uitsondering van die sagtheid van die vleis ($p \leq 0.05$). Vleis verkry van die P lyn was deur die proepaneel as minder sag aangeslaan as die N lyn. Die vleis van die onderskeie vier groepe het chemies betekenisvol verskil ($p \leq 0.05$) ten opsigte van die vog en lipied inhoud. Die PR groep het die hoogste vog (±76%) en die laagste lipied

(±7%) inhoud gehad. Die NE groep het die laagste vog (±70%) en die hoogste lipied (±10%) inhoud gehad. Geen betekenisvolle verskille ($p>0.05$) was waargeneem in die proksimale chemiese samestelling tussen die gegroepeerde P en N lyne nie. Die pH_{48} en WBS het betekenisvolle verskille ($p\leq0.05$) aangedui tussen die vier groepe. Die NR groep het die hoogste pH_{48} en die laagste WBS waarde gehad. Resultate het 'n lyn effek aangedui op WBS sagtheid. Vleis verkry vanaf die P lyn was minder sag in vergelyking met die vleis van die N lyn. Resultate verkry het aangedui dat daar verskille voorkom tussen die reproduksie lyne ten opsigte van die mineraal samestelling en die persentasie samestelling van individuele vetsure. 'n Algemelne neiging het voorgekom vir die P lyn om die hoogste en die N lyn om 'n laagste mineraal inhoud te hê. Betekenisvolle verskille ($p\leq0.05$) was gevind tussen die vier groepe in sommige individuele vetsure. Die PR groep het die hoogste (±8%) en die NR die laagste (±6%) totale poli-onversadigde vetsuur inhoud gehad. Betekenisvolle verskille ($p\leq0.05$) in die totale poli-onversadigde vetsuur samestelling was ook waargeneem tussen lyne met die positiewe lyn wat 'n hoër inhoud (±7%) as die negatiewe lyn gehad het (±6%).

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TABLE OF CONTENTS

This thesis represents a compilation of articles. Language and style used in this thesis are in accordance with the requirements of the *Journal of Meat Science*. Relevant literature regarding the effect of crossbreeding and reproductive fitness on the sensory and objective properties of lamb and mutton is included in the applicable articles. Each article, representing a separate experiment, is presented as a separate chapter in this thesis.

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CHAPTER 1

INTRODUCTION

South Africans are among the world's highest consumers of meat products, and a total of 79% of all South African meat consumers consume lamb. The consumption of lamb and mutton in South Africa was estimated to be 3,5 kg annually per inhabitant during 1999 (SAMIC, 2001), while the annual production was $107x10^3$ t and annual demand $160x10^3$ t (Schoeman, 2000). According to Schönfeldt, Naudé, Bok, Van Heerden and Sowden (1993) the South African consumer is unique in respect of the red-meat consuming world and is prepared to pay more for sheep meat than for either pork or beef.

The past decade has been characterised by rapid changes in consumer trends. With today's progressively declining per capita consumption of lamb and mutton, producers and manufacturers have to meet consumer demands, trends and preferences for the industry to survive in the increasingly competitive market. Consumers of the new millennium are conscious of the link between food products and health. Ultimately, the success of any food product is determined by consumer acceptability, which is largely determined by the perception of quality (Dransfield, 2001). The concept of quality has been evolving following the rapid changes in scientific knowledge, analytical methods and consumer expectations within the meat production industry (Nardone & Valfré, 1999). The quality concept has been widened and redefined as "Total Quality" by Valfré and Moretti (as cited by Nardonne & Valfrè, 1991) as follows:

1. Hygienic quality, i.e. absence (or compliance with the maximum residue level if provided) of heavy metals, pesticides, mycotoxins, feed additives, drugs, pathogens, microbial contaminants, etc;
2. Compositional quality, related to proximate composition (water, protein, fat, ash);
3. Nutritional quality, related to the composition of proteins and lipids, the occurrence of macro- and trace elements, the absence of allergenic compounds;
4. Sensory quality, related to colour, flavour, taste, tenderness and juiciness of meats;
5. Technological quality, i.e. the suitability for processing, storage, distribution.

According to Naudé (1982) the appearance, palatability, nutritional value, processing ability and consumer acceptance of meat are the main components of meat quality. Consumer preferences for meat are extremely difficult to define, but according to Bukula and Kedzior (2001), one of the most important quality attributes of meat and meat products are its sensory characteristics. Horsfield and Taylor (1976) described a system of three independent principal components, namely succulence (initial juiciness, breakdown, bolus formation and uniformity), toughness (resistance, resilience and chewiness) and flavour (including off-flavours) which, in this order, contribute to the prediction of consumer acceptability. In the present investigation the sensory, physical and chemical quality of lamb and mutton will be investigated as components of meat quality.

In South Africa sheep are bred from a diverse range of breeds and genotypes with a continuing trend towards even more diversification. For several decades the most abundant types of sheep are those bred for wool production purposes; however, these breeds have inferior meat production potential. At present woolled breeds such as the South African Mutton Merino, Merino and Dohne Merino contribute up to 60% of South Africa's sheep population (Laas, 1995). Presently, the economic viability of wool farming is inhibited by relatively low and fluctuating wool price, as well as rising production costs. The only alternative to wool production is meat production in the most important wool-producing regions of South Africa. Economic pressures increasingly dictate that farmers breed part of their flocks with meat-producing sires in terminal crossbreeding systems. Such a system could potentially benefit farmers in terms of cashflow and turnover. A lack of breeding material for pure breeding, lower selection differentials for wool traits and the possible contamination of the clip with course and coloured fibres are seen as potential disadvantages of a terminal crossbreeding system. The combining of appropriate breeds in cross breeding systems offers the opportunity to increase productive efficiency through both additive and non-additive genetic effects (Schoeman, 2000). In pure breeding systems the emphasis has shifted towards breeding characteristics that will enhance meat production and lower production costs (Laas, 1995). While selecting for an improved economic yield within breeds, sheep breeders should keep in mind the relationship between the various production traits and their effect on the meat quality characteristics. Although there are industry perceptions of differences in meat quality between breeds (Safari, Forgarty, Ferrier, Hopkins & Gilmour, 2001), little research has been done on meat quality of different pure breeds and crosses raised under typical South African conditions.

Favourable meat prices on the local market dictate that reproduction should also be considered in small stock improvement (Olivier, 1999). Against this background Cloete (1999) undertook an investigation on the divergent selection of South African Merino lines for multiple-rearing ability. The latter experiment demonstrated that selection of sheep for multiple-rearing ability was a viable method for improving lamb output without serious negative effects on qualitative and quantitative production traits in progeny (Cloete & Olivier, 1998). Despite the knowledge of correlated responses on aspects such as live weight and fleece weight, little is known about their potential impact on meat quality.

AIMS

This study was undertaken in collaboration with the Departments of Animal Sciences and Consumer Science at the University of Stellenbosch.

An investigation (Figure 1, Experiment 1) was undertaken to determine the effect of terminal crossbreeding on the sensory quality characteristics and nurient composition of the *M. semimembranosus* of lamb. Using the same muscle, sensory quality characteristics and nutrient compositionwithin a specific breed selected for reproduction fitness were also investigated (Figure 1, Experiment 2). The effect of sheep breed and reproduction fitness on the objective meat quality characteristics was determined on the *M. longissimus dorsi*. The specific characteristics measured are:

- Detailed assessment of sensory qualities of the *M. semimembranosus* meat samples by a trained descriptive sensory panel (AMSA, 1978) using an eight-point structured line scale (Annexure);
- Assessment of shear force of cooked *M. longissimus dorsi* samples using an Warner-Bratzler Shear attachment fitted to an Instron Universal Testing Machine (Voisey, 1976);
- Proximate chemical analysis of raw meat: moisture, fat, protein and ash content of the raw *M. semimembranosus* according to AOAC standard techniques (AOAC, 1997);
- Assessment of chemical composition of the *M. semimembranosus*: mineral and fatty acid content (AOAC, 1997);
- Percentage drip loss of the *M. longissimus dorsi* (Honikel, 1998);

- Percentage cooking loss of the *M. longissimus dorsi* (Honikel, 1998);
- pH of the raw *M. longissimus dorsi* (Honikel, 1998).

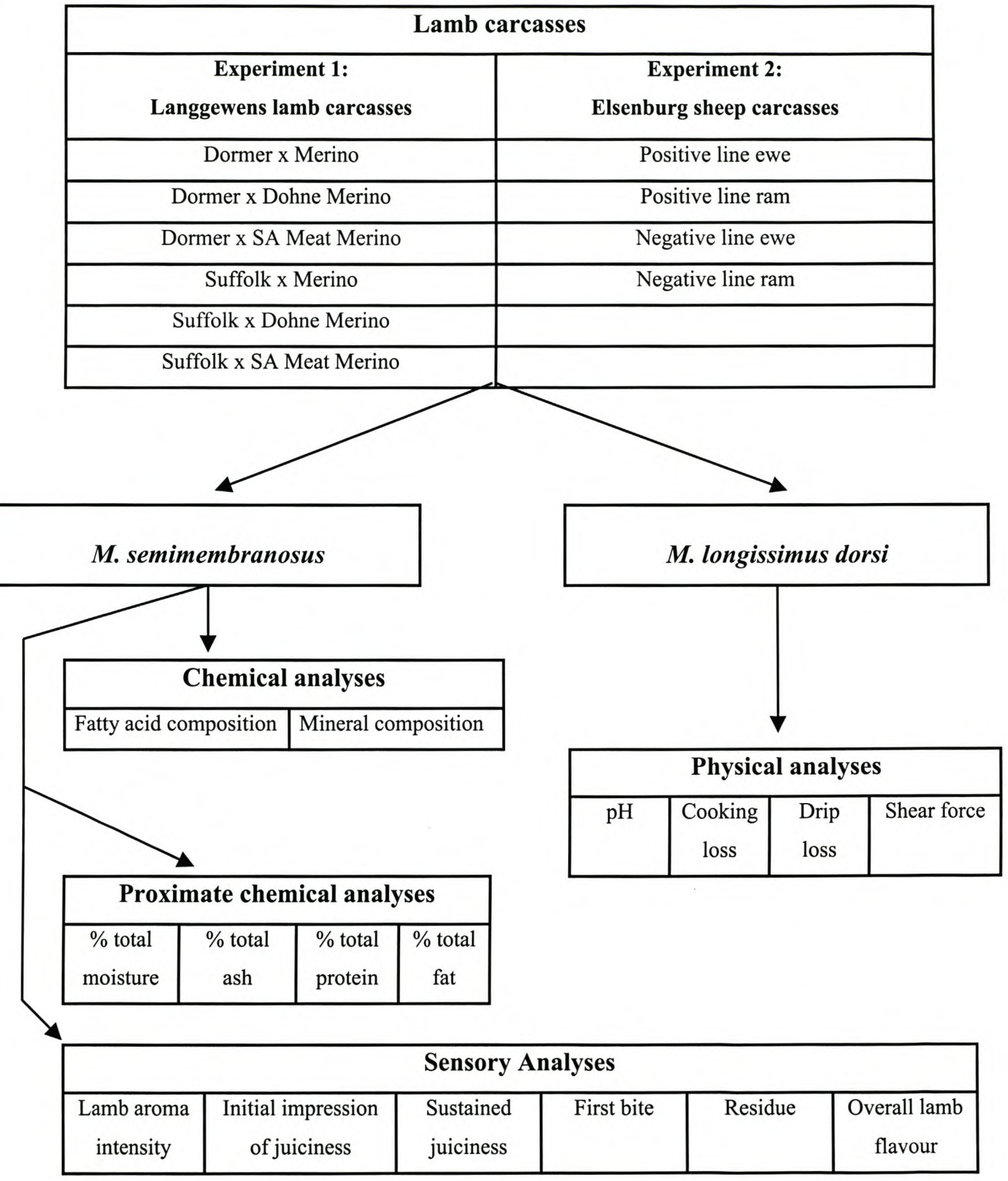

Figure 1
Conceptual framework depicting the research aims

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CHAPTER 2

LITERATURE REVIEW

Numerous factors associated with the living animal influence the quality of meat (Lawrie, 1985). Some of these factors are quite well known and can be controlled. Other factors have not yet been well studied or have a variable or controversial influence (Sanuado, Sanchez & Alfonso, 1998).

Important factors which may affect the quality of lamb and mutton are presented in Table 1 (Sanuado *et al.,* 1998). Intrinsic factors are those factors directly related to the animal itself or its ancestors. Breed and sex are the two intrinsic factors to be assessed in this study. Other factors will not be considered in this investigation.

This literature review covers the sensory and objective properties of lamb and mutton.

SENSORY PROPERTIES OF MUTTON AND LAMB

Ultimate consumer satisfaction with a food product is based upon the satisfaction derived at the point of consumption. The repeated purchases of meat products are overwhelmingly influenced by the previous experience of the consumer regarding its eating quality. Eating quality of meat can be defined in terms of the sensory attributes of colour, tenderness, juiciness and flavour, which are the principal determinants of the acceptability of meat products to consumers (Jeremiah, 1982). The sensory attributes colour, texture, flavour and aroma will be discussed in this literature review.

Colour

Meat and fat colour are an important aspect of consumer acceptability (Demos, Gerrard, Mandigo, Gao & Tan, 1996) and are the first important criteria that the consumer takes into account when judging meat quality (Barton-Gade, Cross, Jones & Winger, 1988). Colour is the visual characteristic of meat that imparts the first impression and it can be measured subjectively and objectively.

The colour of muscle tissue is due to the presence of the heme pigment, namely myoglobin, in its various chemical forms. Myoglobin accounts for three fourths of the pigment in red meat, and the remainder is due to the presence of the blood pigment hemoglobin (Charley & Weaver, 1998). Both pigments combine reversibly with oxygen in the blood stream, whereas myoglobin retains it in the tissue. This protein is bound to the external membrane of the mitochondria and sarcoplasmic reticulum (Geay, Boauchart, Hocquette & Culiole, 2001). The quantity of myoglobin in muscle is determined by breed, sex, age, species, nutritional status and training (Lawrie, 1991). The quantity of myoglobin present and its chemical state, as well as the chemical and physical conditions of the other components in meat, contribute to the colour of meat (Lawrie, 1979). Lamb and mutton contain less myoglobin than beef. Hence lamb and mutton are generally lighter in colour than beef, but this colour darkens as the animal ages. A significant relationship was found between meat colour and pH in four-and-half-year-old sheep. However, weak correlations have been found between the muscle ultimate pH and lamb meat colour in younger animals (six to twenty-four months old). This is in contrast to beef, where both colour and texture are altered at high pH values (Simonsen, Hamm & Rogowski, 1988).

Other factors that affect the colour of meat are the pre-slaughter period, the slaughter process, subsequent processing and the rate and extent of pH and temperature decline. The processes of oxygenation and oxidation of myoglobin does, however, influence the colour during storage, distribution and display (Honikel, 1998).

The myoglobin molecule consists of a haematin nucleus attached to a globin type-protein to form a conjugated protein myoglobin. The haematin portion consists of four pyrrole groups and a central iron atom linked covalently to the nitrogen of the four pyrrole groups (Barton-Gade, Cross, Jones & Winger, 1988). Hemoglobin is also a conjugated protein containing heme and globin. Although the heme portion of these two molecules is identical, the hemoglobin molecule contains four heme protein units, whereas myoglobin has only one and the globins are different. In myoglobin the iron atom is also bound to the nitrogen of a histidyl residue in the globin moiety. A sixth position is open for the formation of compounds with several complexes, which is partly responsible for variations in the colour of meat (Penfield & Campbell, 1998).

Myoglobin, a pigment with a purplish-red colour, exists in equilibrium with its red oxygenated form, namely oxymyoglobin, in living tissue. After slaughter, no more oxygen is carried to the tissue, the oxygen in the tissue is depleted rapidly by muscle glycolysis and the pigment exists almost entirely in the purplish ferrous state. When cut, meat surfaces become bright red as oxygen combines with myoglobin to form oxymyoglobin. The pigment is maintained in the oxygenated form as long as the oxygen levels are high. Exclusion of oxygen results in reversion to a purple red colour as the pigment is deoxygenated to myoglobin (Penfield *et al.*, 1998). If the iron in myoglobin is oxidised from the ferrous to the ferric state, the formation of the brownish red pigment, metmyoglobin, occurs. Reducing substances present in meat changes metmyoglobin back to myoglobin, but when the reducing power of the muscle is lost the colour of the meat becomes brownish. Factors such as high temperatures, micro-organisms that use oxygen and the presence of fluorescent and incandescent light accelerate metmyoglobin formation. The three forms of the pigment exist in an equilibrium in raw, uncured meat (Zhu & Brewer, 1998). Meat from electrically stimulated carcasses appears to maintain its colour longer during cold storage compared with meat from unstimulated carcasses (Simonsen, Hamm & Rogowski, 1988).

The colour of raw fatty tissue also varies with the species, breed and age of the animal, and with the feed. Fresh lamb fat is nearly white (AMIF, 1960). The colour of fatty tissue changes as an animal ages. In older animals the colour of the fatty tissue changes from white to a yellowish colour as carotenoid pigments accumulate (Bennion & Scheule, 2000).

Crouse, Busboom, Field and Ferrel (1981) and Busboom *et al.* (1981) reported that ram carcasses have softer and yellower fat than wether carcasses. It was also observed by Kruggel, Field, Miller, Horton and Busboom (1982) that ram lambs accumulate more lutein in their fat deposits, which results in ram carcasses having softer and more yellow fat than wether carcasses.

