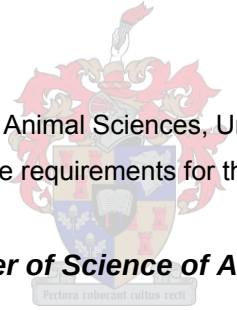
THE EFFECT OF AGRICULTURAL PRODUCTION SYSTEM ON THE MEAT QUALITY OF DORPER LAMBS

by

Bianca Claasen



Thesis submitted to the Department of Animal Sciences, University of Stellenbosch, in partial fulfilment of the requirements for the degree

Master of Science of Agriculture

Supervisor: Prof. LC Hoffman

Co-supervisors: Prof. SWP Cloete

Dr JJ Cloete

March 2008

DECLARATION

By submitting this thesis electronically, I declare that entirety of the work contained therein is my own, original work, that I am the owner of the copyright thereof (unless to the extent explicitly otherwise stated) and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

---------- ----------

Bianca Claasen Date

SUMMARY

The aim of this study was to investigate the effect of South African production system (feedlot {FL-} or free-range {FR-}) and gender (ewes, rams or castrates) on growth and carcass characteristics of Dorper sheep.

Male lambs (castrates and rams) grew twice as fast as ewes ($P<0.05$) under FL-conditions while much smaller differences were observed between gender groups in FR-lambs. FL-lambs produced heavier carcasses ($P=0.0003$) with higher dressing percentages ($P<0.05$) and greater carcass fatness levels ($P<0.052$) than FR- lambs.

No differences attributable to production system were found on meat tenderness (as indicated by Warner Bratzler shear force strength) and on the intramuscular lipid concentration. In contrast, sensory evaluation results suggested that meat from FL-lambs was juicier and more tender than meat from FR-lambs. The sensory panel could not distinguish between FL and FR meat as far as the attributes of aroma and flavour were concerned.

Cholesterol results indicated that for intermuscular fat, higher cholesterol levels were observed for FL-lambs than for FR-lambs. The level of palmitic acid (C16:0) was significantly higher ($P=0.0375$) in the *Longissimus dorsi* (LD) muscles of FL-lambs.

For intramuscular fat from the *Biceps femoris* (BF) muscle, g-linolenic acid (C18:3n-6) was higher ($P<0.0001$) in FL- lambs. Results for intramuscular BF further indicated that ram lambs had the highest ($P=0.0019$) palmitic acid (C16:0) and sum of TUFA ($P=0.0014$), castrates had the highest ($P=0.0260$) α-linolenic acid (C18:3n-3) and g-linolenic acid (C18:3n-6), while ewe lambs had the highest ($P=0.0014$) SFA concentrations. Linoleic acid (C18:2n-6c) was significantly higher ($P=0.0067$) in the subcutaneous fat of FL-lambs while FR-lambs had more linolenic acid (C18:3n-3). For the kidney fat, FR-feeding increased ($P < 0.05$) stearic (C18:0), linolelaidic (C18:2n-6t), α-linolenic (C18:3n-3) and homo-g-linolenic acid (C20:3n-6) percentages. Conversely, linoleic acid (C18:2n-6c) was increased ($P=0.0372$) by FL-feeding. For the intermuscular fat, FR-lambs had higher linolenic acid (C18:3n-3) and SFA ($P=0.0113$ and $P=0.0341$) compared to FL-lambs. On the other hand, the sum of TUFA for the intermuscular fat was higher ($P=0.0341$) in FL-lambs compared to FR-lambs.

Results from the study imply that the consumer may not necessarily be able to discern between meat from FR- or FL-lambs, although they may possibly discriminate against the increase in visible fatness of FL-lambs. No clear advantage of production system in terms of human health could be demonstrated as far as the proximate chemical composition and the fatty acid composition of the meat was concerned. The faster growth and the associated shorter production cycle of FL-lambs could be an advantage under certain production systems. However, it needs to be weighed against the cost of concentrate feeding and the preference consumers are likely to develop for lamb produced in natural environments.

OPSOMMING

Die doel van die studie was om Suid Afrikaanse produksiestelsel (voerkraal {VK-} of veld {VD}) en geslag (ooie, hamels of ramme) op die groeivermoë en karkaseienskappe van die Dorperskape te bepaal.

Manlike lammers (ramme and hamels) het twee keer vinniger (P<0.05) as ooilammers onder VK-toestande gegroei, terwyl kleiner verskille tussen geslagsgroepe by VD-diere waargeneem is. VK-lammers het swaarder karkasse (P=0.0003), hoër uitslagpersentasies (P<0.05) en meer karkas vet (P<0.052) as VD -lammers vertoon.

Geen verskille as gevolg van produksiestelsel is op die sagtheid van vleis (soos aangedui deur Warner-Bratzler skeurkragwaardes) en die binnespierse vetinhoud gevind nie. Daarenteen het sensoriese analises aangedui dat vleis van VK-lammers sappiger en sagter as vleis van VD- lammers was. Die sensoriese paneel kon nie verskille aangaande die aroma en geur van vleis tussen VK- en VD-vleis onderskei nie.

Cholesterolvlakke was hoër vir VK-lammers as by VD-lammers. Die vlak van palmitiese suur (C16:0) was hoër (P=0.0375) in die *Longissimus dorsi* (LD) spier van VK-lammers.

Vir binnespierse vet van die *Biceps femoris* (BF) spier was g-linoleniese suur (C18:3n-6) hoër (P<0.0001) in VK-lammers. Resultate vir binnespierse vet van die BF spier het verder bewys dat ramlammers die hoogste (P=0.0019) palmitiese suur (C16:0) and totale onversadigde vetsure (P = 0.0014) getoon het, hamels die hoogste (P=0.0260) α-linoleniese suur (C18:3n-3) en g-linolenese suur (C18:3n-6) getoon het terwyl ooilammers die hoogste (P=0.0014) versadigde vetsuurvlakke getoon het. Linoliese suur (C18:2n-6c) was hoër (P=0.0067) in die onderhuidse vet van VK-lammers terwyl VD-lammers meer linoliese suur (C18:3n-3) gehad het. Resultate vir niervet het getoon dat VD-voeding die persentasies van stearіese (C18:0), linoleladiese (C18:2n-6t), α-linoleniese (C18:3n-3) and homo-g-linoleniese suur (C20:3n-6) verhoog (P<0.05) het relatief tot VK-voeding. Linoliese suur (C18:2n-6c) is deur VK-voeding verhoog (P=0.0372). Vir intermuskulêre vet het VD-lammers hoër linoleniese suur (C18:3n-3) en versadigde vetsure (P=0.0113 en P=0.0341) as VK-lammers gehad. Die totale onversadigde vetsure vir tussenspiere vet was hoër (P=0.0341) in VK-lammers in vergelyking met VD-lammers.

Resultate van hierdie studie dui daarop dat verbruikers nie noodwendig tussen vleis van VD- en VK-lammers sal onderskei nie, alhoewel hulle dalk teen die sigbaar vetter vleis van VK-lammers kan diskrimineer. Geen definitiewe voordeel in terme van menslike gesondheid kon op grond van die chemiese samestelling van die vleis bevestig word nie. Vinniger groei van VK-lammers, en die korter produksiesiklus wat daarmee verband hou, mag onder sekere produksie stelsels 'n voordeel wees. Die voordeel moet teen die hoër koste van VK-voeding en die voorkeur van verbruikers vir lam produksie in natuurlike omgewing opgeweeg word.

ACKNOWLEDGEMENTS

I wish to express my sincere gratitude to the following persons and their institutions for their contributions to the successful completion of this thesis:

Prof. L.C. Hoffman of the Department of Animal Science, University of Stellenbosch (US) , *Prof. S.W.P. Cloete* of Elsenburg Agricultural College and *Dr J.J.E. Cloete* of Elsenburg Agricultural College, who together comprised the study committee, for their guidance, positive criticism, patience and support.

All the *personnel of Nortier Experimental Farm* near Lamberts Bay, South Africa, for their assistance in the selection, feeding and care of the lambs.

Malmesbury Abattoir for providing the slaughter facilities as well as the staff who assisted in the slaughter process.

Mrs. G. Jordaan of the Department of Animal Science, US, for the statistical analyses of most of the data, especially her guidance, patience and willingness to help.

Mr F. Calitz of Infruitec, Stellenbosch, for the statistical analyses of sensory data, especially his willingness to help.

The Department of Consumer Science, US, for the use of their sensory facility and apparatus for executing physical analysis (Instron UTM);

E. Moelich and *B. van Wyk*, Department of Consumer Science, US, for their knowledge, technical assistance and support in the execution of the sensory analysis;

Resia, *Marvin*, *Nicholas*, *Raymond* and *Nothemba*, the laboratory staff at the Department of Animal Science, US, for their valuable assistance, with the chemical analysis.

My husband, *Alberto*, for his encouragement, support and help.

The Lord, for loving and sustaining me and for giving me the ability, strength and endurance.

LIST OF ABBREVIATIONS

ADG	Average Daily Gain
BF	*Biceps femoris* muscle
df	degrees of freedom
FAME	Fatty acid methyl esters
FL	Feedlot
FR	Free-range
kg	kilogram
LD	*Longissimus dorsi* muscle
mm	millimeter
MS	mean square
MUFA	monounsaturated fatty acids
P:S	Ratio of polyunsaturated to saturated fatty acids
pH45	pH forty five minutes after the animal is bled
pH48	pH forty eight hours after the animal is bled
PUFA	polyunsaturated fatty acids
r	Coefficient of correlation
s.d.	standard deviation
s.e.	standard error
SFA	Saturated fatty acids
TUFA	Total unsaturated fatty acids
USFA	unsaturated fatty acids
WHC	water holding capacity

TABLE OF CONTENTS

Chapter 1

Introduction

In the past, red meat consumption was associated with good health (Higgs, 2000). This perception underwent a metamorphosis in the 1980's when the contribution of meat fat to human health became a focal point (Higgs, 2000). The intake of certain meat constituents, particularly saturated fatty acids (SFA) and its link to the incidence of coronary heart disease and cancer (MacRae *et al.*, 2005) and the incidence of bovine spongiform encephalopathy (BSE) in Belgium (Higgs, 2000; Verbeke & Viaene, 2000) are but two of the factors that have contributed to negative consumer perceptions. The impact of animal production systems on the environment as well as animal welfare issues have also surfaced as components of consumer concern (McEachern & Willock, 2004; Verbeke & Viaene, 2000). The challenge for the meat industry lies in addressing animal welfare concerns, adopting environmentally friendly animal production practices, delivering safe products of good eating quality and in communicating this effectively and efficiently to the final consumer (Verbeke & Viaene, 2000).

Consumer concerns related to health, food safety and animal welfare create the perfect market for free-range animal production. Free-range animal production systems are often viewed as superior for the environment, soil, livestock and those humans that care for them and consume their products (Raven, 2000). Recent surveys show that consumers buy free-range products because of perceived high standards of natural/animal friendly production practices, animal health and the absence of chemicals and growth hormones in meat (McEachern & Willock, 2004; Harper & Makatouni, 2002; Davies *et al.*, 1995). Therefore, free-range animal production and the purchase and consumption of products produced in such a way seem a viable option in attempting to address consumer concerns.