Colour changes during cooking

The final colour of cooked meat depends on pigment changes that take place during cooking. These changes are determined by the cooking method, length of time and temperature (AMIF, 1960). When heated, the pigments in muscle denature. During denaturation, the protein molecule unfolds and the central iron atom is increasingly exposed. In the temperature range between 40-50°C the globin of oxymyoglobin is denatured and the ferrous iron is oxidised to the ferric state. Meat cooked just to the point of pigment denaturation and then cooled may revert from a brown to a red colour as denaturation is reversed and reoxygenation occurs (Penfield *et al.*, 1998).

The question arises whether there exists a relationship between colour and other meat characteristics. In this respect Simonsen *et al.* (1988) found no relationship between the appearance of raw lamb/mutton and the texture, flavour, aroma and juiciness of the cooked product.

The colour of the fat portion of meat changes very little during cooking except for the surface browning that contributes greatly to the attractive appearance of meat cooked by dry heat. This surface browning is the result of fat decomposition and polymerisation with carbohydrate and protein decomposition products (AMIF, 1960).

Texture

The textural qualities of lamb and mutton are affected by the same factors that affect the textural qualities of beef. These factors include animal characteristics (age, breed, etc.), differences between muscles and post-mortem processing. Juiciness and tenderness are the two sensory components of the perceived texture of lamb.

Juiciness

Juiciness of meat plays an important role in conveying an overall impression of palatability to the consumer. Meat juices contain many of the important flavour components and assist in the process of fragmenting and softening of meat during chewing. Regardless of the other virtues of meat an absence of juiciness severely limits its acceptability, and impairs its unique palatability characteristics (Forrest, Aberle, Hedrick, Judge & Merkel, 1975).

Juiciness is an organoleptic characteristic related to both the capacity of muscle to release its constitutive water (initial juiciness) and the infiltration fat content (sustained juiciness) (Dryden & Marchello, 1970). In combination with water, the melted lipid constitutes a broth that, when retained in the meat, is released upon chewing. This broth may also stimulate the flow of saliva, and thus enhance the meat's apparent juiciness (Forest *et al.*, 1975). Thus a certain quantity of free water together with the lubricant effect of fat favours meat palatability (Dryden *et al.*, 1970).

The marbling that is present in meat also serves to enhance juiciness in an indirect way. During cooking, the melted fat becomes translocated along the bands of perimysial connective tissue. This uniform distribution of lipid throughout the muscle may act as a barrier to moisture loss during cooking. Meat with some marbling shrinks less during cooking and remains juicier. However, subcutaneous fat also minimises drying and moisture loss during dry heat roasting (Forrest *et al.*, 1975).

The amount of water released from lamb is similar in both sexes according to Horcada, Beriain, Pyrroyt, Lizaso and Chasco (1998). A larger infiltration fat content is observed in females, suggesting that the meat of females should be more juicy (high sustained juiciness) than the meat of males.

In general, initial juiciness appears to decrease with an increase in animal age, and sustained juiciness seems to increase with increased animal age. The decrease in initial juiciness, with an increase in animal age, could be attributed to the fact that this ability of the muscle to retain water decreases with age. Cooking losses will consequently be higher in cuts from older animals. This is associated with a drier end product, without the rapid release of meat fluid during the first few chews as are expected in meat from young animals. The fact that sustained juiciness increases with an increase in age may be explained by the fact that more mastication is required for samples from older animals (due to the increased cross-linking of the collagen with increased age) and therefore more saliva would be released to increase the perceived sustained juiciness (Schönfeldt, 1989). Huff and Parish (1993) also concluded that samples from beef carcasses of older animals are juicier than samples from carcasses of young bulls and steers.

Tenderness

The increasing importance of lamb eating quality and acceptability to retailers and consumers and the overriding contribution of tenderness to quality has been highlighted in several studies. Meat tenderness is generally regarded as the single most important component of meat quality for the consumer (Dransfield, 1994). This is confirmed by the fact that the price of meat and its relative tenderness show a positive relationship (Savell & Shackelford, 1992).

The tenderness of meat can be evaluated by both instrumental and sensory methods. The Warner Bratzler Shear Device coupled to the Instron Universal Testing Machine is the most widely used instrument in evaluating meat tenderness and correlates the best with sensory evaluation for tenderness. Safari *et al.* (2001) report that the Warner Bratzler shear method can be used successfully as a measurement for determining the tenderness and acceptability of lamb meat. Factors found to affect the accuracy of these instruments include doneness of the cooked meat, uniformity of cylindrical sample size, direction of the muscle fibres, amount of connective tissue, fat deposits present, temperature of the sample and the speed at which the sample is sheared (Simonsen *et al.*, 1988).

According to Tornberg (1996), tenderness evaluation by human senses is the ultimate test in the evaluation of meat tenderness. The overall impression of tenderness to the palate includes

texture, and involves penetration of the meat by teeth, the ease of fragmentation, and the amount of connective residue remaining after chewing (Jeremiah & Phillips, 2001).

A relationships has been reported between taste panel scores for tenderness and meat quality characteristics namely, juiciness, flavour, residue, and collagen solubility and total collagen. In tender meat the juices are released more rapidly by chewing, less residue remains in the mouth after chewing, solubility is higher and collagen content is lower (Bruwer, Grobler, Smit & Naudé, 1987).

Environmental factors, electrical stimulation and ageing proved to have major influences on meat quality, particulary tenderness (Koohmaraie, 1996). Other variables that influence meat tenderness include: animal age and gender, rate of glycolysis, amount of solubility of collagen, sacromere length, ionic strength and degeneration of myofibillar proteins by proteinases (Koohmaraie, 1994).

Meat tenderness originates in the structural and biochemical properties of muscle fibres, especially myofibrils and intermediate filaments, and of the intramuscular connective tissue (the endomysium and the perimysium), which are composed of collagen fibrils and fibres (Takahashi, 1996). Variation in tenderness arises mainly through changes to the myofibrillar protein structure of muscle in the period between animal slaughter and meat consumption. Rapid refrigeration of the carcass after slaughter leads to severe muscle contraction and results in cold shortening in which the force required to shear the fibres after cooking increases dramatically. The latter can be prevented in the tender muscles of the hindleg and back by suspending the carcass from the pelvis rather than from the archilles tendon, thereby stretching the muscles and preventing contraction. Alternatively, high-voltage electrical stimulation of the carcass depletes energy stores in the muscles so that there is none available for contraction (Wood *et al.*, 1999).

The influence of longer conditioning times on meat tenderness has been known for many years. Lately attention has focused on the calpain (*EC* 3.4.22.17) enzyme system composed of m- and μ-calpain and the inhibitor calpastatin. Although the callipyge gene improves meat yield and lean content (Field, McCormick, Brown, Hinds & Snowder, 1996), it reduces meat tenderness as a result of specific changes in calpain enzymes (Koohmaraie, Shackelford, Wheeler, Lonergan & Dounut, 1995).

Much of the muscle variation in tenderness that exists within an animal is due to differences in the amount and nature of the connective tissue. Estimates of the amount of collagen (white, fibrous connective tissue protein) in meat cuts generally indicate that a low connective tissue content is associated with tenderness. Although most of the connective tissue fibres in the muscles are collagenous, elastin and reticulin fibres are also present and may contribute to toughness. The decrease in tenderness that accompanies an animal's ageing is believed to result largely from the connective tissue changes. It is likely that the additional exercise that old animals have experienced causes a strengthening of the connective tissue fibre structure. Although the quantity of connective tissue apparently changes very little after maturity, the number of intermolecular crosslinks in the collagen fibrils probably increases. This results in a decreased solubility of the collagen, and an increased resistance to shearing or chewing action (Forrest *et al.*, 1975).

In general, the higher the soluble collagen content the more tender the meat. Boccard *et al.* (1979) found that collagen content affected toughness of meat, although shear force values seemed to have been influenced to a larger extent by the solubility rather than the content of the muscle collagen. In a study comparing cooking properties and palatability attributes between 1660 lambs varying in chronological age, slaughter weight and gender, Jeremiah, Tong and Gibson (1998) found that important differences were attributable to gender. Ram lambs were the least tender and roasts from ewes were the most tender. The ewe lambs also had the least amount of perceptible connective tissue and ram lambs had the most.

There seem to be controversy among researchers about the effect of marbling (the percentage fat inside the muscle) on the tenderness of the meat. It is accepted as a fact that intramuscular fat content affects the palatability of meat, but the specific relationship to meat tenderness is not clear. Some researchers have reported positive relationships between percentage fat and tenderness, while others have found none. For example, Parrish (1974) found no relationship between percentage fat and tenderness, while Carpenter and King (1965) found a significant correlation between chops that varied in marbling score and tenderness. Results obtained by Schönfeldt *et al.* (1993) indicated that the fatness of ovine and caprine carcasses had a positive relationship with tenderness of muscle and associated muscle characteristics. It is likely that some lipid acts as a lubricant in the mastication of less tender meat, thus improving the apparent tenderness and facilitating the process of swallowing (Forrest *et al.*, 1975).

A wide range of tenderness occurs among muscles in any one animal. In general those muscles containing the least amount of connective tissue, such as psoas major, are the most tender, while those with the largest amount of connective tissue are the least tender. Tenderness also varies within muscles. It decreases rapidly from the pelvic end in the *M. semimembranosus*, is almost uniform in *biceps femoris* and *semitendinosus*, and increases from the centre to both ends of the *M. longissimus dorsi* (AMIF, 1960). According to Mellet (Personal communication, F. D. Mellet, 2001), the *M. semimembranosus* is the most representative muscle of the overall carcass tenderness.

The effect of cooking on the tenderness of muscle depends on the time and temperature of heating, the internal temperature reached and the particular muscle being cooked. In general, connective tissue becomes tender during cooking as collagen is converted to gelatin. On the other hand, myofibrillar proteins coagulate on heating and become less tender. The composition of the cut of meat determines the cooking method that should be used (Moelich, 1999).

Two separate phases of toughness are associated with an increasing cooking temperature. In the first phase, as the cooking temperature rises from 40 to 50°C, there is a three- to fourfold toughening of muscle proteins, which is associated with denaturation of the myofibrillar structure. During the second phase the toughness is doubled as the cooking temperature rises from 60 to 75°C. The second-phase toughening is linked to collagen shrinkage, specifically the epi- and perimysium causing compression of muscle bundles and water loss (Davey & Gilbert, 1972). Boccard (1973) found a higher correlation between collagen solubility and tenderness with moist heat cooking methods, compared to dry heat cooking methods. The explanation is that, as more water molecules are introduced between the collagen chains, more collagen can swell and be removed, and hence the more tender the meat.

Flavour and aroma

Flavour is an important part of the eating quality of all foods, including meat. Meat flavour, like aroma, is very difficult to evaluate and describe. It is very hard to separate these two characteristics, since many of the flavour properties are the result of odour sensations. Flavour, consisting primarily of taste and smell, is also influenced by the appearance, texture and even the sound made upon mastication (Amerine, Pangborn & Roesler, 1965). The flavour of raw meat is bland, salty and blood-like, whilst the true "meaty" flavour develops during cooking (AMIF, 1960).

The taste and odour of cooked meat varies with several ante-mortem and post-mortem factors. Ante-mortem factors include age, gender, breed, nutritional status and composition of the animal. The length of ageing and the method of cooking are both post-mortem factors that may affect meat flavour development (Schönfeldt, Van Heerden, Visser, Van Niekerk & Heinze, 1997). Desirable attributes of flavour develop during cooking and are therefore an important factor. The volatile flavour compounds of cooked meat can be divided into two categories, namely those that develop from the Maillard reaction and those formed from lipid oxidation (Elmore, Mottram, Enser & Wood, 2000).

Carbonyl-amine browning is important in the developing of meat flavours (Penfield *et al.*, 1998). Carbonyl compounds contribute a major portion of the odour obtained upon heating. During cooking these carbonyls undergo a condensation reaction with the amino acids from cyclic carbonyls. The degradation of S-containing amino acids in meat protein results in the release of sulphur and increases with the time and temperature of cooking. Compounds like sugar and S-containing amino acids form thiols, which contribute to meaty flavours (Schönfeldt *et al.*, 1997). These flavour compounds, or their precursors, are apparently present in only trace amounts in the fat. Heating the bulk of the triglycerides, after these trace components are removed, does not generate the characteristic lamb aroma. Meat flavour per se arises from the water-soluble components, whereas the species flavour or aroma originates from the fatty tissues (Hornstein & Crowe, 1963). This is in agreement with Pearson *et al.* (1973), who concluded that the lean tissue contributes little to the species characteristic aroma of boiled lamb meat. In lamb the precursors responsible for the typical "lamb" flavour on heating are low-molecular-weight, water-soluble compounds. A variety of chemicals are thought to be associated with mutton flavour. Two of the most important chemicals

responsible for mutton flavour have been identified as 4-methyloctanoic acid and 4-methylnonanoic acid. These components (methyl-branched-chain saturated fatty acids) have been identified as the characteristic "sweaty-sour" odour of mutton (Schönfeldt *et al.*, 1993). This "sweaty-sour" flavour is not typical of all mutton/lamb and tends to be more common in meat from older animals (Simonsen *et al.*, 1988). Sink and Caporaso (1977) have identified sulphur-containing components of the lipid fraction as important contributors to mutton flavour.

The nature and intensity of meat flavour depend in part on the type, length of time and temperature of cooking. Dry-heat cooking methods develop certain flavours, especially at the exposed surfaces where the temperature becomes very high (Schönfeldt, 1989). Leg of lamb roasted to an internal temperature of 65°C has an aroma and taste more distinctive of lamb than similar roasts cooked to an internal temperature of 75°C (AMIF, 1960). Moist cooking methods, on the other hand, cause the development of distinctive and unique flavour changes in the deeper tissues of the the lamb meat cuts (Schönfeldt, 1989).

Sink and Caporaso (1977) noted a low consumption of mutton amongst American consumers. A reason often given for the lack of popularity is the stronger and less pleasant flavour of the cooked meat and the presence of an undesirable smell given off during the cooking process. This mutton flavour is less noticeable in the meat from lambs than in sheep over 2 years old. The South African consumer, however, does not consider the species-specific flavour of sheep meat as undesirable.

The basic flavour characteristics of lamb and mutton can be markedly influenced by animal diet (Fisher *et al.*, 1999; Elmore *et al.*, 1999). The effect of diet on the sensory properties of meat is accomplished through the deposition of unique components in the fat, while the extent of the influence is dependent on the animal species. It is accepted that dietary factors do not change the body fat composition in ruminants to the extent that they do in monogastric animals, but more recent research has indicated diet-induced changes in the fat composition of ruminants. Both long-chain fatty acids and volatile fatty acids contribute to lamb aroma, but the dietary influences on the eating quality of lamb are limited to the long-chain fatty acids (Webb, Bosman & Casey, 1994). Ruminants preferentially deposit polyunsaturated fatty acids (PUFA) in phospholipids. Therefore, very lean breeds can have relatively high proportions of PUFA compared to fatter lambs in which the phospholipid effect is diluted by

higher levels of neutral storage lipid (marbling fat). Variations in the different fatty acids and the absolute concentration will affect the flavour profile.

It has been stated that there are definite sex-related flavours in mutton (Jeremiah *et al.*, 1998). According to Dryden *et al.* (1970) the composition of subcutaneous, intramuscular and intermuscular fat deposits have important implications in the characteristic flavour of meat. The absence of significant differences in mono-unsaturated fatty acid (MUFA) and PUFA content between males and females suggests that at low slaughter weight sex has no influence on the nature and composition of fat (Horcoda *et al.*, 1998). In a study by Ellis, Webster, Merrel and Brown (1997) carcasses from female lambs, compared with males, showed thicker subcutaneous and greater intermuscular fat deposits. It was observed that entire male lambs presented harder and drier meat with less intense flavour than castrated male lambs (Crouse *et al.*, 1981) and that ram meat was assessed as better than meat from wethers (castrated male) or ewes (Dransfield, Nute, Hogg & Walters, 1990). However, Ellis *et al.* (1997) found no palatability differences between sexes.

BIOCHEMICAL COMPOSITION AND NUTRITIONAL VALUE OF LAMB AND MUTTON

With 43.1 kg carcass equivalent (CE) per person per year in 2000, the consumption of meat from ruminants (3.6 kg CE for lamb and mutton and 13,5 kg CE for beef) represents less than 40% of the total meat consumption in South Africa (Personal communication, G. J. Hallowell, 2001). The consumption of lamb and mutton was the highest during the 1970's and decreased by 6 kg per head since 1970. The consumption of beef also declined from 24.5 kg per head during the 1970s to 13.5 kg per head in 2000 (Figure 2). This decrease has also been observed in France, Europe and the USA (Geay *et al.*, 2001). The explanation for the decrease in red meat consumption can be partly explained by the fierce competition with white meats, which are marketed at a relatively low price. Another explanation could be health concerns of the consumer due largely to statements from medical circles and mass media that beef and lamb/mutton contain a substantial amount of saturated fatty acids (SFA) and cholesterol, which can be a major contributor to the development of coronary heart disease. Coronary heart disease is one of the major causes of death in adults. High blood cholesterol and high blood pressure are two factors which are associated with an increased risk for the development of coronary heart disease. These factors are both affected adversely by diets high in fat, particulary SFA, although there also seems to be an important genetic

component to a person's susceptibility (Warris, 2000). However, the National Cholesterol Educational Programme (1988) recommends a limited consumption of unsaturated fatty acids and SFA. Futhermore, meat containing low levels of PUFA, especially those of the n-3 series, may benefit health by lowering blood cholesterol concentrations.