Numerous scientific investigations report that free-range systems result in slower lamb growth rates (Notter *et al.*, 1991), lower slaughter weights (Crouse *et al.*, 1981), lighter carcasses, lower dressing percentages (Diaz *et al.*, 2002; Murphy *et al.*, 1994) and carcasses with less overall fat (Diaz *et al.*, 2002) compared to feedlot systems. Also, sex hormones seem to play an important part in the growth pattern of lambs. Intact males grow faster (an effect amplified under feedlot conditions), and produce higher yielding carcasses with more meat and less fat than castrates and ewe lambs, as they are able to utilize feed more efficiently (Notter *et al.*, 1991; Arnold & Meyer, 1988; Seideman *et al.*, 1982; Crouse *et al.*, 1981). However, the growth advantage of rams over castrates is insignificant when nutritional levels are reduced or when diets are of poor quality (Crouse *et al.*, 1981). Ewe lambs generally have higher dressing percentages than rams and castrate lambs (Johnson *et al.*, 2005; Vergara *et al.*, 1999).

In general the appearance of a product (meat colour, fat content, in pack purge and price) determines how consumers perceive quality, which in turn influences purchasing behaviour (Grunert, 2006; 1997). Meat colour is the foremost selection criteria used by consumers in the purchase of meat and meat products. Studies show that meat from lambs finished off under a free-range production system is darker than meat from lambs finished off in a feedlot (Diaz *et al.*, 2002). Colour differences are attributed to a higher haemic pigment concentration in muscles of free-range lambs as a result of exercise (Diaz *et al.*, 2002) and a higher ultimate pH. Differences in storage time and temperature, slaughter weight, carcass fatness, animal species and muscle type (Diaz *et al.*, 2002; Lawrie, 1998) have also been implicated. The amount of visible fat is another strong cue for consumers considering purchase at retail and is viewed as a negative criterion for health reasons (Dransfield, 2001), while the positive aspects of meat fat such as its contribution to flavour is not perceived as important (Grunert, 1997). Excessive in-pack purge which is dependent on the water holding capacity of meat (WHC) may also negatively influence the visual appraisal of the meat product. The WHC of meat of free-range lambs has been noted to be less than from lambs fed a concentrate based diet (Santos-Silva *et al.*, 2002).

Other parameters such as cooked meat colour, juiciness and tenderness are important product quality ques upon consumption. Consumers consider meat tenderness the most important palatability trait (Gonzalez *et al.*, 2001; Boleman *et al.*, 1997). An increase in meat tenderness increases overall consumer acceptability (Cross & Stanfield, 1976). Juiciness and flavour are important in overall product acceptability. Feedlot lambs are generally fatter at slaughter than free-range lambs and hence juicier and more tender (Nuernberg *et al.*, 2005; Arnold & Meyer, 1998; Notter *et al.*, 1991; Oltjen *et al.*, 1971). The difference in meat tenderness may also be attributed to cooling rate, post-mortem proteolysis, animal age, gender, WHC, muscle pH and temperature, sarcomere length, quantity and type of collagen, muscle fibre type and size as well as species differences, differences among animals within a species, differences between carcasses and between muscles within a cut (Muir, 1998; Lawrie, 1998; Young & Kaufmann, 1978). Animals that are raised under the same environmental conditions and slaughtered at the same weight and/or fat cover show no differences in flavour (Muir *et al.*, 1998). Sheep meat odour and flavour are also affected by age, breed, gender and pre- and post slaughter factors (Lawrie, 1998). As for the gender effect, leaner carcasses from ram lambs are associated with less juicier and less tender meat compared to fatter carcasses of ewes and castrate lambs (Seideman *et al.*, 1982; Field, 1971).

Feedlot diets result in fatter carcasses which display lower moisture, protein and ash percentages and higher ether extract (Rowe, 1999; Summers *et al.*, 1978). Studies involving beef cattle indicate that there are no differences in moisture content between forage- and grain-finished beef (Schoeder *et al.*, 1980). Rowe *et al.* (1999) found that muscle protein was not affected by production system. Leaner carcasses of intact males compared to fatter castrates and ewe lambs (Arnold & Meyer, 1988; Seideman *et al.*, 1982; Crouse *et al.*, 1981; Field, 1971) have more moisture. Castration affects the chemical composition of muscle by inducing a decrease in the moisture content and an increase in fat content (Monin & Quali, 1991). Kemp *et al.* (1976) observed that whether carcasses contain more moisture and protein and less fat

than ewe carcasses. Solomon *et al.* (1980) and Kemp *et al.* (1976) observed that lambs slaughtered at heavier weights contained less moisture and protein and more ether extract.

Research results indicate that different nutritional regimes can change muscle fatty acid composition, PUFA level and the n-3:n-6 PUFA ratio (Enser *et al.*, 1998). Gender studies indicate that total muscle lipid content is lower and PUFA level and the PUFA: SFA ratio is greater in rams than in ewes (Matsuoka *et al.*, 1997; Johnson *et al.*, 1995). Increased age at slaughter changes the fatty acid composition of depot fats with decreasing proportions of stearic acid and increasing proportions of all other acids (Zygoyiannis *et al.*, 1992). For goats slaughtered at heavier live weights, the content of SFA increased and the level of MUFA decreased in all depots (Sauvant *et al.*, 1979).

Although there is plenty of information on the effect of free-range and feedlot production systems on lamb growth and meat quality, this has not yet been reported under South African conditions. This study intends to fill this gap by studying the performance of Dorper sheep under South African conditions. The Dorper sheep is an early maturing breed selected for adaptability under South African harsh conditions (Cloete *et al.*, 2005; Cloete *et al.*, 2000). In terms of meat production, the Dorper out performs wooled breeds and other native South African breeds, while comparing favourably with specialist meat sheep breeds (Schoeman, 2000).

The objective of this study was therefore to investigate the effect of production system on the

- Growth and carcass characteristics
- Physical and chemical quality characteristics
- Sensory quality characteristics
- Fatty acid profile of the muscles and lipid depots

Of Dorper lambs of the same age slaughtered after a predetermined period. In addition, it was also the objective of this study to quantify the effect of gender (ram, castrate, ewe) on these characteristics.

REFERENCES

Arnold, A.M. & Meyer, H.H. 1988. Effects of gender, time of castration, genotype and feeding regime on lamb growth and carcass fatness. Journal of Animal Science, 66, 2468-2475.