Recent media reports on, for example, elicit trading, the use of hormones and animal health concerns such as bovine spongiform encephalopathy (BSE) may also account for the decrease in red meat consumption. Nevertheless, muscle foods are unquestionably a valuable primary dietary component and form a very important part of a balanced, varied diet. For example, a 85 g serving of meat (lamb) provides 40% of a person's daily protein needs, 79% vitamin B_{12} (cyanocobalamin), 31% of zinc (Zn), 17% of iron (Fe) and 36% of niacin (nicotic acid). Meat also contributes significantly to the B-vitamins required in the diet, particulary vitamin B_{12}, which is absent in plant foods.

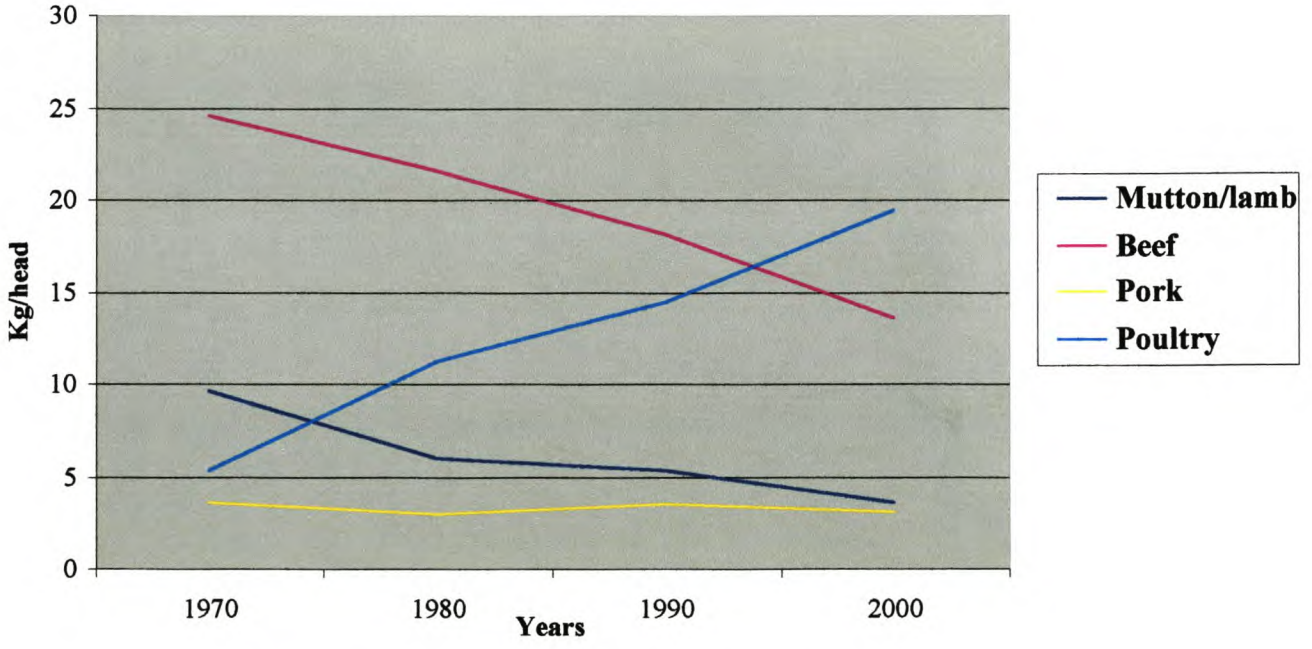

Figure 2

Per capita (kg per head) meat and poultry consumption in South Africa, 1970-2000 (Hallowell, 2001)

Livestock breeders and animal scientists face the task of researching and explaining the mechanisms behind the interaction of factors affecting the health quality of meat and determining the possibility of enhancing the health-promoting properties of meat and meat products.

Contrary to adipose tissue, skin, bones, muscles and organs exert high metabolic activities in the living animal. Therefore, they contain large quantities of very important nutrients, e.g. essential amino acids, fatty acids, vitamins, minerals and some carbohydrates (mostly glycogen) as energy source and are regarded as nutrient-dense foods (Simonsen, Hamm & Rogowski, 1988).

Lipid content and fatty acid composition

The amount and quality of fat in meat affects the nutritive value, appearance, processability, shelf life and palatability of meat. Fat is thus an important determinant of meat quality and the degree of saturation of the fat contributes substantially to the sensory properties of meat (Webb *et al.*, 1994).

As an animal is fattened, the fat is firstly deposited under the skin and around the organs and later as marbling within the muscles. Intramuscular fat cells occur in the spaces within the perimysium, most frequently along the smaller blood vessels (Penfield *et al.*, 1998). The percentage of fat in meat varies widely, depending on the animal species, breed, sex, nutritional state and the part of the carcass from which the cut is taken. Observed trends by Jeremiah, Jones, Tong, Robertson and Gibson (1997) report that rams produce leaner carcasses than wethers, which in turn produce leaner carcasses than ewes. Meat cuts are usually trimmed of excess fat by butchers and many consumers demand leaner meats. The trimming of excess fat is costly to the meat industry, therefore there are concerted attempts to develop biological types and genetic lines of animals that produce lean carcasses (Bennion, & Scheule, 2000).

Most neutral lipids consist of ± 95% triglycerides. The remaining 5% include monoglycerides, diglycerides, phospholipids, sterols and fatty acids (Mahan & Escott-Stumph, 1996). Fatty acids are regarded as the most important lipid fraction and have a very

particular role in the immune function and prevention of inflammation, and they are an important energy source (Wan, Haw & Blackburn, 1989). Fatty acids are straight hydroxycarbon chains terminating in a methyl group on the one end and a carboxyl group at the other end. Twenty-four different fatty acids exist which differ in degree and nature of saturation and chain length. Fatty acids are classified according to the number of carbons, position of the first double bond and the number of double bonds. MUFA contain only one double bond, whereas PUFA contain two or more double bonds. SFA contain the maximum amount of hydrogens that the chain can hold (Mahan *et al.*, 1996).

Each fatty acid affects the plasmatic lipids differently and therefore the fatty acid composition has a considerable effect on the diet/health relationship.

Lamb and mutton lipids contain less than 50% SFA and up to 50-52% MUFA and PUFA. The presence of MUFA and PUFA in the diet reduces the level of plasma low-density lipoproteins (Jiménez-Colmenero, Carballo & Cofrades, 2001). Meat therefore cannot be described generally as a highly saturated food, as was believed earlier.

Linoleic acid (C18:2), linolenic acid (C18:3) and arachidonic acid (C20:4) cannot be synthesised in the body and must be present in the diet to prevent certain deficiency symptoms. These fatty acids are termed essential dietary fatty acids (Mahan *et al.*, 1996). Arachidonic acid serves as an active biological compound and occurs primarily in animal fat (AMIF, 1960).

According to Lawrie (1991), the concentration of fatty acids varies between the muscles within particular species and also between fractions within any single muscle. The fatty acid composition of meat from different species is shown in Table 1 (Sayed, Frans & Schönfeldt, 1999). The fatty acid composition of lipids affects the keeping and eating qualities of meat. SFA increase the hardness of fat and influence meat palatability by being easily solidified upon cooling. Unsaturated fatty acids on the other hand increase the potential for lipid oxidation, which influences shelf life (Banskalievaa, Sahlu & Goetsch, 2000).

The most abundant fatty acid found in meat fat is unsaturated oleic acid (C18:1*n*9) with one double bond (Forest *et al.*, 1975). Ram lambs are known to have intramuscular lipids richer

in PUFA and poorer in SFA compared to ewes and wethers (Solomon, Lynch, Ono, & Paroczay, 1990).

Fatty acid tissue characteristics vary within different meat species because fatty acids in the triglycerides (neutral lipids) vary in degree of saturation and in chain length (Penfield *et al.*, 1998). In ruminants dietary fatty acids are hydrogenated in the rumen and result in intramuscular fatty acids that are far more saturated in bovines and ovines than those in pigs and poultry (Geay *et al.*, 2001). C18:2, the major plant fatty acid, is much lower in ruminant tissue compared to the concentrations found in pork. This low concentration leads to a polyunsaturated:saturated (PUFA:SFA) fatty acid ratio (an important nutritional index in the United Kingdom) below the recommended value of 0.45. In contrast, the n-6: n-3 value for lamb/mutton is closer to the recommended value of ‹4.0 than that in pork (Warris, 2000). This difference occurs due to the fact that C18:3 is relatively high in ruminant animals, being the major fatty acid in grass. A high proportion is broken down to stearic acid (C18:0) in the rumen, but still significant quantities pass through the rumen to be absorbed in the small intestine (Wood *et al.*, 1999). Conversely, the muscle of concentrate-fed animals has higher C18:2 concentrations, the major fatty acid in cereal-based concentrates, compared to grass-fed animals (Enser *et al.*, 1998).

Webb *et al.* (1994) studied the effect of breed on subcutaneous fatty acid profiles of wethers. A significant greater proportion of palmitic acid (C16:0) was found in the subcutaneous fat of South African Mutton Merinos compared to that of Dorpers. The interaction between breed and slaughter weight and the effect of this on C16:0 was also significant. The proportion of palmitoleic acid (C16:1) in the subcutaneous fat from South African Mutton Merinos decreased with an increase in slaughter weight, but increased with increasing slaughter weight in Dorpers.

Table 2

Fatty acid content of meat from different species (g/100 g)

FOOD NAME	C10:0	C12:0	C14:0	C16:0	C18:0	C16:1	C18:1	C20:1	C18:2	C18:3	C20:4-g	C20:5
Beef, raw	0.04	0.03	0.29	2.93	2.66	0.6	4.67	0.02	0.46	0.14	0.03	0.01
Beef, loin, cooked dry	-	-	0.43	3.97	3.57	0.54	6.41	-	0.24	-	0.05	-
Mutton, raw	0.06	0.1	0.87	4.75	2.98	0.63	7.96	0	1.24	0.39	0.07	0
Mutton, leg (meat & fat), roasted	0.04	0.07	0.64	3.51	2.22	0.48	6.32	0	0.9	0.23	0.06	0
Pork, raw (fat untrimmed)	0.03	0.05	0.44	7.65	4.2	0.99	14.66	0.27	3.3	0.29	0.11	0
Pork, leg, roasted	0.02	0.01	0.22	4.01	2.11	0.5	7.23	0.12	1.52	0.05	0.07	0

(Sayed *et al.*, 1999)

Mineral content

The mineral content of several species is shown in Table 2 (Sayed *et al.,* 1999). Meat is considered as one of the best sources of iron (Fe), zinc (Zn), and magnesium (Mg) in the human diet, due to its high bioavailability (Lin *et al.*, 1989). Approximately 40% of the iron in meat is heme iron. This form of iron is more easily absorbed from the human gut than non-heme iron, found in plant materials (Simonsen *et al.*, 1988). Calcium (Ca), phosphorus (P), iron (Fe) and potassium (K) have received most attention in the research conducted on the mineral content of meat (AMIF, 1960) and, of these, K is quantitatively the most important, followed by P and Fe. Meat, however, is relatively low in calcium (Ca) content. Some copper (Cu) and other trace minerals are also supplied by meat (Bennion *et al.*, 2000). Meat provides about 10 µg selenium (Se) per 100 g of meat, which is ± 25% of the daily requirements. Recent data illustrate that meat, raw and cooked, provides Se with a greater bioavailability than that from plant foods (Higgs, 2000).

Comparisons between studies reveal variability in the mineral contents due to species, age, meat cut, feeding regimen, breed, season and geographical differences.

Generally it is accepted that the K content of lamb/mutton decreases as the age of the animal increases, while the Na values are only slightly influenced by the age of animals. The Mg and Ca content of lean tissue does not increase with age, whilst the Fe content increases (Doornenbal & Murray, 1981). Kotula and Lusby (1982) reported an increase in Zn levels with increasing age for bovine muscle. These findings were well supported by Ono *et al.* (1984), who found that older lambs exhibited higher Zn levels than younger lambs.

Various researchers have indicated variations in the mineral concentrations between different muscles. These differences are due to the variation in muscle fibre type and physical activity of the different muscles (Doornenbal *et al.*, 1981; Lin *et al.*, 1989). Beecher *et al.* (1968) compared the mineral content of both the red and white fibres. For red fibres a higher level of Fe, Cu, Na and Zn was reported, with a lower potassium (K) content in the red fibres.

Table 3

Mineral content of meat from different species (per 100 g)

FOOD NAME	Ca (mg)	Fe (mg)	Mg (mg)	P (mg)	K (mg)	Na (mg)	Cl (mg)	Zn (mg)	Cu (mg)	Se (µg)	I (µg)	Fl (µg)	B (µg)	Cr (µg)	Mn (µg)
Beef, raw	13	0.7	19	164	247	85	63	3.42	0.32	8.6	12	-	63	19.4	17
Beef, silverside cooked-moist	5	2.4	25	196	307	67	40	4.59	0.1	9.1	15	-	76	23.6	16
Mutton, raw	12	1.6	22	160	230	58	99	3.33	0.1	2.7	8	31	39	6.3	19
Mutton, leg (meat & fat), raw	11	2	24	191	313	66	67	4.4	0.12	4	3	34	2	6.8	24
Pork, (meat & fat), Raw	19	0.7	13	155	253	3	42	98	1.59	0.06	28.4		91	2.8	11
Pork, leg, roasted	14	1	22	263	352	60	2.96	0.1	45.3	0.09	-	82	32	10	0.7

(Sayed *et al.*, 1999)

Protein and amino acid composition

Nutritionally meat is regarded as a very good source of protein, with a high biological value and rich in essential amino acids. These proteins are slightly deficient in sulphur amino acids but are rich in lysine (Geay *et al.*, 2001).

The basis of the protein structure is amino acids. Some amino acids are classified as essential and others as non-essential amino acids. The body synthesises some essential amino acids, but in inadequate amounts to meet metabolic needs. Therefore, essential amino acids must be supplied as part of the diet. The essential amino acids are threonine, tryptophane, histidine, lysine, leucine, isolysine, methionine, valine, phenylanine and arginine. The non-essential amino acids are alanine, aspartic acid, asparagine, glutamic acid, glutamine, glycine, proline and serine. Non-essential amino acids can either be synthesised from the essential amino acids or from nitrogen and carbon precursors (Mahan *et al.*, 1996).

The amino acid composition of pork, beef and lamb/mutton meat proteins is shown in Table (Sayed *et al.*, 1999). Despite the minor differences between the species, more significant differences might exist between muscles, animal age and breed. All meats contain tryptophane, the amino acid that serves as the precurcer of niacin in the body (Bennion *et al.*, 2000).

The amino acid content of meat may be influenced by processing, but such destruction is minimal, as long as the processing conditions are not severe and prolonged (Lawrie, 1991).

Table 4

Amino acid composition of meat from different species (g/100 g)

FOOD NAME	Alanine	Arginine	Aspartic acid	Cystine	Glutamic acid	Glycine	Histidine	Isoleucine	Leucine	Lysine	Methionine	Phenylala-nine	Proline	Serine	Threonine	Trypto-phyna	Tyrosine	Valine
Beef, raw	1.03	1.15	1.47	0.23	2.44	1.15	0.49	0.64	1.25	1.55	0.25	0.59	0.86	0.7	0.69	0.19	0.45	0.66
Beef, loin, cooked dry	1.59	1.7	2.2	0.31	3.69	1.62	0.72	1.01	1.99	2.34	0.37	0.9	1.29	1.05	1.04	0.28	0.79	0.95
Mutton, raw	1.015	1.003	1.486	0.202	2.45	0.825	0.535	0.815	1.313	1.491	0.433	0.687	0.708	0.628	0.723	0.197	0.567	0.911
Mutton, leg (meat & fat), roasted	1.537	1.518	2.249	0.305	3.708	1.248	0.809	1.233	1.987	2.256	0.656	1.04	1.072	0.95	1.094	0.299	0.859	1.379
Pork, raw (fat untrimmed)	0.832	0.911	1.249	0.169	2.062	0.868	0.509	0.616	1.088	1.23	0.347	0.547	0.672	0.574	0.61	0.16	0.454	0.737
Pork, leg, roasted	1.585	1.717	2.445	0.333	4.077	1.493	1.022	1.218	2.122	2.39	0.687	1.062	1.198	1.108	1.198	0.324	0.903	1.437

(Sayed *et al.*, 1999)

Vitamin composition

The vitamin composition in various meats is shown in Table 5 (Sayed *et al.*, 1999). A wide variety of vitamins are found in all types of meat, but the quantity of particular vitamins differs markedly with respect to the type of meat and whether the meat is cooked or in the raw state.

The principal vitamin in all animal tissues is the B-vitamins. Lean meat is especially rich in vitamin B_{12} (which is absent in plant foods), thiamin (B_1), riboflavin and niacin. The B-vitamin contents of different cuts within species is relatively similar, whereas large differences are noted between different species (AMIF, 1960). The vitamin B_1 content of pork is considerably higher than that of other meat, while beef contains a relatively high concentration of folic acid compared to meat from other species (Lawrie, 1991).

The fat-soluble vitamins A and D are nearly absent in lean meat, but the liver is particularly rich in vitamin A (Simonsen *et al.*, 1988). The liver is also an excellent source of nicotinic acid, vitamin B_6, pantothenic acid, biotin and vitamin B_{12} (AMIF, 1960). Organs, especially the liver, have a high ascorbic acid content, while this acid is detected only in small amounts in lean meat (Simonsen *et al.*, 1988).

The vitamin content of meat derived from ruminants is not directly affected by the feed intake of the animal, as in the case of fresh pork. Micro-organisms present in the rumen synthesise some nutrients and vitamin B complex vitamins, which may not be present in the ingested feed. Rumen micro-organisms may also utilise a significant proportion of such nutrients when the feed contains significant amounts. The overall operation of the rumen therefore equalises or evens out the variations in the nutrient content of the feed (Lawrie, 1991).

Table 5

Vitamin composition of meat from different species (per 100 g)

FOOD NAME	Vit A (μgRE[1])	Vit D (μg)	Vit E (mg)	Vit K (μg)	Thiamin (mg)	Riboflavin (mg)	Niacin (mg)	Vit B_6 (mg)	Folate (μg)	Vit B_{12} (μg)	Pantothenic (mg)	Biotin (μg)
Beef, raw	0	0.62	0.16	0.39	0.13	0.08	5.40	0.21	10.00	1.00	0.31	1.50
Beef, loin, cooked dry	0	0.60	0.03	0.51	0.21	0.18	5.20	0.37	13.00	2.00	0.24	1.90
Mutton, raw	0	0.53	0.21	-	0.12	0.22	6.10	0.13	18.00	2.40	0.67	2.70
Mutton, leg (meat & fat), roasted	0	0.60	0.15	-	0.10	0.27	6.60	0.15	20.00	2.60	0.68	2.00
Pork, raw (fat untrimmed)	3.00	1.00	0.29	0.10	0.60	0.21	3.80	0.28	4.00	0.6	0.53	3.90
Pork, leg, roasted	3.00	1.00	0.26	0.09	0.64	0.31	4.60	0.40	10.00	0.70	0.62	5.00

[1] μg –RE=μg retinol equivalents

(Sayed *et al.*, 1999)

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CHAPTER 3

THE EFFECT OF BREED ON THE SENSORY AND OBJECTIVE MEAT QUALITY CHARACTERISTICS OF LAMB DERIVED FROM SIX TERMINAL SHEEP BREED COMBINATIONS

ABSTRACT

The effect of crossbreeding on lamb meat quality was examined on the *M. longissimus dorsi* and *M. semimembranosus* of 34 South African lamb breed combinations. The lambs were sired by Dormer (D) and Suffolk (S) rams and born to Merino (M), Dohne Merino (DM) and SA Meat Merino (SAMM) ewes. This outlay resulted in six distinct breed combinations (DxM, DxDM, DxSAMM, SxM, SxDM, SxSAMM). Ratings of sensory attributes on the *M. semimembranosus* of the different lamb breed combinations were obtained from a trained taste panel and related to data on physical and chemical characteristics. The moisture, total lipids, protein, ash, mineral content and fatty acid composition of the *M. semimembranosus* were obtained. Physical parameters measured on the *M. longissimus dorsi* were: ultimate pH (pH_{48}), drip loss, cooking loss and Warner-Bratzler shear force (WBS). Significant differences were detected between the lamb breed combinations for the sensory attribute of initial juiciness ($p \leq 0.05$), whereas the taste panel did not identify breed differences for the attributes of tenderness, flavour, aroma, sustained juiciness and residue. Although pH_{48} and WBS differed significantly between the breed combinations ($p \leq 0.05$), they did not correlate to the eating quality attributes. No significant differences were detected between breed combinations for cooking or drip loss ($p > 0.05$). Differences existed between breed combinations pertaining to the mineral composition and the percentage content of individual fatty acids. The iron, potassium, magnesium and phosphorus content differed significantly ($p \leq 0.05$) between some breed combinations. There was a tendency for the DxSAMM group to have the highest mineral content and the SxDM group the lowest. Total saturated fatty acids (SFA) and total mono-unsaturated fatty acids (MUFA) were significantly influenced ($p \leq 0.05$) by breed, with the DxM group having the highest (±61%) and the DxDM having the lowest (50.27%) total SFA. The DxM group had the lowest total MUFA (±33%) and the DxDM group the highest (±44%). Percentage concentration of individual fatty acids (C16:0, C22:0, C24:0, C18:1*n*9, C20:1*n*9, C24:1*n*9, C20:2*n*6, C20:3*n*3, C22:5*n*3 and C22:6*n*3) were affected ($p \leq 0.05$) by breed. The poly-unsaturated/saturated fatty acid ratios of all the breeds

in this investigation were low and below the recommended human consumption value of 0.45. Although the taste panel could not detect any breed differences, differences were noted pertaining to the effect of breed on the nutritional value of the meat.

INTRODUCTION

The past decade has been characterised by rapid changes in consumer trends pertaining to meat comsumption. With today's progressively declining per capita consumption of lamb meat in South Africa, producers and manufacturers have to meet consumer demands, trends and preferences for the industry to survive in the increasingly competitive market. Consumers of the new millennium are health conscious and demand high-quality food products. Ultimately, the success of any food product is determined by consumer acceptability, which is largely determined by the perception of quality (Dransfield, 2001). The concept of quality has evolved with rapid changes in scientific knowledge, analytical methods and consumer expectations within the meat production industry (Nardone & Valfré, 1999). As a result, the concept of "Total Quality" has been widened and redefined by Valfré and Moretti (as cited by Nardone and Valfre, 1999) to include the following quality traits: hygienic, compositional, nutritional, sensory and technological quality.

Although consumer preferences for meat are difficult to define, the most important quality feature in meat and meat products are sensory characteristics (Bukala and Kedzior, 2001). Horsfield and Taylor (1976) described a system of three independent principal components, namely succulence (initial juiciness, breakdown, bolus formation and uniformity), toughness (resistance, resilience and chewiness) and flavour (including off-flavours) which, in this order, contribute to acceptability. Lamb quality is influenced by factors inherent to the animals from which the products are derived, such as chronological age (Bouton, Harris, Ratcliff & Roberts, 1978; Ono *et al.*, 1984), slaughter weight (Jeremiah, Tong, & Gibson, 1998) and gender (Butler-Hogg, Francombe & Dransfield, 1984; Dransfield, Nute, Hogg & Walters, 1990).

In addition to the above-mentioned factors, the effect of breed is an important factor influencing lamb quality. Limited research has been done on the effect of breed or genotype on the eating quality of lamb, especially with regard to the sensory quality characteristics (Fisher *et al.*, 1999; Safari *et al.*, 2001). According to Sink and Caporaso (1977) studies on lamb and mutton indicate a great deal of variation between breeds. To produce lambs with

maximum consumer appeal, producers and processors need to recognise the importance of the interactions between breed, chronological age, slaughter weight and gender in the utilisation of genetics and nutritional regimes.

In South Africa sheep are bred from a diverse range of breeds and genotypes. The most numerous breeds are those bred for wool production. These woolled breeds are known to have inferior meat-production potential. The economic viability of wool production is limited by the relatively low and fluctuating wool prices, as well as increasing input costs. Wool sheep farmers are increasingly forced to breed part of their herds with meat-producing sires in a terminal crossbreeding system. Such a system could potentially benefit farmers in terms of cashflow and turnover.

Against this background, the influence of ewe (Merino, Dohne Merino, SAMM) and sire (Dormer or Suffolk) breed on lamb quality was investigated. Differences in sensory attributes, proximate chemical composition, fatty acid and mineral composition between the resultant six diverse breed combinations were reported. Muscle pH, cooking, drip loss and shear force were also recorded.

MATERIALS AND METHODS

Animals and sampling

Lamb carcasses representing six breed combinations (n=6 ewes per breed) were obtained from Langgewens Experimental Farm, Western Cape, South Africa. The lambs were sired by either Dormer (D) or Suffolk (S) rams and born to Merino (M), Dohne Merino (DM) and SA Meat Merino (SAMM) ewes in a 2 (sire breed) x 3 (ewe breed) experiment. This outlay resulted in 6 possible breed combinations (DxM, DxDM, DxSAMM, SxM, SxDM, SxSAMM). The lambs were grown to commercial slaughter weight (±38 kg) and slaughtered using standard South African techniques and conditions. No electrical stimulation was applied. During the first 48 h postmortem, the carcasses were chilled at a temperature of 5°C. Ultimate pH was measured 48 h postmortem (pH_{48}) with a penetrating glass electrode on a hand-held Crison pH/mV-506 meter. The measurement was taken between the 2nd and 3rd last thoracic vertebrae, 45 mm from the midline. The pH meter was re-calibrated after every fourth reading and the electrode rinsed with distilled water between each measurement. The

pH meter contained a temperature probe ensuring automatic adjustment of the pH for temperature. The *M. longissimus dorsi* was removed from the carcass to assess measurements of drip loss, cooking loss, WBS and pH_{48}. The legs were removed from the carcasses at a position between the last lumbar and the first sacral vertebrae. The legs was labelled, vacuum packed, frozen and stored at -18°C until further analysis. After thawing, the *M. semimembranosus* from both the legs were dissected and used for sensory, proximate, mineral and fatty acid analyses. The *M. longissimus dorsi*, cooked according to the dry-heat cooking method, is recognised throughout the world as the most representative muscle to indicate overall carcass eating quality. However, Schönfeldt, Naudé, Bok, Van Heerden and Sowden (1993) found that the *M. semimembranosus* cooked according to a moist-heat cooking method showed clearer differences between specific attributes that were tested.

Sensory analyses

Sample preparation: The right legs were defrosted at a temperature of 3 - 4°C for a period of 48 h for the purpose of deboning and the removal of the *M. semimembranosus*. The legs were placed on a flat surface with the lateral side facing upwards. An incision was made on the septa, followed by an incision of the knife at the top end and cutting as close as possible to the pelvic bone. The natural division between muscles then became visible and the *M. semimembranosus* could be separated from the other muscles by cutting between the muscles. The *M. semimembranosus* cuts were coded, vacuum packed, frozen and stored at -18°C until further analysis.

***Cooking procedures*:** *M. semimembranosus* samples were oven-roasted prior to subsequent sensory analysis. The meat cuts were defrosted for 48 h at a temperature of 3 - 4°C, wrapped individually in cooking bags and placed fat-side up on the rack of an open roasting pan. The samples were roasted at 160°C in two conventional electric Defy 835 ovens connected to a computerised electronic temperature control system (Viljoen, Muller, De Swardt, Sadie & Vosloo, 2001). A thermocouple was inserted in the centre of each sample and the meat was roasted to an internal temperature of 70°C (AMSA, 1978).

Presentation and scoring of samples: Immediately after cooking all visible subcutaneous fat was removed from each sample. Six 1.5 cm x 1.5 cm cubed samples were taken from the middle of each sample and wrapped immediately in aluminium foil marked with random three

digit codes. The samples were placed in preheated glass ramekins in a preheated oven of 100°C and evaluated within 10 min (Personal communication, I. Van Heerden, 2001).

Sensory analyses: Analytical sensory analyses were done on the oven-roasted meat. Panellists were selected and trained in accordance with the AMSA guidelines for the sensory evaluation of meat (AMSA, 1978). A six-member, trained descriptive panel evaluated the meat for the following sensory attributes: aroma intensity, initial impression of juiciness, sustained juiciness, tenderness, residue and overall lamb flavour by means of an eight-point structured line scale (Addendum). Table 1 depicts the definitions of the attributes used in the sensory analyses of the lamb.

The panellists were seated in individual booths in a temperature- and light-controlled room, receiving a set of four samples served in a completely random order. Crackers and distilled water were used to cleanse the palate between samples (AMSA, 1978).

Table 1: Definition of attributes for sensory analyses of lamb

Attribute	Definition
Lamb aroma 1=Extremely bland; 8=Extremely intense	Aroma associated with the animal species
Initial juiciness 1= Extremely dry; 8= Extremely juicy	The amount of fluid exuded on the cut surface when pressed between fingers
Sustained juiciness 1=Extremely dry; 8=Extremely juicy	Degree/amount of water perceived during mastication
First bite 1=Extremely tough; 8=Extremely tender	Force needed to compress the sample of meat between molar teeth on the first bite
Residue 1=Abundant; 8=None	The connective tissue remaining after most of the sample has been masticated
Lamb flavour 1=Extremely typical; 8=Extremely untypical	Flavour associated with the animal species

Proximate chemical analyses

Proximate chemical analyses were carried out on the raw *M. semimembranosus* from the left leg. Total percentages of moisture, protein and ash were determined according to AOAC methods (AOAC, 1997). The protein content was determined by the block digestion method and ashing was done at 500°C for 5 h. The moisture content was determined by drying at

100°C for 24 h. The lipid content was determined by means of chloroform:methanol extraction (Lee, Trevino & Chaiyawat, 1996).

Instrumental analyses

For the drip loss determination 1.5 x 1.5 cm thick meat samples from the *M. longissimus dorsi* were weighed immediately after being removed from the carcass. The samples were placed in netting and suspended in an inflated plastic bag. After a storage period of 24 h at 4°C, samples were weighed again and the drip loss was calculated as weight loss expressed as a percentage of the original weight of the sample (Honikel, 1998).

For the cooking loss determination freshly cut *M. longissimus dorsi* samples (1.5 cm thick) were weighed and placed in thin-walled plastic bags in a water-bath at 75°C. After one hour the samples were removed from the water-bath, cooled in cold water, blotted dry and weighed. Cooking loss was calculated as the difference in sample weight before and after cooking, expressed as a percentage of the initial sample weight (Honikel, 1998).

The shear force measurements of the cooked *M. longissimus dorsi* samples were obtained with a Warner-Bratzler shear (WBS) attachment (Voisey, 1976), fitted to an Instron Universal Testing Machine (Model 4444). Three cylindrical cores were cut from each muscle using a 12.7 mm diameter bore. Samples were randomly removed from the centre of each *M. longissimus dorsi*. Maximum WBS values (N) required to shear a cylindrical core of cooked muscle, perpendicular to the grain (at a crosshead speed of 200.0 mm/min), were recorded for each sample and the mean was calculated for each muscle. A larger value indicated greater shear force and therefore, tougher meat.

Mineral analyses

A wet ashing method was used to prepare the meat samples for mineral analysis. The elements calcium (Ca), iron (Fe), selenium (Se), potassium (K), magnesium (Mg), sodium (Na), phosphorus (P), zinc (Zn), copper (Cu), and lead (Pb) of the digestates were determined by direct current plasma emission spectrometry (Pinta, 1982).

Fatty acid analyses

After the extraction of the lipids, the fatty acid methyl esters (FAME) were prepared according to procedures published by Morrison and Smith (1964). The FAME were analysed with a gas-liquid chromatograph (Varian Model 3300), equipped with flame ionisation detection and two 30 m fused silica megabore DB-225 columns of 0.53 mm internal diameter (J&W Scientific, Folsom, CA). Gas flow rates were hydrogen 25 ml/min and nitrogen (carrier gas) 5-8 ml/min. The temperature programme was linear at 4°C/min with initial and final temperatures of 160°C and 220°C (held for 10 min), respectively. The injector temperature was 240°C and the detector temperature 250°C. The FAME was identified by comparison of the retention times to those of a standard FAME mixture (Nu-Chek-Prep Inc., Elysian, Minnesota).

Statistical analyes

The experiment consisted of a completely randomised design with six treatments (breeds). The treatment design was a 2x3 factorial with two sire breeds (S and D) and three ewe breeds (S, SM and SAMM) as factors. A total of 6 distinct genotypes was thus present in the interaction. Where appropriate, data were also pooled to test for the main effects of sire and ewe breed. An experimental unit was regarded as a carcass from which samples were taken for measurements.

Prior to analyses of variance the sensory scores were transformed to ranks. For Pearson correlations, the sensory scores from an eight-point scale were subjected to logistic analysis to transform the data to interval scale data using a general linear model procedure in order to create maximum likelihood estimators as location values (X-Betas) (McCullagh & Nelder, 1989).

A factorial analysis of variance was performed on all data using SAS version 8.12 (SAS, 1990). The Shapiro-Wilk test was performed to test for non-normality (Shipiro & Wilk, 1965). In some cases deviations from normality were the cause of one or two outliners, which were removed before the final analysis. Where there was still significant evidence of non-normality, this could be ascribed to kurtosis rather than skewness. Interpretation of results

was thus continued (Glass, Peckham & Sanders, 1972). Student's t-Least Significant Differences (LSD) was calculated at the 5% significance level to compare treatment means.

RESULTS AND DISCUSSION

Sensory quality characteristics

Rank means for sensory quality characteristics of the *M. semimembranosus* samples are presented in Table 2. The means (in brackets) are also provided below the rank means for the interpretation of the results using the rating scale. All sensory quality characteristics, except initial juiciness, were similar ($p>0.05$) for all breed combinations.

According to Dryden and Marchello (1970), juiciness is an organoleptic characteristic related to both the capacity of the muscle to release its constitutive water (initial juiciness) and the infiltrated fat content (sustained juiciness). In combination with water, the melted lipid constitutes a broth that, when retained in the meat, is released upon chewing. This broth may also stimulate the flow of saliva, and thus improve the meat's apparent juiciness (Forest, Aberle, Hendrick, Judge & Merkel, 1975). The initial juiciness of the meat from the six breed combinations differed significantly ($p\leq0.05$), with the DxSAMM having the highest score for initial juiciness (4.31) and the SxM having the lowest score (3.00). These results support the results in moisture content (Table 3), where the DxSAMM group had the highest moisture content (±72%) and the SxM group had the lowest moisture content (65%). There was, however, not a significant difference in the moisture content between the breed combinations. The derived rank correlation value between initial juiciness and moisture content ($r=0.24$) was not of any significance ($p>0.05$).