Boleman, S.J. Boleman, S.L., Miller, R.K., Taylor, J.F., Cross, H.R., Wheeler, T.L., Koohmaraie, M., Schackelford, S.D., Miller, M.F., West, R.L:, Johnson, D.D. & Savell, J.W. 1997. Consumer evaluation of beef known categories of tenderness. Journal of Animal Science, 75, 1521-1524.

Cloete, J.J.E., Cloete, S.W.P. & Hoffman, L.C. 2005. Behaviour of Merinos divergently selected for multiple rearing ability in response to external stimuli. Small Ruminant Research, 60, 227-236.

Cloete, S.W.P., Snyman, M.A. & Herselman, M.J. 2000. Productive performance of Dorper sheep. Small Ruminant Research, 36, 119-135.

Cross, H.R. & Stanfield, M.S. 1976. A research note: Consumer Evaluation of restructed beef steaks. Journal of Food Science, 41, 1257-1258.ansf

Crouse, J.D., Busboom, J.R., Field, R.A. & Ferell, C.L. 1981. The effects of breed, sex, location and slaughter weight on lamb growth, carcass composition and meat flavour. Journal of Animal Science, 53, 376-381.

Davies, A., Titterington, A.J. & Cochrane, C. 1995. Who buys organic food? A profile of the purchasers of organic food in Northen Ireland. British Food Journal, 97, (10), 17-23.

Díaz, M.T., Valesco, S., Caneque, V., Lauzurica, S., de Huidobro, F.R., Perez, C., Gonzalez, J. & Manzanares, C. 2002. The use of concentrate or pasture for fattening lambs and its effect on carcass and meat quality. Small Ruminant Research, 43, 257-268.

Dransfield, E. 2001. Consumer issues and acceptance of meat. In: Proceedings of the 47th International Congress of Meat Science and Technology, 1, 72-79. August 2001, Krakow, Poland.

Enser, M., Hallet, K.G., Hewwett, B., Fursey, G.A.J., Wood, J.D., & Harrington, G. 1998. Fatty acid and composition of UK beef lamb muscle in relation to production system and implications for human nutrition. Meat Science, 49, 329-341.

Field, R.A. 1971. Effect of castration on meat quality and quality. Journal of Animal Science, 32, 849-858.

Gonzalez, C.B., Salitto, V.A. & Carduza, F.J. 2001. Effect of calcium chloride marination on bovine *Cutaneus trunci* muscle. Meat Science, 57, 251-256.

Grunert, K.G. 2006. Future trends and consumer lifestyles with regard to meat consumption. Meat Science, 74, 149-160.

Grunert, K.G. 1997. What's in a steak? A cross-cultural study on the quality perception of beef. Food quality and Preference, 8, 157-174.

Harper, G.C. & Makatouni, A. 2002. Consumer perception of organic food production and farm animal welfare. British Food Journal, 104 (3/4/5), 287-299.

Higgs, J.D. 2000. The changing nature of red meat: 20 years of improving nutritional meat quality. Trends in Food Science and Technology, 11, 85-95.

Johnson, P.L., Purchas, R.W., Mc Ewan, J.C. & Blair, H.T. 2005. Carcass composition and meat quality differences between pasture- raired ewe and ram lambs. Meat Science, 71, 383-391.

Johnson, D.D., Eastridge, J.S., Neubauer, D.R., McGowan, C.H. 1995. Effect of sex class on nutrient content of meat from young goat. Journal of Animal Science, 73, 296-301.

Kemp, J.D., Johnson, A.E., Stewart, D.F., Ely, D.G. & Fox, J.D. 1976. Effect of dietary protein, slaughter weight and sex on carcass composition, organoleptic properties and cooking losses of lamb. Journal of Animal Science, 42 (3), 575-583.

Lawrie, R.A. 1998. Meat Science, 6th edition. New York: Pergamon Press.

MacRae, J., O'Reilly, L. & Morgan, P. 2005. Desirable characteristics from a human health perspective. Livestock Production Science, 94, 95-103.

Matsuoka, A., Furokawa, N., Takahashi, T. 1997. Carcass traits and chemical composition of meat in male and female goats. Journal of Agricultural Science, Tokyo, Nogyo Daigaki 42(2), 127-135.

McEachern, M.G. & Wilcock, J. 2004. Producers and consumers of organic meat: A focus on attitudes and motivations. British Food Journal, 7, 534-552.

Monin, C. & Quali, A. 1991. Muscle differentiation and meat quality. In R. Lawrie (Ed.), Developments in meat science, 5, (pp 89-157). London: Elsevier Applied Science.

Muir, P.D., Deaker, J.M. & Brown, M.D. 1998. Effects of forage- and grain-based feeding systems on beef quality: A review. New Zealand Journal of Agricultural Research, 41, 623-635.

Murphy, T.A., Loerch, S.C., McClure, K.E. & Solomon, M.B. 1994. Effects of restricted feeding on growth performance and carcass composition of lambs subjected to different nutritional treatments. Journal of Animal Science, 72, 3131-3137.

Notter, D.R., Kelly, R.F. & McClaugherty, F.S. 1991. Effects of ewe breed management system on efficiency of lamb production: II. Lamb growth, survival and carcass characteristics. Journal of Animal Science, 69, 22-33.

Nuernberg, K., Dannenberger, D., Nuernberg, G. & Ender, K.R.I. 2005. Effects of grass based feeding system on meat quality characteristics and fatty acid composition of *longissimus* muscle in different cattle breeds. Livestock Production Science, 94, 137-147.

Oltjen, R.R., Rumsey, T.S. & Putman, P.A. 1971. All forage diets for finishing beef steers. Journal of Animal Science, 46, 716-724.

Raven, H. 2000. New voice for Scotland's organic farmers. The Scottish Farmer, ABC Bussiness Publication Ltd, Glasgow, 8 April.