Flavour did not differ ($p>0.05$) between the respective breed combinations. The latter is consistent with the results reported by Crouse, Busboom, Field and Ferrel (1981) that breed does not influence the flavour of lamb. However, Fisher *et al.* (1999) and Sink *et al.* (1977) both found breed differences pertaining to lamb flavour. In the present investigation there may have been a masking effect of the flavour of a specific breed, due to the fact that breed combinations were evaluated.

When pooled together for sire and ewe breed effects, no significant differences ($p>0.05$) were found for any of the sensory quality characteristics.

Table 2

Rank means (Means) for the sensory quality characteristics of *M. semimembranosus* as influenced by different lamb breed combinations

	Breed combinations						
	D x M	D x DM	D x SAMM	S x M	S x DM	S x SAMM	LSD[c]
Aroma[e]	3.875	3.375	3.458	3.229	2.958	4.104	NS[d]
	(6.042)	(5.833)	(5.833)	(5.750)	(5.625)	(6.125)	
Initial juiciness[f]	3.354[ab]	3.229[ab]	4.313[a]	3.000[b]	4.000[ab]	3.104[ab]	1.254
	(5.875)	(5.833)	(6.333)	(5.708)	(6.167)	(5.792)	
Sustained juiciness[g]	3.083	3.125	4.021	3.458	3.938	3.375	NS
	(5.458)	(5.500)	(5.917)	(5.667)	(5.917)	(5.625)	
First Bite[h]	3.146	3.500	3.646	3.854	3.083	3.771	NS
	(5.792)	(5.958)	(6.042)	(6.083)	(5.750)	(6.042)	
Residue[i]	3.354	3.188	3.771	3.771	3.146	3.771	NS
	(5.625)	(5.500)	(5.792)	(5.792)	(5.458)	(5.750)	
Flavour[j]	3.604	3.479	3.146	3.875	3.271	3.625	NS
	(5.958)	(5.875)	(5.750)	(6.042)	(5.750)	(5.958)	

[a,b]Rank means in the same row with different superscripts are significantly different ($p \leq 0.05$)

[c]LSD=Least significant difference ($p=0.05$)

[d]NS=Not significant ($p>0.05$)

[e]Aroma: 1=extremely bland; 8=extremely intense

[f]Initial juiciness: 1= extremely dry; 8= extremely juicy

[g]Sustained juiciness: 1=extremely dry; 8=extremely juicy

[h]First bite: 1=extremely tough; 8=extremely tender

[i]Residue: 1=abundant; 8=none

[j]Flavour: 1=extremely unflavourable; 8=extremely flavourable

Proximate chemical composition

There were no significant differences between the different breed combinations with regard to moisture, lipid and ash content (Table 3). The fact that there were no significant differences regarding the lipid content could possibly be due to the marked variation in the lipid content (ranging from 4.20 to 28.90 g/100 g meat) and from the small number of observations.

The meat from the different breed combinations differed significantly ($p \leq 0.05$) in protein content, with the DxSAMM having the highest protein content (±21%). When pooled together for sire and ewe breed effects, the D and SAMM genotypes had the highest protein content and the M and S genotypes the lowest (Table 4). Of all the breed combinations the

DxSAMM breed also had the higher moisture (±72%) and ash (±1%) content and the lower lipid (8%) content of all the breed combinations. Although not significant, there was a tendency that the protein content of the pooled groups had a reverse relationship to the fat content of the meat. Muscles with the highest protein content were characterised by the lower fat content.

Furthermore, the results of this study indicated no significant association between lipid content and tenderness, juiciness or flavour of the cooked lamb. These results correspond with those of Batcher, Dawson, Pointer and Giblin (1962), who found that neither marbling nor intramuscular fat percentage was significantly associated with tenderness, juiciness or flavour of cooked lamb roasts.

Table 3

Means for proximate chemical analysis of *M. semimembranosus* as influenced by different lamb breed combinations (g/100 g meat sample)

	Breed combinations						
	D x M	**D x DM**	**D x SAMM**	**S x M**	**S x DM**	**S x SAMM**	**LSD[c]**
Moisture	66.94	68.35	72.02	65.35	69.17	67.73	**NS[d]**
Lipid	13.57	11.81	8.375	16.11	12.57	14.33	NS
Protein	18.89[b]	19.71[ab]	20.88[a]	18.45[b]	18.83[b]	18.71[b]	1.560
Ash	1.098	1.024	1.139	1.038	1.054	1.047	NS

[a,b]Means in the same row with different superscripts are significantly different (p≤0.05)

[c]LSD=Least significant difference (p=0.05)

[d]NS=Not significant (p>0.05)

Table 4

Means for proximate chemical analysis of *M. semimembranosus* as influenced by the respective ewe and sire lamb breeds (g/100 g meat sample)

	Ewe breed				Sire breed		
	M	SAMM	DM	LSD[c]	D	S	LSD
Moisture	66.14	69.87	68.76	NS[d]	69.10	67.41	NS
Lipid	14.84	11.35	12.19	NS	11.25	14.34	NS
Protein	18.67[b]	19.79[a]	19.27[ab]	1.103	19.83[a]	18.66[b]	0.901
Ash	1.068	1.093	1.039	NS	1.087	1.046	NS

[a,b]Means in the same row with different superscripts differ significantly ($p \leq 0.05$)

[c]LSD=Least significant difference ($p=0.05$)

[d]NS=Not significant ($p>0.05$)

Objective quality characteristics

The traits that were measured physically, namely pH_{48}, cooking loss, drip loss and WBS resistance of the *M. longissimus dorsi* are presented in Table 5. Due to unforeseen circumstances it was not possible to measure the WBS values of the SxSAMM group.

Cooking and drip loss differences indicated non-significant results ($p>0.05$) and were therefore not related to breed combinations. Both the pH_{48} and WBS values showed significant differences ($p \leq 0.05$) between breed combinations. The latter difference in WBS, were, however, not detected by the taste panel.

It is well known that the ultimate pH of the muscle is an important contributing factor to the quality of meat. In this experiment there was no significant correlation between pH and any of the sensory attributes. The latter results are similar to the findings of Safari *et al.* (2001). The low correlation can be attributed to the fact that the mean pH values of the different breed combinations were all within the normal pH range and less than 5.8 (Lawrie, 1991). According to Devine, Graafhuis, Muir and Chrystall (1993) an ultimate pH value greater than 5.8 is regarded as undesirable.

As noted in Table 5, the SxM group had the highest pH and the lowest WBS value. The correlation between pH and WBS ($r=0.23$) was, however, not significant ($p>0.05$). Conflicting reports regarding the relationship between pH and tenderness (WBS, as well as sensory tenderness) are found in the literature. Devine *et al.* (1993) reported an increase in

shear force with higher pH values in the range of 5.4-6.0, while Young, Reid and Scales (1993) showed a curvilinear relationship. Safari *et al.* (2001), however, found no relationship between pH and shear force or sensory tenderness in six diverse lamb genotypes.

When pooled together for the main effects of sire and ewe breeds (Table 6), there were no significant differences ($p>0.05$) between the sire breeds for pH or shear force values. However, the pooled ewe breeds indicated significant differences ($p\leq0.05$) in pH, where the M group differed from the SAMM and DM groups. Although the WBS values of the pooled ewe group did not differ significantly, there was a tendency for higher pH values to be associated with lower shear force values.

There is a great deal of controversy amongst researchers regarding tenderness and the influence of marbling (the percentage fat in the muscle) on it. It is accepted as a fact that intramuscular fat content affects the palatability of meat, but the specific relationship does not seem clear. Some researchers have reported a positive relationship between tenderness and fat percentage, while others have found none. Parrish (1974), for example, found no relationship between tenderness and percentage fat, while Carpenter and King (1965) found a significant correlation between chops with variations in marbling score and tenderness. Results obtained by Schönfeldt *et al.* (1993) indicate that the fatness of ovine and caprine carcasses correlate positively with tenderness of muscle and associated muscle characteristics. In this investigation no significant correlation was found between tenderness (WBS, as well as sensory tenderness) and fatness of meat. The correlation values between fat on the one hand and WBS and tenderness, on the other hand, were $r=-0.114$ and $r=0.108$ respectively. Therefore, the results of this investigation as well as literature cited indicate that there is no clear evidence of a relationship between lamb carcass fatness and tenderness.

Table 5

Means of pH, cooking loss, drip loss and shear force resistance of lamb *M. longissimus dorsi* as influenced by different lamb breed combinations

	Breed combinations						
	DxM	DxDM	DxSAMM	SxM	SxDM	SxSAMM	LSD[d]
pH_{48}	5.712[ab]	5.608[bc]	5.562[c]	5.793[a]	5.537[c]	5.642[bc]	0.141
Cooking loss (%)	23.04	21.36	21.95	17.76	22.54	19.97	NS[e]
Drip loss (%)	1.055	0.771	1.154	1.008	1.152	0.751	NS
WBS[f](N)	81.45[ab]	105.1[a]	74.54[b]	66.35[b]	73.73[b]	-	26.52

[a,b,c] Means in the same row with different superscripts are significantly different (p≤0.05)

[d]LSD=Least significant difference (p=0.05)

[e]NS=Not significant (p>0.05)

[f]WBS=Warner-Bratzler shear force value

Table 6

Means of pH, cooking loss, drip loss and shear force resistance of lamb *M. longissimus dorsi* as influenced by ewe and sire lamb breeds

	Ewe breed				Sire breed		
	M	SAMM	DM	LSD[d]	S	D	LSD
pH_{48}	5.753[a]	5.602[b]	5.569[b]	0.100	5.657	5.628	NS[e]
Cooking loss(%)	20.40	20.96	22.10	NS	19.94	22.35	NS
Drip loss(%)	1.029	0.952	1.009	NS	1.025	0.982	NS
WBS[f](N)	74.74	74.54	86.29	NS	69.52	85.17	NS

[a,b] Means in the same row with different superscripts are significantly different (p≤0.05)

[d] LSD=Least significant difference (p=0.05)

[e]NS=Not significant (p>0.05)

[f] WBS=Warner-Bratzler shear force value

Mineral composition

Results from this study indicated significant differences (p≤0.05) between the six breed combinations in Fe, K, Mg and P content with K, P and Mg, in that order, being the major contributors to the mineral content of all the breeds (Table 7). The DxSAMM group had the highest iodine (72.32mg/100g meat), potassium (160.5mg/100g meat), magnesium (22.03mg/100g meat) and phosphorus (139.9mg/100g meat) content, while the SxDM group had the lowest. A general tendency was noted that the DxSAMM group had the highest overall mineral content and the SxDM group the lowest. When pooled together for sire breed,

no significant differences ($p>0.05$) were detected in any of the minerals for the S and D groups. The ewe breed, however, showed significant differences ($p\leq0.05$) in the iodine, potassium, magnesium and phosphorus content, with the SAMM group having the highest content and the DM group the lowest content of these minerals (Table 8).

The mineral content of retail cuts within any single carcass varies significantly (Lin *et al.*, 1989; Ono *et al.*, 1984). The latter is caused by variation in muscle fibre type and physical activity between muscles (Kotula & Lusby, 1982). The literature cited indicated enormous variability in the mineral composition of meat due to the effects of age, feeding regimen, breed, season and geographical differences. Since lambs in the present study were selected from a single geographical location, feeding regimen and the same age group, variation in mineral composition can be explained as an effect of breed. In the research literature the Ca, P, Fe and K content of meat has received substantial attention (AMIF, 1960) of these, K is quantitatively the most important, followed by P and Fe. It is well known that meat is an excellent food source of Fe and Zn, especially considering the higher bioavailability of these two minerals compared to that from plants (Lin *et al.*, 1989). Approximately 40% of the Fe in meat is heme iron and this form of iron is more available to man than non-heme iron (Simonsen, Hamm & Rogowski, 1988).

Meat is a primary dietary component and forms an important part of a balanced varied diet. Meat provides a significant contribution to the minerals required by the diet and the concentration of Fe, Zn and Cu in meat is higher than that provided by the rest of the diet as a whole (Williams, 1987). The results of this investigation indicated significant statistical differences in the mineral composition between breeds and therefore some breeds can be considered as making a better nutritional contribution to human dietary mineral requirements.

Table 7

Means for mineral composition of *M. semimembranosus* as influenced by different lamb breed combinations (mg/100 g meat sample)

	Breed combinations						
	D x M	**D x DM**	**D x SAMM**	**S x M**	**S x DM**	**S x SAMM**	**LSD[c]**
Ca	5.338	5.293	4.597	4.761	4.708	6.471	NS[d]
Fe	1.515[ab]	1.421[b]	1.609[ab]	1.571[ab]	1.629[ab]	1.883[a]	0.416
Se	0.115	0.118	0.10	0.065	0.049	0.117	NS
K	151.0[ab]	138.5[ab]	160.5[a]	147.1[ab]	130.1[b]	151.6[ab]	22.58
Mg	19.99[ab]	19.95[ab]	22.03[a]	20.15[ab]	17.97[b]	21.93[a]	2.835
Na	18.85	18.81	19.75	16.39	16.15	18.19	NS
P	129.6[a]	125.7[ab]	139.9[a]	128.1[ab]	111.6[b]	137.8[a]	17.75
Zn	3.554	3.490	3.262	3.174	2.786	3.124	NS
Cu	0.088	0.117	0.087	0.140	0.143	0.106	NS
Pb	0.017	0.019	tr[e]	0.014	0.002	0.010	NS

[a,b] Means in the same row with different superscripts are significantly different ($p \leq 0.05$)

[c]LSD= Least significant difference ($p=0.05$)

[d]NS=Not significant ($p>0.05$)

[e]tr=trace= <0.001 mg/100 g meat sample

Table 8

Means for mineral composition of *M. semimembranosus* as influenced by different ewe and sire lamb breeds (mg/100 g meat sample)

	Ewe breed				Sire breed		
	M	SAMM	DM	LSD[d]	S	D	LSD[c]
Ca	5.050	5.533	5.000	NS	5.313	5.076	NS[d]
Fe	1.543	1.746	1.525	NS	1.694	1.515	NS
Se	0.090	0.108	0.084	NS	0.077	0.111	NS
K	149.0[ab]	156.1[a]	134.3[b]	15.97	142.9	150.0	NS
Mg	20.07[ab]	21.98[a]	18.96[b]	2.005	20.02	20.66	NS
Na	17.62	18.97	17.48	NS	16.91	19.14	NS
P	128.9[ab]	138.8[a]	118.6[b]	12.55	125.8	131.71	NS
Zn	3.364	5.466	3.138	NS	4.543	3.435	NS
Cu	0.114	0.096	0.130	NS	0.130	0.097	NS
Pb	0.016	0.064	0.011	NS	0.048	0.012	NS

[a,b] Means in the same row with different superscripts are significantly different ($p \leq 0.05$)

[c] LSD=Least significant difference ($p=0.05$)

[d] NS=Not significant ($p>0.05$)

Fatty acid composition

Results of the effect of lamb breed combination on fatty acid composition of the *M. semimembranosus* samples are shown qualitatively (percent of total fatty acids) in Table 9.

Enser *et al.* (1998) compared the fatty acid composition of lamb, beef and pork muscle. Significant differences ($p \leq 0.05$) were not only noted between ruminants and non-ruminants, but also between lamb and beef. Lamb muscle presented higher levels of stearic acid (C18:0) and lower levels of palmitic acid (C16:0) and oleic acid (C18:1*n*9) than beef and pork. Webb, Bosman and Casey (1994) studied the effect of breed on subcutaneous fatty acid profiles of wethers. A significantly greater proportion of C16:0 was found in the subcutaneous fat of South African Mutton Merinos (SAMM) compared to that of Dorpers. Results obtained in this investigation concur with the above and indicated a significant effect ($p \leq 0.05$) of breed on the fatty acid composition of lamb *M. semimembranosus*.

Total mono-unsaturated fatty acids (MUFA) were influenced significantly ($p \leq 0.05$) by breed. C18:1*n*9, eicosenoic acid (C20:1*n*9) and nervonic acid (C24:1*n*9) differed significantly ($p \leq 0.05$), with C18:1*n*9 being the most abundant MUFA.

Linoleic acid (C18:2*n*6) was the most abundant polyunsaturated fatty acid (PUFA) at ±3%, followed by α-linolenic acid (C18:3*n*3) at ±1.2%. Significant differences ($p \leq 0.05$) were found in the eicosadienoic acid (C20:2*n*6), eicosatrienoic acid (C20:3*n*3), docosapentaenoic acid (C22:5*n*3) and docosahexaenoic acid (C22:6*n*3).

Total saturated fatty acids (SFA) were influenced significantly by breed ($p \leq 0.05$). The effect of breed on the total percentage of SFA was due largely to the C16:0 being the most abundant (±28%) SFA, followed by C18:0 contributing to approximately 25% of the total fatty acids. The DxM group had the highest (±61%) and the DxDM group the lowest (±50%) total SFA content. Significant differences ($p \leq 0.05$) were detected in C16:0, behenic acid (C22:0) and lignoceric acid (C24:0) SFA.

Table 9 contains PUFA:SFA, desirable fatty acids (DFA) and (C18:0+C18:1):C16:0 ratios. Values of 0.45 or above for the P:S ratio in dietary fats have been recommended in the United Kingdom (Warris, 2000). The PUFA:SFA ratio is presented as an important guideline representing the total impact of all SFA on the blood cholesterol content. PUFA:SFA ratios are lower in ruminants than non-ruminants because of biohydrogenation of dietary unsaturated fatty acids by ruminal micro-organisms (Banskalievaa, Sahlu & Goetsch, 2000). C 18:2*n*6, the major plant fatty acid, is much lower in ruminant than in non-ruminant tissue. This low concentration leads to a PUFA:SFA ratio below the recommended value of 0.45 (Warris, 2000). Previous reports found PUFA:SFA values from bovine or lamb meats between 0.11 and 0.15, which are lower than the recommended values (Geay *et al.*, 2001). The PUFA:SFA ratios of all the breed combinations in this investigation were also very low and below the recommended value of 0.45. The DxM group had the lowest ratio of 0.10 and the SxDM group had the highest ratio of 0.15.

The plasma cholesterol concentration in humans is influenced by the fatty acid composition of dietary fat. High dietary levels of long-chain SFA increase plasma cholesterol compared to high levels of PUFA and MUFA; however, not all SFA have the same effect (Grundy & Denke, 1990). As mentioned earlier, C18:1n9, C16:0 and C18:0 represent the majority of the

fatty acids measured in the *M. semimembranosus* of all the meat samples analysed in this investigation. It is well known that C16:0 increases blood cholesterol content, whereas C18:0 has a neutral effect and C18:1*n*9 decreases blood cholesterol content. Therefore, the ratio of (C18:0+C18:1):C16:0 indicates the possible health effects of the lipids (Grundy, 1997; Banskalievaa *et al.,* 2000). DFA, according to the health classification of Rhee (1992), is the sum of all unsaturated fatty acids and C18:0. The DFA and (C18:0+C18:1):C16:0 ratio differed significantly between breeds with the DxDM group having the highest value (and thus more desirable) for DFA (±71%) and (C18:0+C18:1):C16:0 (±3%) respectively.

Table 9

Means of fatty acid composition of *M. semimembranosus* as influenced by different lamb breed combinations (% by weight of total fatty acids)

Fatty Acid	Breed combinations						LSD[d]
	DxM	DxDM	DxSAMM	SxM	SxDM	SxSAMM	
C14:0	4.603	2.782	3.325	2.482	3.720	4.125	NS[e]
C16:0	30.88^{ab}	25.69^{b}	27.13^{ab}	30.98^{a}	25.91^{ab}	27.30^{ab}	5.270
C18:0	25.29	21.49	24.91	24.27	26.05	25.13	NS
C20:0	0.485	0.278	0.418	0.290	0.503	0.500	NS
C22:0	0.110^{ab}	0.033^{b}	0.073^{ab}	0.118^{ab}	0.228^{a}	0.120^{ab}	0.156
C24:0	0.095^{ab}	0.000	0.063^{ab}	0.133^{a}	0.173^{a}	0.125^{ab}	0.129
C16:1*n*7	1.083	1.410	1.148	1.103	0.998	0.900	NS
C18:1*n*9	31.29^{b}	42.27^{a}	35.16^{b}	34.32^{b}	33.79^{b}	35.08^{b}	6.993
C20:1*n*9	0.170^{a}	0.140^{ab}	0.128^{ab}	0.098^{b}	0.150^{ab}	0.150^{ab}	0.065
C24:1*n*9	0.058^{ab}	0.015^{b}	0.023^{b}	0.027^{b}	0.090^{ab}	0.138^{a}	0.081
C18:2*n*6	2.915	3.130	3.725	2.938	3.773	2.920	NS
C18:3*n*6	0.045	0.070	0.020	0.018	0.085	0.030	NS
C18:3*n*3	1.333	1.140	1.535	1.270	1.625	1.328	NS
C20:2*n*6	0.083^{ab}	0.023^{c}	0.058^{bc}	0.020^{c}	0.120^{a}	0.063^{bc}	0.053
C20:3*n*6	0.055	0.083	0.108	0.115	0.098	0.103	NS
C20:4*n*6	0.363	0.523	0.723	0.500	0.538	0.475	NS
C20:3*n*3	0.088^{ab}	0.028^{b}	0.045^{ab}	0.043^{ab}	0.145^{a}	0.078^{ab}	0.114
C20:5*n*3	0.195	0.190	0.378	0.195	0.285	0.268	NS
C22:2*n*6	0.413	0.155	0.170	0.010	0.333	0.375	NS
C22:4*n*6	0.023	0.085	0.030	0.175	0.145	0.105	NS
C22:5*n*3	0.360^{ab}	0.368^{ab}	0.580^{a}	0.268^{b}	0.450^{ab}	0.508^{ab}	0.282
C22:6*n*3	0.078^{ab}	0.100^{ab}	0.130^{ab}	0.195^{a}	0.127^{ab}	0.073^{b}	0.120
SFA[f]	61.46^{a}	50.27^{b}	55.92^{ab}	58.27^{ab}	56.61^{ab}	57.30^{ab}	8.247
MUFA[g]	32.60^{b}	43.83^{a}	36.46^{b}	35.67^{b}	35.02^{b}	36.26^{b}	7.101
PUFA[h]	5.950	5.900	7.628	6.065	8.370	6.438	NS
PUFA:SFA[i]	0.097	0.117	0.136	0.104	0.148	0.112	NS
DFA[j]	63.83^{b}	71.22^{a}	69.00^{ab}	66.00^{ab}	69.44^{ab}	68.83^{b}	6.61
(C18:0+C18:1):C16:0	1.843^{b}	2.530^{a}	2.225^{ab}	1.895^{b}	2.345^{ab}	2.318^{ab}	0.058

[a,b,c] Means in the same row with different superscripts differ significantly ($p \leq 0.05$)

[d] Least significant difference ($p=0.05$)

[e] NS=Not significant ($p>0.05$)

[f] SFA=Saturated fatty acids

[g] MUFA=Mono-unsaturated fatty acids

[h] PUFA=Polyunsaturated fatty acids

[i] PUFA:SFA=Ratio of polyunsaturated to saturated fatty acids

[j] DFA=Desirable fatty acids

CONCLUSION

The aim of this investigation was to determine whether breed, when used in a terminal crossbreeding system, has a significant effect on lamb quality. This investigation confirms that breed does not have a significant effect on the sensory quality of lamb, except for DxSAMM lambs having significantly higher initial juiciness compared to that of the other breed combinations. However, breed had a significant effect on pH_{48} and shear force values. Furthermore, the meat from the different breed combinations differed significantly in protein content, with the DxSAMM having the highest protein content. Results obtained in this investigation also indicate significant differences between breeds with regard to fatty acid and mineral composition.

This investigation provides an important scientific insight into the effect of breed on general lamb quality. The results obtained show that the present practice of breeding wool-type ewes to mutton ram breeds will not have a negative effect pertaining to meat quality. Panelists could not distinguish between breed combinations and the meat was of excellent quality. Therefore this study justifies and indicates great scope for further research into breed as well as possible interactions between breed and other factors such as chronological age, slaughter weight and gender and their effects on lamb quality. This will provide valuable information for the meat industry.

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CHAPTER 4

SENSORY, PHYSICAL AND CHEMICAL MUTTON QUALITY CHARACTERISTICS OF SOUTH AFRICAN MERINO SELECTED FOR AND AGAINST REPRODUCTIVE FITNESS

ABSTRACT

The effect of divergent selection for ewe multiple-rearing ability over a 15-year period on mutton quality was examined on the *M. longissimus dorsi* and *M. semimembranosus* of entire ram (R) and ewe (E) sheep derived from two Merino lines. The selection of these two lines was based on maternal ranking values for multiple-rearing ability in a positive (P) and negative (N) line. In the negative line the replacements were based on the progeny of ewes that rear less than one lamb per joining or lambing opportunity (i.e. failed to lamb or lost all progeny born at least once). Progeny of ewes that reared more than one lamb per joining (i.e. reared twins at least once) were selected for the positive line. Ratings of sensory quality characteristics on the *M. semimembranosus* of the different line genotypes were obtained from a trained taste panel and related to data on physical and chemical characteristics. The moisture, total lipids, protein, ash, mineral content and fatty acid composition of the *M. semimembranosus* were obtained. Physical parameters measured on the *M. longissimus dorsi* were: ultimate pH (pH_{48}), drip loss, cooking loss and Warner-Bratzler shear force (WBS). The influence of selection line on sensory meat quality was in most instances negligible, with the exception of the sensory attribute of first bite ($p \leq 0.05$), where meat derived from the positive line was rated to be less tender than that of the negative line contemporaries. Chemically, the meat derived from the four different groups differed significantly ($p \leq 0.05$) in moisture and lipid content. The positive ram group had the highest moisture (±76%) and the lowest lipid (±7%) content, whereas the negative ewe group the lowest moisture (±70%) and the highest lipid (±10%) content. No significant differences ($p > 0.05$) were detected in the proximate chemical composition between the positive and negative lines. The pH_{48} and shear force (WBS) values, showed significant differences ($p \leq 0.05$) between the four groups. The NR group had the highest pH_{48} and the lowest WBS value. Results indicated a line effect on WBS tenderness. Meat derived from the positive line was less tender compared to the meat from the negative line. Results indicated differences between the reproductive lines pertaining to the mineral composition and the percentage content of individual fatty acids. A general tendency was noted for the positive ewes to have the highest and the negative ewes to

have the lowest mineral content. Significant differences ($p \leq 0.05$) were detected between the four groups for reproductive fitness in the individual fatty acids arachidic acid (C20:0), lignoceric acid (C24:0), eicosenoic acid (C20:1*n*9), linoleic acid (C18:2*n*6), homo-γ-linolenic acid (C20:3*n*6), arachidonic acid (C20:4*n*6), eicosapentaenoic acid (C20:5*n*3), docosadienoic acid (C22:2*n*6), docosapentaenoic acid (C22:5*n*3) and docosahexaenoic acid (C22:6*n*3) contents. The PR group had the highest total PUFA (polyunsaturated fatty acids) content (±8%) and the NR the lowest PUFA content (±6%). The positive group had significantly higher ($p \leq 0.05$) C18:2*n*6, C20:3*n*6, C20:4*n*6, C20:5*n*3, C22:5*n*3 and C22:6*n*3 contents in comparison with the negative line. Significant difference ($p \leq 0.05$) in the total PUFA composition was also detected between lines, with the positive line showing a higher content (±7%) compared to the negative line (±6%).

INTRODUCTION

South African sheep farmers are faced with stagnant product prices and ever-increasing input costs. Local farmers need to run their enterprises in the most effective manner in order to survive economically. Given the increasing economic pressures on sheep farmers, it is evident that reproduction should receive the necessary attention. Lamb mortality is regarded as a major constraint on efficient sheep production (Alexander, 1988). It is one of the components of net production rate which is of great importance in small stock farming (Olivier, 1999). The efficiency of reproduction affects all users of animal products such as wool and meat because consumer prices start with production costs (Laas, 1995). The profitability of sheep production in South Africa is largely influenced by net reproduction rate, defined as total weight of lamb weaned per ewe joined (Olivier, 1999).

Against this background Cloete (1999) undertook an investigation on the divergent selection of South African Merino sheep for multiple-rearing ability. The experiment demonstrated that selection of sheep for multiple-rearing ability was a viable method for improving lamb production without serious negative correlated responses on qualitative and quantitative production traits in progeny (Cloete & Olivier, 1998). When retained for breeding purposes, the lower producing negative line had a higher average live weight as well as a higher average wool weight when joined at 5.5 years of age than the positive line contemporaries. Stress placed on the positive line ewes by pregnancy and lactation possibly played a role in this regard (Cloete, 1999). However, despite the apparent importance of reproductivity on aspects

such as live weight and fleece weight, little is known about the consequences of reproductive fitness on the quality of mutton in progeny.

The pre-eminent question in this investigation is to what extent does reproduction fitness influence mutton quality. This investigation reports on the differences in sensory attributes, proximate chemical composition, fatty acid and mineral composition between the two lines of South African Merino sheep. Muscle pH, cooking loss and drip loss and WBS were also determined.

MATERIALS AND METHODS

Animals and sampling

Since 1986 two lines of South African Merino sheep have been divergently selected for and against multiple-rearing ability from the same base population at the Tygerhoek Experimental Farm. Selection of ewe and ram replacements were based on maternal ranking values for multiple-rearing ability in a positive (P) and negative (N) line (Cloete & Durand, 1994; Cloete & Scholtz, 1998). In the negative line progeny of ewes that rear less than one lamb per joining or lambing opportunity (i.e. failed to lamb or lost all progeny born at least once) were prefered as replacements. Progeny of ewes that reared more than one lamb per joining (i.e. reared twins at least once) were preferably selected as replacements in the positive line. At the end of 1992 both lines were transferred to Elsenburg experimental farm for detailed data collection on lamb mortality, lambing and neonatal behaviour, lamb production, weight and wool traits (Cloete & Scholtz, 1998).

In this investigation ten mature animals (equal sex ratio) from the positive and ten from the negative reproduction lines (of the 5^{th} generation) were randomly selected to test for the effect of reproductivity and sex on the physico-chemical and sensory palatablility traits of the mutton.

The animals from both lines originated from similar environments, although the rams and ewes were kept apart to avoid casual mating. The animals grazed on adjacent fields that were rotated regularly. The sheep were grown to commercial slaughter weight and slaughtered using standard South African techniques and conditions. The mean carcass weights for the positive line were 44.7 kg (n=10) and for the negative line 42.0 kg (n=10). No electrical

stimulation was applied. During the first 48 h post-mortem, the carcasses were chilled at a temperature of 5°C. Ultimate pH was measured 48 h post-mortem (pH_{48}) with a penetrating glass electrode on a hand-held Crison pH/mV-506 meter. The pH meter was re-calibrated after every fourth reading and the electrode rinsed with distilled water between each measurement. The pH meter contained a temperature probe ensuring automatic adjustment of the pH for temperature. The measurement was taken between the 2nd and 3rd last thoracic vertebrae, 45 mm from the midline. The *M. longissimus dorsi* was removed from the carcass to assess drip loss, cooking loss, shear force and pH_{48}. The legs were removed from the carcasses at a position between the last lumbar and the first sacral vertebrae. The legs were labelled, vacuum packed, frozen and stored at -18°C until further use. After thawing, the *M. semimembranosus* from both the legs were dissected and used for sensory, proximate, mineral and fatty acid analyses.

Sensory analyses

Sample preparation: The right legs were defrosted at a temperature of 3 - 4°C for a period of 48 h for the purpose of deboning and the removal of the *M. semimembranosus*. The legs were placed on a flat surface with the lateral side facing upwards. An incision was made on the septa, followed by an incision of the knife at the top end and cutting as close as possible to the pelvic bone. The natural division between muscles then became visible and the *M. semimembranosus* could then be separated from the other muscles by cutting between the muscles. The *M. semimembranosus* cuts were coded, vacuum packed, frozen and stored at -18°C until further analysis.

***Cooking procedures*:** *M. semimembranosus* samples were oven-roasted prior to subsequent sensory analysis. The meat cuts were defrosted for 48 h at a temperature of 3 - 4°C, wrapped individually in cooking bags and placed fat-side up, on the rack of an open roasting pan. The samples were roasted at 160°C in two conventional electric Defy 835 ovens connected to a computerised electronic temperature control system (Viljoen, Muller, De Swardt, Sadie & Vosloo, 2001). A thermocouple was inserted in the centre of each sample and the meat was roasted to an internal temperature of 70°C (AMSA, 1978).

Presentation and scoring of samples: Immediately after cooking all visible subcutaneous fat was removed from each sample. Six 1.5 cm x 1.5 cm cubed samples were taken from the

middle of each sample and wrapped immediately in aluminium foil marked with random three digit codes. The samples were placed in preheated glass ramekins in a preheated oven of 100°C and evaluated within 10 min (Personal communication, I. Van Heerden, 2001).

Table 1

Definition of attributes for sensory analyses of mutton

Attribute	Definition
Lamb aroma 1=Extremely bland; 8=Extremely intense	Aroma associated with the animal species
Initial juiciness 1= Extremely dry; 8= Extremely juicy	The amount of fluid exuded on the cut surface when pressed between fingers
Sustained juiciness 1=Extremely dry; 8=Extremely juicy	Degree/amount of water perceived during mastication
First bite 1=Extremely tough; 8=Extremely tender	Force needed to compress the sample of meat between molar teeth on the first bite
Residue 1=Abundant; 8=None	The connective tissue remaining after most of the sample has been masticate
Lamb flavour 1=Extremely typical; 8=Extremely untypical	Flavour associated with the animal species

Proximate chemical analyses

Proximate chemical analyses were carried out on the raw *M. semimembranosus* from the left leg. Total percentages of moisture, protein and ash were determined according to AOAC Methods (AOAC, 1997). The protein content was determined by the block digestion method and ashing was done at 500°C for 5 h. The moisture content was determined by drying at 100°C for 24 h. The lipid content was determined by means of chloroform:methanol extraction (Lee, Trevino & Chaiyawat, 1996).

Instrumental analyses

For the drip loss determination, 1.5 x 1.5 cm meat samples from the *M. longissimus dorsi* were weighed immediately after being removed from the carcass. The samples were placed in netting and suspended in an inflated plastic bag. After a storage period of 24 h at 4°C, samples were weighed again and the drip loss was calculated as weight loss expressed as a percentage of the original weight of the sample (Honikel, 1998).

For the cooking loss determination, the freshly cut *M. longissimus dorsi* samples were weighed and placed in thin-walled plastic bags in a water-bath at 75°C. After one hour the samples were removed from the water-bath, cooled in cold water, blotted dry and weighed. Cooking loss was calculated as the difference in sample weight before and after cooking, expressed as a percentage of the initial sample weight (Honikel, 1998).