Rowe, A., Macedo, F.A.F., Visentainer, J.V., Souza, N.E. & Matsushita, M. 1999. Muscle composition and fatty acid profile in lambs fattened in drylot or pasture. Meat Science, 51, 283-288.

Santos-Silva, J., Mendes, L.A. & Bessa, J.R.B. 2002. The effect of genotype, feeding system and slaughter weight on the quality of light lambs 1. Growth, carcass composition and meat quality. Livestock Production Science, 76, 17-25.

Sauvant, D., Bas, P. & Morand-Fehr, P. 1979. Heavy kids production. II. Influence of milk ingestion and weaning on performance of adipose tissue composition of kids. Ann. Zootech, 28, 73-92.

Schoemen, S.J. 2000. A comparative assessment of Dorper sheep in different Production environments and systems. Small Ruminant Research, 9, 265-281.

Schroeder, J.W., Cramer, D.A., Bowling, R.A & Cook, C.W. 1980. Palatability, shelf-life and chemical differences between forage- and grain- finished beef. Journal of Animal Science, 50, 852-859.

Seideman, S.C., Cross, H.R., Oltjen, R.R. & Scanbacher, B.D. 1982. Utilization of intact male for red meat production. Journal of Animal Science, 55, 826-840.

Solomon, M.B., Kemp, J.D., Moody, W.G., Ely, D.G. & Fox, J.D. 1980. Effect of breed and slaughter weight on physical, chemical and organoleptic properties of lamb carcasses. Journal of Animal Science, 15(5), 1102-1107.

Summers, R.L., Kemp, J.D., Ely, D.G. & Fox, J.D. 1978. Effects of weaning, feeding systems and sex on lamb characteristics and palatability. Journal of Animal Science, 47, 622-631.

Verberke, W.A.J. & Viane, J. 2000. Ethical challenges for livestock production: Meeting consumer concerns about meat safety and animal welfare. Journal of Agricultural and Environmental Ethics, 12, 141-151.

Vergara, H., Molina, A. & Gallego, L. 1999. Influence of sex and slaughter weight on carcass and meat quality in light and medium weight lambs produced in intensive systems. Meat Science, 52, 221-226.

Young, A.W. & Kaufman, R.G. 1978. Evaluation of beef steers fed grain, corn silage or haylage corn-silage diets. Journal of Animal Science, 46, 41-49.

Zygoyiannis, D., Kufidis, D., Katsaounis, N., Phillips, P. 1992. Fatty acid composition of carcass fat of indigenous (*Capra prisca*) suckled Greek kids and milk of their does. Small Ruminant Research, 104, 360-365.

Chapter 2

Literature review

BACKGROUND

The Dorper, a white-bodied sheep with a black head, is an indigenous South African mutton sheep. It is numerically the second largest breed in South Africa (Schoeman, 2000; Cloete *et al.*, 2000). The distribution of this breed is widespread; it is found throughout southern and central Africa, in the desert areas of North Africa and the Middle East as well as other continents namely, Northern America and Australia (Schoeman, 2000). Although the Dorper is popular for its meat characteristics (Snowder & Duckett, 2003), there is lack of literature on the comparisons of production systems on lamb growth and meat quality characteristics of lamb produced by local South African breeds. Moreover, the comparison of free-range with feedlot finishing for Dorper sheep under South African conditions has not yet been made.

The Dorper

During the 1930's the need for a mutton breed that is adapted to dry extensive regions and can produce good quality lambs at the same time was realized (Nel, 1993). This need was emphasized by the surplus of mutton and the slump of wool prices experienced at the beginning of the early '30's. An export market for mutton was sought but results proved futile since Southern African fat-tail sheep types could not compete with the high quality mutton from Australia, New Zealand and Argentenia (Nel, 1993). Moreover, the fat-tail sheep types were not desirable according to the English grading system (Milne, 2000). It thus became essential to improve the quality of South African mutton. As a result, the Dorper breed was developed in the Karoo region of South Africa by crossing imported Black Head Persian ewes to British Dorset Horn rams (Snowder & Duckett, 2003; Milne, 2000). The Dorper breed, because of its inherent quality characteristics (adaptability, meat and carcass quality, mothering ability, growth potential) has since become a popular sire breed around the world (Snowder & Duckett, 2003; Schoeman, 2000).

The Dorper sheep is an early maturing breed that does well in various veldt and feeding conditions and reacts favourably under intensive feeding conditions. This breed tends to put on more localized fat at an earlier age (at lower live weights) than later maturing breeds, a phenomenon that is amplified by intensive feeding regimes or favourable environmental conditions. The Dorper can reach a live weight of about 36 kg at 3-4 months which ensures a high quality carcass of approximately 16 kg. A well grown Dorper lamb has carcass qualities in respect of conformation and fat distribution which generally qualifies for super grading.

The Dorper is fertile, has a high fecundity and the percentage of ewes that become pregnant in one mating season is relatively high. A Dorper ewe produces large quantities of milk, is instinctively fond of her lambs and has the ability to care for and rear her offspring well. This is an easy care breed which requires a minimum of labour. It has a thick skin (pelt) which is highly prized and protects the sheep under harsh climatic conditions.

CONSUMER PERCEPTIONS

Consumer attitudes and behaviour towards food choices are based on information acquired through various media (television programmes and commercials, newspapers, books and pamphlets) as well as from the health authorities (Richardson, 1994). Meat consumption on the other hand is affected by consumer characteristics (general economic situation, health, family or educational aspects) as well as product characteristics (sensory, nutritional, safety, price, convenience) (Jimenez-Colmenero *et al.*, 2001). During the 1940's and 1950's consumer decisions to purchase meat were based on price, availability and quality (Richardson, 1994). In recent years some segments of the larger population have become particularly interested in diet / health relationships (Jimenez-Colmenero *et al.*, 2001), the impact of animal production systems on the environment and animal welfare issues (McEachern & Willock, 2004; Verbeke & Viaene, 2000). The successful future development of the meat industry therefore depends on how current consumer concerns are addressed.

Diet / Health relationships

In ancient times, man's diet mostly comprised of green plants, fresh fruit, fish and lean meat. This diet was rich in omega-3 (n-3) polyunsaturated fatty acids (PUFA), and believed to contribute to good health (Vitamin Information Centre, 2005). Red meat consumption in particular was associated with optimal health because of its nutritional composition (Valsta *et al.*, 2005; Higgs, 2000).

About 30-40 years ago, epidemiologists identified a strong relationship between the proportion of dietary energy that was consumed as saturated fatty acids (SFA) and the incidence of coronary heart disease and cancer (MacRae *et al.*, 2005). SFA was identified as the key component in the development of high levels of cholesterol in the circulating serum proteins. Meat fat in particular is linked to considerable levels of fat and SFA. The excessive consumption of these can lead to the development of high levels of cholesterol in circulating lipoproteins (MacRae *et al.*, 2005).

In recent years it has become clear that the inappropriate consumption of red meat (relatively high in protein and fat) coupled with insufficient dietary fibre, fruits and vegetables (Higgs, 2000) is responsible for the escalating incidence of lifestyle and dietary induced diseases such as obesity, insulin resistance and type two diabetes, cardiovascular disease, cancer, multiple sclerosis, mental health, depression,

schizophrenia, Alzheimer's disease, bone health, skin conditions, immunity and attention deficit hyperactivity disorder (Vitamin Information Centre, 2005). This is primarily because modern diets principally contain more omega-6 (n-6) polyunsaturated fatty acids (PUFA) than that of early man (Vitamin Information Centre, 2005). The n-3: n-6 ratio has thus been altered from the favourable 1:4 ratio to the less favourable 1:25 (Vitamin Information Centre, 2005).

Research results indicate that the inclusion of PUFAs in the diet seems to modulate insulin sensitivity, dietary alpha-linolenic acid reduces inflammatory and lipid cardiovascular risk factors in hypercholesterolemic subjects, the inclusion of PUFAs in the diet increase heart rate variability and regular intake of omega-3 reduces the risk of cancer, especially cancer of the gastrointestinal tract and breast tissue (Vitamin Information Centre, 2005). It is therefore recommended that people reduce their consumption of SFA, increase their intake of monounsaturated fatty acids (MUFA) containing omega-9 oleic acid and PUFA containing n-3 and n–6 fatty acids that are perceived as beneficial to human health (Vitamin Information Centre, 2005). The United Kingdom's Department of Health recommends that people reduce their intake of SFA from 15% to 10% of the total energy intake while increasing the ratio of PUFA to SFA to above 0.4. In Germany it is recommended that people reduce their intake of SFA (10% of the total calories) and trans fatty acids (less than 1%) and increase their intake of unsaturated fatty acids (0.5%) and decrease the n-6:n-3 ratio to levels <5:1 (Nuernberg *et al.*, 2005).

Production systems, animal welfare and food safety

Intensive agricultural production systems make use of additives such as hormones, pesticides, herbicides and antibiotics. The use of these hormones has led to consumer concern for food safety, farm animal welfare and the growth of the organic/free-range food market (Harper & Makatouni, 2002). Free-range products are perceived to be safer and healthier than products from intensive agricultural production systems (Davies *et al.*, 1995). It has been shown that consumers demand food that is more "animal friendly", free-range eggs being an example. Moreover, consumers use animal welfare as an indicator of other more important product characteristics such as food safety and quality (Harper & Henson, 1999). Available research results indicate that consumers purchase organic products for health reasons (Davies *et al.*, 1995), better taste and as being free from BSE and other food additives (Harper & Makatouni, 2002). In addition, consumers buy organic products for ethical reasons (Morris, 1996). Consumers who are concerned about animal welfare issues are also willing to pay for improved animal welfare standards (Bennet, 1996). The organic/free-range market could therefore take advantage of research on consumer motivation to buy free-range products by embodying ethical concerns as an indicator of product quality (Harper & Makatouni, 2002).

Meat quality

The International Organization of Standardization (ISO) defines product quality as the totality of features and characteristics of a product that bear on its ability to satisfy stated or implied needs. This definition takes into consideration the inherent characteristic of a product as well as perceived quality, which relates to customer expectations irrespective of the value of the product (Longdell, 1997). In Meat Science, meat quality encompasses physical, chemical and sensory attributes.

Modern day consumers are particularly concerned about the treatment the animal receives ante mortem (Jimenez-Colmenero *et al.*, 2001). Available research results indicate that some segments of the larger consumer population prefer to buy free-range products because meat produced in such systems is perceived to be of high quality (McEachern & Wilcock, 2004; Harper & Makatouni, 2002; Davies *et al.*, 1995).

Meat colour, fat content and price determines how consumers perceive quality and certainly influences purchasing behaviour (Grunert, 2006, 1997). Meat colour is used as the foremost selection criterion in the purchase of meat and is commonly used as an indicator of freshness. Discolouration of the meat surface decreases consumer acceptance (Carpentar *et al.*, 2001). The amount of noticeable fat is a strong cue for consumers considering purchase at retail. Many consumers view meat fat as a negative criterion for health reasons (Dransfield, 2001) while vital aspects of meat fat such as flavour is rather insignificant (Grunert, 1997). In pack purge (which is depended on the water holding capacity of meat) can also negatively influence the visual appraisal of the meat product (Lawrie, 1998).

Cooked meat colour, juiciness and tenderness are important product quality cues during consumption. Consumers regard meat tenderness as the most important palatability trait (Pietisik & Shand, 2004) and express their willingness to pay a higher price for tenderness (Miller *et al.*, 2001). Juicy meat is generally preferred over meat that is less juicy (Risvik, 1994). Meat flavour is also important in overall product acceptability. In order to satisfy consumer satisfaction these quality attributes therefore need to be considered.