The WBS measurements of the cooked *M. longissimus dorsi* samples were obtained with a Warner-Bratzler shear (WBS) attachment (Voisey, 1976), fitted to an Instron Universal Testing Machine (Model 4444). Three cylindrical cores were cut from each muscle using a 12.7 mm diameter bore. Samples were randomly removed from the centre of each *M. longissimus dorsi* muscle. Maximum WBS values (N) required to shear a cylindrical core of cooked muscle perpendicular to the grain (at a crosshead speed of 200.0 mm/min) were recorded for each sample and the mean was calculated for each muscle. An increasing value indicated greater WBS and therefore tougher meat.

Mineral analyses

A wet ashing method was used to prepare the meat samples for mineral analysis. The elements calcium (Ca), iron (Fe), selenium (Se), potassium (K), magnesium (Mg), sodium (Na), phosphorus (P), zinc (Zn), copper (Cu), and lead (Pb) of the digestates were determined by direct current plasma emission spectrometry (Pinta, 1982).

Fatty acid analyses

After the extraction of the lipids, the fatty acid methyl esters (FAME) were prepared according to procedures published by Morrison and Smith (1964). The FAME were analysed with a gas-liquid chromatograph (Varian Model 3300), equipped with flame ionisation detection and two 30 m fused silica megabore DB-225 columns of 0.53 mm internal diameter (J&W Scientific, Folsom, CA). Gas flow rates were hydrogen 25 ml/min and nitrogen (carrier gas) 5-8 ml/min. The temperature programme was linear at 4°C/min with initial and final temperatures of 160°C and 220°C (held for 10 min), respectively. The injector temperature was 240°C and the detector temperature 250°C. The FAME was identified by comparison of the retention times to those of a standard FAME mixture (Nu-Chek-Prep Inc., Elysian, Minnesota).

Statistical analyses

The experiment consisted of a completely randomised design (2x2 factorial) with two reproduction lines (P and N) and two sexes (S and D) as the factors. Data were also pooled to test for the main effects of reproduction line and sex. An experimental unit was a carcass from which samples were taken for measurements.

Prior to analysis of variance the sensory scores were transformed to ranks. A factorial analysis of variance was performed on all data using SAS version 8.12 (SAS, 1990). The Shapiro-Wilk test was performed to test for non-normality (Shapiro & Wilk, 1965). In some cases deviations from normality were the cause of one or two outliners, which were excluded before the final analysis. In cases where there was still significant evidence of non-normality, this could be ascribed to kurtosis rather than skewness. Interpretation of the results was thus continued (Glass, Peckham & Sanders, 1972). Student's t-Least Significant Differences (LSD) was calculated at the 5% significance level to compare treatment means.

RESULTS AND DISCUSSION

Sensory quality characteristics

Rank means for sensory quality characteristics of the *M. semimembranosus* are presented in Table 2. The means are also provided below the rank means (in brackets) for the interpretation of the results using the rating scale. All sensory quality characteristics, except first bite, were similar ($p>0.05$) for all the groups. The first bite of the meat from the four groups differed significantly ($p\leq0.05$), with the PE group having the highest (3.02) and the NR group having the lowest (2.19) rank means. The latter represents the tougher product. The results of this experiment further indicate that, although not significant ($p>0.05$), the sensory panel also rated the PE group higher in initial juiciness, sustained juiciness and flavour, and slightly higher in the perceived amount of residue compared to the other groups.

Table 2

Rank means (Means) for the sensory quality characteristics of *M. semimembranosus* as influenced by the main effects of line and sex

Line	Positive		Negative		
Sex	Ewe	Ram	Ewe	Ram	LSD[c]
Aroma[d]	2.917	2.479	2.479	2.125	NS
	(6.125)	(5.833)	(5.792)	(5.583)	
Initial juiciness[e]	2.896	2.521	2.271	2.313	NS
	(6.292)	(5.875)	(5.917)	(6.083)	
Sustained juiciness[f]	2.979	2.375	2.354	2.292	NS
	(6.375)	(5.958)	(6.000)	(5.958)	
First Bite[g]	3.021[a]	2.333[ab]	2.458[ab]	2.188[b]	0.826
	(6.375)	(5.875)	(6.042)	(5.917)	
Residue[h]	2.313	2.604	2.625	2.458	NS
	(5.625)	(5.750)	(5.792)	(5.750)	
Flavour[i]	2.792	2.625	2.438	2.146	NS
	(6.292)	(6.208)	(6.042)	(5.917)	

[a,b] Rank means in the same row with different superscripts are significantly different ($p \leq 0.05$)

[c]LSD=Least significant difference ($p=0.05$); NS=Not significant ($p>0.05$)

[d]Aroma: 1=extremely bland; 8=extremely intense

[e]Initial juiciness: 1= extremely dry; 8= extremely juicy

[f]Sustained juiciness: 1=extremely dry; 8=extremely juicy

[g]First bite: 1=extremely tough; 8=extremely tender

[h]Residue: 1=abundant; 8=none

[i]Flavour: 1=extremely unflavourable; 8=extremely flavourable

When the data were pooled for main effects of line and sex, significant differences ($p \leq 0.05$) were observed in flavour intensity (Table 3). Meat from the positive line was rated more flavoursome (2.71) than the negative line (2.29). The higher flavour intensity of the positive reproduction line could be the result of differences in slaughter weight. The animals in the positive reproduction line were found to be slightly heavier than the negative line contemporaries at the age of 18 months (Cloete & Olivier, 1998). Crouse, Ferrel and Cross (1983) also observed an increase in mutton flavour as slaughter weight increased and Kemp, Johnson, Steward, Ely and Fox (1976) reported that as weight increased, from 36 to 54 kg, the flavour of both ewes and wethers became more desirable. In absolute terms rank means for the positive line tended to be higher in aroma, initial juiciness and sustained juiciness than in the negative line. The positive line also had a higher amount of residue, as detected by the

sensory panel, compared to that of the negative line. No significant ($p>0.05$) differences were, however, found (Table 3).

When pooled for ram and ewe effects (Table 3), significant differences ($p\leq0.05$) were found in first bite with the ewe group having the highest score (2.74) and the ram group having the lowest taste panel score (2.26). Therefore, meat derived from ewes was more tender than meat from rams. However, Ellis, Webster, Merrel and Brown (1997) found no palatability differences between sexes in meat quality. Results of the present investigation agree with findings by Jeremiah, Tong and Gibson (1998), who in a study comparing cooking properties and palatability attributes between 1660 lambs varying in chronicle age, slaughter weight and gender, found that meat derived from ewe lambs was more tender than roasts from rams.

Table 3

Rank means (Means) for the sensory quality characteristics of *M.semimembranosus* as influenced by main effects of line and sex

	Line			Sex		
	Positive	Negative	LSD[c]	Ram	Ewe	LSD
Aroma[d]	2.698	2.302	NS	2.302	2.698	NS
	(5.979)	(5.688)		(5.708)	(5.958)	
Initial juiciness[e]	2.604	2.396	NS	2.417	2.583	NS
	(6.083)	(6.000)		(5.979)	(6.104)	
Sustained juiciness[f]	2.677	2.323	NS	2.333	2.667	NS
	(6.167)	(5.979)		(5.958)	(6.188)	
First Bite[g]	2.677	2.323	NS	2.260[b]	2.740[a]	0.442
	(6.125)	(5.979)		(5.896)	(6.208)	
Residue[h]	2.458	2.542	NS	2.531	2.469	NS
	(5.688)	(5.771)		(5.750)	(5.708)	
Flavour[i]	2.708[a]	2.292[b]	0.398	2.385	2.615	NS
	(6.250)	(5.979)		(6.063)	(6.167)	

[a,b] Rank means in the same row with different superscripts are significantly different ($p \leq 0.05$)

[c]LSD=Least significant difference ($p=0.05$), NS=Not significant ($p>0.05$)

[d]Aroma: 1=extremely bland; 8=extremely intense

[e]Initial juiciness: 1= extremely dry; 8= extremely juicy

[f]Sustained juiciness: 1=extremely dry; 8=extremely juicy

[g]First bite: 1=extremely tough; 8=extremely tender

[h]Residue: 1=abundant; 8=none

[i]Flavour: 1=extremely unflavourable; 8=extremely flavourable

Proximate chemical composition

The moisture, protein, fat and ash content of the *M. semimembranosus* samples are presented in Table 4. The meat from the four distinct groups differed significantly ($p \leq 0.05$) in moisture and lipid content. The content of moisture was highest in the PR group (±76%) and lowest in the NE group (±70%). The PR group also had the lowest lipid content (±7%) and the NE group the highest (±10%). No significant differences between the four groups were detected regarding the ash or protein content.

Table 4

Means for the proximate chemical analysis of *M. semimembranosus* as influenced by the interaction between the main effects of line and sex (g/100 g meat sample)

Line	Positive		Negative		
Sex	Ewe	Ram	Ewe	Ram	LSD[d]
Moisture	71.67[bc]	75.94[a]	70.04[c]	73.91[ab]	3.16
Protein	16.29	17.12	16.68	16.12	NS[e]
Lipid	9.29[ab]	6.66[b]	9.82[a]	6.69[b]	2.94
Ash	1.08	1.02	1.04	1.09	NS

[a,b,c] Means in the same row with different superscripts are significantly different ($p \leq 0.05$)

[d] LSD=Least significant difference ($p=0.05$)

[e] NS=Not significant ($p>0.05$)

When pooled for sex (Table 5), the ewes had a significant lower moisture (±71%) and higher lipid content (±10%) than the rams ($p \leq 0.05$). In a study by Ellis *et al.* (1997) carcasses from female lambs, compared to males, showed thicker subcutaneous and greater intermuscular fat content. Observed trends by Jeremiah, Jones, Tong, Robertson and Gibson (1997) further substantiate the fact that rams produce leaner carcasses than ewes. Tendencies in flavour intensity differences between ewes and rams suggested an association between the higher lipid content of the mutton derived from ewes and the flavour, aroma, initial juiciness and sustained juiciness ratings of their meat. The quantity of fat and its quality affect the nutritive value, appearance, processability, shelf life and palatibility of meat. Therefore, fat is an important determinant of meat quality and the degree of saturation of the fat contributes substantially to the sensory properties of meat (Webb, Bosman & Casey, 1994; Rhee, 1992).

The pooled P and N groups did not differ ($p>0.05$) in moisture, protein, lipid or ash contents (Table 5). This could possibly be due to the large co-efficient of variation shown by the means.

Table 5

Means for the proximate chemical analysis of *M. semimembranosus* as influenced by main effects of line and sex (g/100 g meat sample)

	Line			Sex		
	Positive	Negative	LSD[c]	Ram	Ewe	LSD
Moisture	74.04	72.46	NS[d]	74.93[a]	70.97[b]	2.223
Protein	16.75	16.32	NS	16.62	16.46	NS
Lipid	7.83	7.86	NS	6.67[b]	9.52[a]	2.07
Ash	1.04	1.07	NS	1.06	1.06	NS

[a,b] Means in the same row with different superscripts are significantly different ($p \leq 0.05$)

[c] Least significant difference ($p=0.05$)

[d] NS=Not significant ($p>0.05$)

Objective quality characteristics

Physical measured traits, pH_{48}, cooking loss, drip loss and WBS resistance of the *M. longissimus dorsi,* are presented in Table 6. The pH_{48} and WBS values showed significant differences ($p \leq 0.05$) between the four groups. The NR group had the highest pH_{48} and the lowest WBS value. The significant difference in WBS values were however not reflected by findings of the taste panel for the attribute of first bite (Table 2). When pooled together for ram and ewe groups (Table 7), there were significant differences ($p \leq 0.05$) in pH_{48}, WBS values and cooking loss. Rams had higher ultimate pH and cooking loss values and a lower WBS value than ewes ($p<0.05$). There was a tendency for the higher pH values to result in lower WBS values, with the pooled ram group having the highest pH value and the lowest WBS value. Results in Table 7 also indicate a line effect on meat tenderness. The positive line group had significantly higher ($p \leq 0.05$) WBS values, indicating that meat derived from the positive line is less tender compared to the meat from the negative line.

Conflicting reports regarding the relationship between pH and tenderness (WBS and sensory tenderness) are found in the literature. Young, Reid and Scales (1993) showed a curviliniear relationship between pH and WBS values, while Safari, Forgarty, Ferrier, Hopkins and Gilmour (2001) found no relationship between pH and WBS or tenderness in four lamb genotypes. Results represented in Table 6 agree with the results by Devine, Graafhuis, Muir, and Chrystall (1993), who reported a decrease in WBS with higher pH values within the range of 5.4-6.0.

Table 6

Means of pH_{48}, drip loss, cooking loss and shear force resistance of lamb *M. longissimus dorsi* as influenced by the main interaction between the effects of line and sex

Line	Positive		Negative		
Sex	**Ewe**	**Ram**	**Ewe**	**Ram**	**LSD[d]**
pH_{48}	5.624[b]	5.716[b]	5.588[b]	5.874[a]	0.129
Drip loss (%)	1.480	1.075	1.375	1.292	NS[e]
Cooking loss (%)	29.92	25.74	25.63	31.53	NS
WBS[f] (N)	168.05[a]	106.58[bc]	129.54[b]	95.34[c]	26.39

[a,b,c] Means in the same row with different superscripts are significantly different (p≤0.05)

[d] Least significant difference (p=0.05)

[e]NS=Not significant (p>0.05)

[f] WBS = Warner-Bratzler shear force value

Table 7

Means of pH_{48}, drip loss, cooking loss and shear force resistance of lamb *M. longissimus dorsi* as influenced by line and sex

	Line			Sex		
	Positive	**Negative**	**LSD[c]**	**Ram**	**Ewe**	**LSD**
pH_{48}	5.670	5.731	NS[d]	5.795[a]	5.606[b]	0.091
Drip loss (%)	1.278	1.334	NS	1.184	1.428	NS
Cooking loss (%)	27.83	27.47	NS	30.72	27.77	NS
WBS [e](N)	137.3[a]	112.4[b]	18.66	101.0[b]	148.8[a]	18.66

[a,b] Means in the same row with different superscripts are significantly different (p≤0.05)

[c] Least significant difference (p=0.05)

[d]NS=Not significant (p>0.05)

[e] WBS=Warner Bratzler shear force value

Mineral composition

Results from this study indicated significant differences (p≤0.05) between the four groups involved in the line x sex interaction regarding the Ca, Fe, K, Mg, P and Zn contents (Table 8). The major contributors to the mineral content of the mutton were K (±122 mg/100g meat sample) and P (± 110 mg/100g meat sample). There was a general tendency for the PE group to have the highest mineral content measured, except for Zn and Cu, whereas the NE group had the lowest content in all the minerals with the exception of Se.

Table 8

Means for mineral composition of *M. semimembranosus* as influenced by the interactions between the main effects of line and sex (mg/100 g meat sample)

Line	Positive		Negative		
Sex	Ewe	Ram	Ewe	Ram	LSD[c]
Ca	6.498[a]	5.792[a]	3.347[b]	4.622[ab]	2.420
Fe	1.828[a]	1.747[a]	1.108[b]	1.335[ab]	0.575
Se	0.087	0.054	0.067	0.054	NS
K	134.5[a]	128.1[ab]	99.63[b]	126.9[ab]	28.73
Mg	19.15[a]	18.13[ab]	14.93[b]	16.57[ab]	3.998
Na	17.56	17.76	13.36	17.29	NS
P	124.1[a]	117.1[a]	92.02[b]	107.7[ab]	24.49
Zn	2.717[a]	2.966[a]	2.077[b]	2.403[ab]	0.583
Cu	0.003	0.012	tr[e]	0.028	NS
Pb	0.007	0.001	tr	0.003	NS

[a,b] Means in the same row with different superscripts are significantly different ($p \leq 0.05$)

[c] Least significant difference ($p=0.05$)

[d] NS=Not significant ($p>0.05$)

[e] tr=trace= <0.001mg/100g meat sample

Table 9

Means for mineral composition of *M. semimembranosus* as influenced by the main effects of line and sex (mg/100 g meat sample)

	Line			Sex		
	Positive	Negative	LSD[d]	Ram	Ewe	LSD[c]
Ca	6.106[a]	4.144[b]	1.678	5.207	5.148	NS[d]
Fe	1.783[a]	1.250[b]	0.399	1.541	1.519	NS
Se	0.069	0.058	NS	0.054	0.078	NS
K	130.9	116.7	NS	127.5	119.5	NS
Mg	18.58	15.95	NS	17.35	17.34	NS
Na	17.67	15.82	NS	17.53	15.76	NS
P	120.2[a]	101.8[b]	16.97	112.4	110.3	NS
Zn	2.855[a]	2.281[b]	0.404	2.685	2.443	NS
Cu	0.007	0.017	NS	0.021	0.001	NS
Pb	0.004	tr[e]	NS	0.002	0.002	NS

[a,b] Means in the same row with different superscripts are significantly different ($p \leq 0.05$)

[c] Least significant difference ($p=0.05$)

[d] NS=Not significant ($p>0.05$)

[e] tr=trace= <0.001mg/100g meat sample

When pooled together across sexes for positive and negative reproduction groups (Table 9), positive line animals had higher concentrations of Ca, Fe, P and Zn than their negative line contemporaries. Rams and ewes did not differ with regard to mineral concentrations.