LAMB GROWTH

Growth is considered a fundamental process to both livestock and meat industries. Animal growth can be defined as a normal increase in size that is accomplished by hyperplasia and hypertrophy. Development, considered along with growth, is a gradual progression from a lower to a higher state of complexity (Arbele *et al.*, 2001).

Animal growth begins with the fertilized ovum and proceeds through three distinct phases of prenatal growth (conception to parturition); the ovum, embryonic and prenatal phases (Arbele *et al.*, 2001). Phases of postnatal growth are not as distinct as that of prenatal growth. After parturition, an animal experiences slow growth. This is followed by a rapid growth phase during which the increase in size may be nearly constant and the slope of the curve remains unchanged. During the later stages, growth rates of muscles, bones and vital organs slow down and fattening accelerates (Arbele *et al.*, 2001).

During both pre-and postnatal growth, some tissues have priority over others because of their functional importance. The order of priority is as follows; tissues that constitute vital organs and physiological processes, bone, muscle and fat deposition. Muscle and fat are important components of a carcass and are usually evaluated during carcass classification.

In young animals, fat depots usually appear first in visceral areas. Then, if nutrient intake is adequate, fat is deposited intermuscularly, subcutaneously, and intramuscularly (Arbele *et al.*, 2001). Although genotype dictates the maximum amount of growth and development that is possible, nutrition, along with other environmental factors, govern actual rate of growth and extent to which development is attained (Arbele *et al.*, 2001).

Production system effects on lamb growth and carcass characteristics

Feedlot diets, because of its dense energy content, are often associated with rapid lamb growth patterns and greater fat deposition (Díaz *et al.*, 2002; Notter *et al.*, 1991). Free-range diets on the other hand are associated with slower lamb growth patterns that allow muscle tissue growth without excess fattening thus yielding leaner carcasses. Lambs finished off in the feedlot are heavier at slaughter (Crouse *et al.*, 1981). In addition, they have heavier carcasses and higher commercial dressing values than free-range lambs. Differences between the carcass characteristics of these lambs are attributed to differences in carcass fatness (Díaz *et al.*, 2002). Higher slaughter weights may result in higher dressing percentages (Díaz *et al.*, 2002; Solomon *et al.*, 1980; Kemp *et al.*, 1976).

Feedlot lambs generally display greater carcass fatness than free-range lambs (Díaz *et al.*, 2002; Crouse & Field 1978). Less fat in free-range lambs may be due to the effects of weaning which leads to a modification of body composition which is caused by either fat loss or by a sharp drop in body fat accumulation (Boer *et al.*, 2002). Furthermore, lower fatness in free-range lambs may also be due to changes in metabolism as a result of exercise, which in turn lead to mobilization of reserve lipids in order to form muscle tissue with a subsequent drop in carcass fatness. Carcass fatness may also be influenced by slaughter weight since heavier lamb present significantly higher fatness scores (Díaz *et al.*, 2002; Kemp *et*

al., 1976). In fact, Solomon *et al.* (1980) observed that the percentage of kidney and subcutaneous fat measurements increased with increasing slaughter weight.

Sex hormones play a significant role in lamb growth patterns and fat deposition (Seidemann *et al.*, 1982). It is known that intact males grow faster than castrates and ewe lambs because they are able to utilize feed more efficiently (Arnold & Meyer, 1988; Seideman *et al.*, 1982; Crouse *et al.*, 1981; Field, 1971). Ram lambs owe the growth advantage over castrates and ewe lambs to testicular hormones, particularly testosterone (Schanbacher *et al.*, 1980). The growth advantage of rams over castrates and ewe lambs is amplified with feedlot diets. Irrespective of production system, ram lambs yield leaner carcasses than castrates or ewe lambs (Dransfield *et al.*, 1990). When nutritional levels are however reduced, ram lambs may not show clear growth advantages over castrates during post weaning periods and are likely to yield less carcass weight per unit of live weight (Purchas, 1978). Ewe growth rates may be optimized with concentrate supplementation (Salim *et al.*, 2003). Carcasses from ram lambs are generally heavier than carcasses from castrates and ewe lambs (Dransfield *et al.*, 1990) although ewe lambs usually display higher dressing percentages than rams and castrate lambs (Johnson *et al.*, 2005; Wellington *et al.*, 2003; Wolf *et al.*, 2001; Vergara *et al.*, 1999). Kemp *et al.* (1976) observed that castrates are fatter than rams, and that both groups increased in fatness as weight increased. Ewe carcasses are fatter with more fat over the midline, than wether lambs (Kemp *et al.*, 1976).

Production system and gender interactions show that ram lambs make better use of feedlot diets for growth than castrates and ewe lambs (Notter *et al.*, 1991; Arnold & Meyer, 1988; Seideman *et al.*, 1982; Crouse *et al.*, 1981; Bradford & Spurlock, 1964). Some authors concur that a high feed level is necessary for ram lambs to fully exhibit their superiority in growth over castrates and ewe lambs (Bradford & Spurlock, 1964).

Kemp *et al.* (1976) observed that there was a general decrease in muscular cuts such as legs and an increase in fat cuts such as breast and flank as weight increased with its accompanying increase in fatness.

PHYSICAL MEAT QUALITY

Ruminant meat quality is influenced by intrinsic and extrinsic factors (Lawrie, 1998). Among the extrinsic factors, feeding plays an important role in the determination of meat quality (Priolo *et al.*, 2001).

Post-mortem pH

The influence of muscle/meat pH (a measurement of acidity) is widespread (Lawrie, 1998), since it gives valuable information about the keeping quality and technical processing characteristics of meat. The pH of normal living muscle is around 7.2 (Sales, 1999). After exsanguination, oxidative decarboxylation and phosphorylation no longer operates and any subsequent metabolism is anaerobic (Lawrie, 1998).