Marked variation in the mineral composition of meat, due to the effects of age, feeding regimen, breed, season and geographical differences have been noted. The mineral content of retail cuts within any single carcass also varies significantly (Lin *et al.,* 1989; Ono *et al.* 1984). The latter is caused by variation in muscle fibre type and physical activity between muscles (Kotula and Lusby, 1982). The sheep in the present study were selected from a single geographical location, feeding regimen and the same age group. It is well known that meat is an excellent food source of Fe and Zn, especially considering the higher bioavalability of these two minerals compared to that from plants (Lin *et al.*, 1989). Approximately 40% of the Fe in meat is heme iron and this form of Fe is more available to man than non-heme iron (Simonsen, Hamm & Rogowski, 1988). Meat therefore contributes significantly to the minerals required by the human diet. The concentration of Fe, Zn and Cu in meat is higher than that provided by the other food sources in the rest of the diet as whole (Williams, 1987). The results from this investigation indicated significant statistical differences in the mineral

composition between lines. The meat from the positive line could contribute higher concentrations of minerals to the human diet than the negative line could.

Fatty acid composition

The fatty acid composition of the *M. semimembranosus* from the four sheep groups are given in Table 10. Oleic acid (C18:1*n*9) occurred at the highest proportion of all groups contributing to approximately 39% of the total fatty acids, followed by palmitic acid (C16:0) (±27%) and stearic acid (C18:0) ±23%. These results agree with those of Webb, Bosman & Casey (1997), who found that C16:0, C18:0 and C18:1*n*9 contibuted the highest proportions of fatty acids in meat derived from South African Mutton Merino wethers.

According to Table 10, no significant differences were detected between the four groups with regard to the major saturated fatty acids (SFA), i.e C16:0 and C18:0, but there were significant differences ($p \leq 0.05$) between the groups regarding arachidic acid (C20:0) and lignoceric acid (C24:0). Total SFA did not differ significantly between the four groups. Eicosenoic acid (C20:1*n*9) was the only mono-unsaturated fatty acid (MUFA) that differed significantly ($p \leq 0.05$) between the four groups. Total MUFA did not differ significantly ($p > 0.05$) between groups.

As far as the poly-unsaturated fatty acids (PUFA) are concerned, significant differences ($p \leq 0.05$) were detected between the groups in linoleic acid (C18:2*n*6), homo-γ-linolenic acid (C20:3*n*6), arachidonic acid (C20:4*n*6), eicosapentaenoic acid (C20:5*n*3), docosadienoic acid (C22:2*n*6), docosapentaenoic acid (C22:5*n*3) and docosahexaenoic acid (C22:6*n*3) contents. These differences in individual PUFA resulted in a significant difference ($p \leq 0.05$) in total PUFA between the four groups. The PR group had the highest total PUFA concentration (±8%) and the NR the lowest (±6%).

Table 10

Means of the fatty acid content of *M. semimembranosus* as influenced by the interaction between the main effects of line and sex (% by weight of total fatty acids)

Line	Positive		Negative		
Sex	Ewe	Ram	Ewe	Ram	LSD[d]
C14:0	2.988	2.342	2.383	2.412	NS[e]
C16:0	26.33	27.65	27.02	27.65	NS
C18:0	23.27	21.63	24.28	22.84	NS
C20:0	0.317[a]	0.202[b]	0.263[ab]	0.303[a]	0.068
C22:0	0.063	0.044	0.047	0.056	NS
C24:0	0.038[ab]	0.050[a]	0.040[ab]	0.026[b]	0.021
C16:1*n*7	1.423	1.590	1.197	1.542	NS
C18:1*n*9	38.56	38.52	38.22	39.18	NS
C20:1*n*9	0.200[a]	0.106[b]	0.247[a]	0.098[b]	0.065
C24:1*n*9	0.023	0.020	0.017	0.016	NS
C18:2*n*6	3.735[ab]	4.356[a]	3.570[ab]	3.406[b]	0.817
C18:3*n*6	0.093	0.053	0.070	0.074	NS
C18:3*n*3	1.310	1.260	1.277	1.140	NS
C20:2*n*6	0.055	0.022	0.033	0.040	NS
C20:3*n*6	0.098[b]	0.138[a]	0.087[b]	0.076[b]	0.030
C20:4*n*6	0.605[ab]	0.848[a]	0.470[b]	0.472[b]	0.266
C20:3*n*3	0.025	0.010	0.013	0.014	NS
C20:5*n*3	0.298[ab]	0.450[a]	0.220[b]	0.270[b]	0.176
C22:2*n*6	0.080[ab]	0.074[b]	0.220[a]	0.036[b]	0.141
C22:4*n*6	0.028	0.038	0.025	0.026	NS
C22:5*n*3	0.398[ab]	0.500[a]	0.210[c]	0.284[bc]	0.167
C22:6*n*3	0.120[a]	0.118[a]	0.060[b]	0.072[b]	0.046
SFA[f]	52.97	51.89	54.04	53.25	NS
MUFA[g]	40.21	40.23	39.69	40.83	NS
PUFA[h]	6.835[ab]	7.924[a]	6.293[ab]	5.914[b]	1.699
PUFA:SFA[i]	0.130[ab]	0.154[a]	0.120[ab]	0.112[b]	0.036
DFA[j]	70.31	69.78	70.27	69.59	NS
(C18:0+C18:1):C16:0	2.370	2.202	2.313	2.266	NS

[a,b,c]Means in the same row with different superscripts differ significantly ($p \leq 0.05$)

[d]Least significant difference ($p=0.05$)

[e]NS=Not significant ($p>0.05$)

[f]SFA=Saturated fatty acids

[g]MUFA=Mono-unsaturated fatty acids

[h]PUFA=Polyunsaturated fatty acids

[i]PUFA:SFA=Ratio of polyunsaturated to saturated fatty acids

[j]DFA=Desirable fatty acids

When pooled across selection lines, no significant differences ($p>0.05$) occurred between sexes for either total SFA, total MUFA or total PUFA (Table 11). Except for C20:1*n*9, no significant differences ($p>0.05$) were detected in the individual fatty acid composition. The absence of significant differences in SFA, MUFA and PUFA content between males and females suggests that the fatty acid profile was independent of sex (at a slaughter weight of ±43 kg). These results agree with the findings of Horcoda, Beriain, Pyrroyo, Lizaso and Chasco (1998), but differ from those of Solomon, Lynch, Ono, and Paroczay (1990), who found that the ram lambs had lipids richer in PUFA and poorer in SFA than ewes. The latter could be due to an age effect as the sheep used in the present investigation were older.

When pooled across sexes (Table 11), the positive line animals had a higher PUFA content (±7%) than their N group contemporaries (±6%). The total SFA and MUFA composition did not differ significantly ($p>0.05$) between the lines. The P group had significantly higher ($p\leq0.05$) proportions C18:2*n*6, C20:3*n*6, C20:4*n*6, C20:5*n*3, C22:5*n*3 and C22:6*n*3 concentrations than the the N group.

Desirable fatty acids (DFA), according to the health classification of Rhee (1992), are the sum of all unsaturated fatty acids and C18:0. C18:1n9, C16:0 and C18:0 represented the majority of the fatty acids measured in the *M. semimembranosus* of all the meat samples analysed in this investigation. It is well known that C16:0 increases blood cholesterol content, whereas C18:0 has no effect and C18:1*n*9 decreases blood cholesterol content. Therefore, the ratio of (C18:0 + C18:1):C16:0 indicates the possible health effects of the lipids (Grundy, 1997; Banskalievaa, Sahlu & Goetsch, 2000). Within the four reproduction fitness groups (Table 10), as well as in the pooled groups for sexes and lines (Table 11), no significant differences were detected in DFA or (C18:0+C18:1):C16.

The PUFA:SFA ratio is an important guideline illustating the total impact of SFA on blood cholesterol. Values of 0.45 or above for the PUFA:SFA ratio in dietery fats have been recommended in the United Kingdom (Warris, 2000). The PUFA:SFA ratio is lower in ruminants than non-ruminants because of the biohydrogenation of dietary unsaturated fatty acids by ruminal micro-organisms (Banskalievaa *et al.*, 2000). C18:2*n*6, the major plant fatty acid, is much lower in ruminant tissue than in non-ruminant tissue. These factors lead to a PUFA:SFA ratio below the value of 0.45 in the human diet (Warris, 2000). Previous reports found PUFA:SFA ratio of lipids from bovine or lamb between 0.11 and 0.15 (Geay,

Boauchart, Hocquette & Culiole, 2001). The PUFA:SFA ratio of the four groups in this investigation differed significantly ($p \leq 0.05$), but were all markedly below the recommended value of 0.45. The P group had a higher PUFA:SFA ratio of 0.143, compared to the N production group that had a PUFA:SFA ratio of 0.115.

Table 11

Means of the fatty acid content of *M. semimembranosus* as affected by the main effects of line and sex (% by weight of total fatty acids)

	Line			Sex		
	Positive	Negative	LSD[d]	Ram	Ewe	LSD
C14:0	2.629	2.401	NS[e]	2.377	2.729	NS
C16:0	27.06	27.41	NS	27.65	26.63	NS
C18:0	23.38	22.36	NS	22.23	23.61	NS
C20:0	0.245	0.286	NS	0.247	0.290	NS
C22:0	0.052	0.053	NS	0.050	0.055	NS
C24:0	0.043	0.031	NS	0.035	0.039	NS
C16:1*n*7	1.516	1.413	NS	1.566	1.326	NS
C18:1*n*9	38.54	38.82	NS	38.85	38.42	NS
C20:1*n*9	0.148	0.154	NS	0.102[b]	0.220[a]	0.046
C24:1*n*9	0.021	0.016	NS	0.018	0.020	NS
C18:2*n*6	4.080[a]	3.468[b]	0.566	3.881	3.664	NS
C18:3*n*6	0.073	0.073	NS	0.064	0.083	NS
C18:3*n*3	1.282	1.191	NS	1.200	1.296	NS
C20:2*n*6	0.037	0.038	NS	0.031	0.046	NS
C20:3*n*6	0.120[a]	0.080[b]	0.021	0.107	0.093	NS
C20:4*n*6	0.740[a]	0.471[b]	0.184	0.660	0.547	NS
C20:3*n*3	0.017	0.014	NS	0.012	0.020	NS
C20:5*n*3	0.382[a]	0.251[b]	0.122	0.360	0.264	NS
C22:2*n*6	0.077	0.105	NS	0.055	0.140	NS
C22:4*n*6	0.033	0.026	NS	0.031	0.027	NS
C22:5*n*3	0.454[a]	0.256[b]	0.115	0.392	0.317	NS
C22:6*n*3	0.119[a]	0.068[b]	0.032	0.095	0.094	NS
SFA[f]	52.37	53.55	NS	52.57	53.42	NS
MUFA[g]	40.22	40.40	NS	40.53	39.98	NS
PUFA[h]	7.440[a]	6.056[b]	1.177	6.919	6.603	NS
PUFA:SFA[i]	0.143[a]	0.115[b]	0.025	0.133	0.126	NS
DFA[j]	70.13	69.84	NS	69.68	70.29	NS
(C18:0+C18:1):C16:0	2.277	2.284	NS	2.234	2.346	NS

[a,b] Means in the same row with different superscripts differ ($p \leq 0.05$)

[d] Least significant difference ($p=0.05$)

[e] NS=Not significant ($p>0.05$)

[f] SFA=Saturated fatty acids

[g] MUFA=Mono-unsaturated fatty acids

[h] PUFA=Polyunsaturated fatty acids

[i] PUFA:SFA=Ratio of polyunsaturated to saturated fatty acids

[j] DFA=Desirable fatty acids

CONCLUSIONS

The objective of this investigation was to determine if meat quality differed between two lines of South African Merino sheep that were divergently selected for and against multiple-rearing ability. Differences detected in meat quality between the two lines were of a slight magnitude, although more important differences were found in the mineral and fatty acid composition of the meat. However, the latter did not affect the sensory quality of the meat.

This investigation provides important scientific insight into the effect of reproduction rate on general mutton quality. Results indicated that the selection of sheep for an increased multiple-rearing ability did not result in negative correlated responses on general mutton quality and therefore appears to be feasible. The only possible exception was with regard to tenderness, where the mutton derived from the positive line animals was generally tougher, according to WBS measurements, than the negative line contemporaries.

Analytical results of the fatty acid and mineral content of mutton derived from sheep raised under typical South African conditions are reported on a fresh meat basis and will serve as valuable information to use in national food composition tables.

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CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Until recently, no investigation determining the effect of different genotypes on the physical, chemical and sensory quality characteristics of South African lamb and mutton had yet been conducted. This study field became the object of this investigation.

South African sheep farmers are faced with major constraining factors such as stagnant product prices, ever-increasing production costs and a declining consumer demand for lamb and mutton. Sheep farmers need to run their enterprises in the most effective manner in order to survive economically. Efficient livestock production is of the utmost importance in small stock farming. Selection objectives for higher flock profitability, such as for an increased reproduction rate, thus need to be considered. Alternative strategies, such as crossbreeding for dual-purpose sheep breeds, need to be carefully evaluated in terms of their net effects on livestock production and meat quality.

This investigation was conducted by means of two experiments. Firstly, an investigation was undertaken to determine whether breed combinations, in a terminal crossbreeding system, have an effect on lamb quality. Secondly, against the background of the current trend of sheep breeders to select for net reproduction rate, progeny from a divergent selection experiment for ewe multiple-rearing ability were investigated in terms of meat quality.

Regarding the sensory qualities, measured on the *M. semimembranosus*, initial juiciness was the main discriminant between meat derived from the different lamb breed combinations used in this investigation. The differences detected in the sensory meat quality characteristics were only of slight magnitude and the panelists scored all the sensory attributes on the positive side of the rating scale. Therefore it can be concluded that, although crossbreeding significantly influenced initial juiciness, all the meat used in this investigation was still highly acceptable in terms of sensory quality attributes.

In respect of the proximate chemical composition of the *M. semimembranosus*, crossbreeding influenced the protein content of lamb significantly. Although pH and WBS values of the *M.*

longissimus dorsi significantly differed between the breed combinations, they were poor indicators of any of the sensory quality attributes measured.

The influence of reproduction rate on sensory meat quality characteristics, was in most instances negligible, with the exception of first bite. WBS measurements and pH values indicated that the *M. semimembranosus* derived from the higher reproductive group were significantly less tender than mutton derived from the lower reproductive group. Mean pH values varied from 5.5 to 5.8, but were all typical of normal meat pH.

The selection for reproduction rate affected the lipid and moisture content of the *M. semimembranosus*. Differences detected in lipid and moisture content could partially be explained by a sex effect due to the fact that rams produced leaner carcasses compared to the ewes and that no proximate chemical differences were detected when pooled for line effect.

Results obtained in both experiments indicated that breed and reproduction fitness significantly affected the fatty acid composition, the percentage content of individual fatty acids and the mineral composition of the *M. semimembranosus*. Findings suggest that possibilities exist for the production of lamb and mutton with specific nutritional quality characteristics. Previous investigations into lamb primarily indicated the role of nutrition in this respect. This research project also points to important evidence of differences in fatty acid and mineral composition of lamb and mutton derived from different genetic backgrounds.

The above could serve as an important basis of premium quality marketing schemes. Future studies in this domain could provide valuable information facilitating the production of lamb and mutton with specific health-promoting properties, and thus the more effective promotion of these products.

Analytical results of the fatty acid and mineral content of lamb and mutton raised under typical South African conditions are reported on a fresh tissue basis and will serve as valuable information to use in South African food composition tables.

This investigation provides important scientific insight into the effect of breed and reproduction rate on meat quality. Results obtained indicate that the present practice of

breeding wool type ewes to mutton ram breeds as well as the selection for multiple-rearing ability for an improved economic yield will not have a negative effect on meat quality characteristics.

This study justifies and indicates great scope for the continuous research into breed and reproduction fitness, as well as possible interactions with other factors affecting lamb and mutton quality. Future scientific investigations will yield valuable information to the meat industry in order to better control the production of market lambs of consistent and predictable high-quality meat with maximum consumer appeal.

ANNEXURE

SCORE SHEET USED FOR SENSORY ANALYSIS OF MEAT

SESSION: **DATE:**

PANEL MEMBER NUMBER: **NAME:**

Evaluate the samples in the order that they are presented.

Rinse your mouth with water and crackers between samples and sets.

CHARACTERISTIC	SCORE						
LAMB AROMA INTENSITY Take a few short sniffs as soon as you remove the foil	8 Extremely intense 7 Very intense 6 Moderately intense 5 Slightly intense 4 Slightly bland 3 Moderately bland 2 Very bland 1 Extremely bland						
INITIAL IMPRESSION OF JUICINESS The amount of fluid exuded on the cut surface when pressed between your thumb and forefinger	8 Extremely juicy 7 Very juicy 6 Moderately juicy 5 Slightly juicy 4 Slightly dry 3 Moderately dry 2 Very dry 1 Extremely dry						
SUSTAINED JUICINESS The impression that you form after the first two to three chews between the molar teeth	8 Extremely juicy 7 Very juicy 6 Moderately juicy 5 Slightly juicy 4 Slightly dry 3 Moderately dry 2 Very dry 1 Extremely dry						
FIRST BITE The impression of tenderness after the first two to three chews between the molar teeth	8 Extremely tender 7 Very tender 6 Moderately tender 5 Slightly tender 4 Slightly tough 3 Moderately tough 2 Very tough 1 Extremely tough						
RESIDUE The amount of residue left in the mouth after the first twenty to thirty chews.	8 None 7 Practically none 6 Traces 5 Slightly 4 Moderate 3 Excessive amount 2 Moderately Abundant 1 Abundant						
OVERALL LAMB FLAVOUR This is a combination of taste and swallowing	8 Extremely typical 7 Very typical 6 Moderately typical 5 Slightly typical 4 Slightly untypical 3 Moderately untypical 2 Very untypical 1 Extremely untypical						