Adenosine triphosphate (ATP) is regenerated through the breakdown of glycogen by glycolysis. As glycogen is broken down, lactic acid accumulates in the animal carcass; the muscle gradually acidifies, causing a decline in muscle pH (Warriss, 2000). The conversion of glycogen to lactic acid continues until a pH of 5.4 – 5.5 (the iso-electric point of the principal proteins) is reached (Lawrie, 1998). At this pH, enzymes affecting the breakdown of glycogen become inactivated and a loss in water holding capacity (WHC) is inevitable as the fall in muscle pH continues.

If lactic acid builds up too quickly when muscle pH is declining rapidly, denaturation of muscle protein can result in loss of meat tenderness, loss of juiciness and muscle discolouration and in extreme cases, the muscle can become pale, soft and exudative (PSE). The higher the ultimate pH, the less will be the decrease in WHC. The ultimate pH is determined by the extent of pH decline 24 hours after slaughter, which in turn depends on type of animal, breed, rearing characteristics and treatment of the animal prior to slaughter. In well-fed unstressed animals, ultimate pH is reached when the carcass has reached a temperature low enough to prevent excessive protein denaturation. The pH value typically falls from 7.2 to around 5.5 (Sales, 1999).

Under normal conditions free-range lambs have sufficient glycogen to lead to a normal muscle ultimate pH, although higher than feedlot animals (Priolo *et al.*, 2001). Ante mortem stress could be a risk for higher ultimate pH (Bowling *et al.*, 1977). High-energy diets protect animals from potentially glycogen depleting stressors (Immonen *et al.*, 2000). Free-range animals are generally not accustomed to human presence and handling and this could also have some influence on the pre-slaughter glycogen depletion (Priolo *et al.*, 2001). It is known that fatter carcasses (normally from feedlot lambs) cool down at a slower rate than leaner carcasses and therefore have a more rapid post mortem glycolysis, which results in a lower pH (French *et al.*, 2001; Lawrie, 1998; Priolo *et al.*, 2001). Diaz *et al.* (2002) found that feeding system had no effect on muscle pH, possibly because there was an adequate food supply and minimal animal stressors in their experiment.

Ram lambs have been shown to have a higher muscle ultimate pH than ewe lambs (Johnson *et al.*, 2005). In fact, Bickerstaffle *et al.* (2000) reported an elevated pH in meat from ram lambs that were kept with ewe lambs till slaughter. Other investigations have found no differences in pH between different gender groups (Diaz *et al.*, 2003; Dransfield *et al.*, 1990).

Meat colour

The bright red colour of lamb is due to oxygenation of myoglobin when meat is exposed to air. Meat colour depends on the concentration of pigments (myoglobin, haemoglobin), their chemical states, type of myoglobin molecule, and the light scattering properties of meat (Lawrie, 1998).

Myoglobin (Mb), a water-soluble protein, is composed of globin and an iron containing heme group. The heme has a centrally located iron atom that can form six bonds. The nature of the sixth ligand influences the light absorbing characteristics of the colour of the ligand-myoglobin complex (Mancini & Hunt, 2005). When no ligand is present at the rather sixth position of the iron, the heme iron is ferrous (Fe^{2+}), and muscle colour is purplish red or purplish pink (Brewer, 2004). Discolouration of the muscle surface results from the oxidation of both ferrous myoglobin and oxymyglobin to ferric iron. The central iron is oxidised (Mb $Fe^{2+} + O_2 \rightarrow Mb^3 + O=O^-$), thus loosing an electron and yielding brown or grey brown metmyoglobin ($MbFe^{3+}$). Oxidation to $MbFe^{3+}$ is slower than oxygenation.

The rate and extent of muscle pH decline has a great impact on the colour of meat and meat products. Normal pH decline in muscles is from approximately 7.0-7.2 to 5.5-5.7 (Sales, 1999). If the muscle pH decreases to 5.5-5.7 within 45 minutes or less the muscle will appear very pale and soft and will exudate a high volume of drip (PSE) (Sales, 1999; Lawrie, 1998). If the pH does not drop to a large extent in post mortem muscle the meat will be dark with a dull dry surface (Sales, 1999; Lawrie, 1998). A high ultimate pH exhausts the activity of the enzymes to reduce metmyoglobin to myoglobin (Lawrie, 1998).

In recent years, research activities involving modified atmospheric packaging (MAP) centred on finding the correct combination of gases that would maximize and stabilize product colour while maximizing shelf life and minimizing microbial growth and lipid oxidation. High-oxygen atmospheres maintains colour during storage (Kropf, 2004), but rancidity develops while the colour remains desirable (Jayasingh *et al.*, 2002). Ultra low oxygen atmospheres in MAP are beneficial in minimizing lipid oxidation and microbial growth but poor blooming establishes especially if ultra-low oxygen levels are not maintained after long storage. Hunt *et al.* (2004) and Jaysingh *et al.* (2001) found that the inclusion of carbon monoxide in MAP lead to a bright-cherry red colour on the surface of beef.

Several scientific investigations report meat from free-range lambs to be darker than meat from feedlot lambs (Diaz *et al.*, 2002; Priolo *et al.*, 2002; Piansentier, 2003; Bidner *et al.*, 1981; Baardseth *et al.*, 1988). Colour differences between production systems may be due to different levels of physical activity undertaken by the animals (Vestergaard *et al.*, 2000), differences in muscle ultimate pH (Pethick *et al.*, 2005; Immonen *et al.*, 2000) and haemic pigment concentration in muscles (Diaz *et al.*, 2002; Priolo *et al.*, 2002; Piansentier, 2003).

Gender studies pertaining to meat colour often report that meat from intact males is darker than that of castrates (Johnson *et al.*, 2005; Monin and Quali, 1991; Seideman *et al.*, 1982), although reports exist where no differences in colour between gender groups have been detected (Destefanis *et al.*, 2003; Diaz *et al.*, 2003; Vergara *et al.*, 1999; Jeremiah *et al.*, 1997; Boccard *et al.*, 1979; Field, 1971).

Water holding capacity (WHC)

The WHC of meat refers to its ability to retain its water during the presence of external factors such as cutting, mincing and storage (Sales, 1996). Water holding capacity affects the appearance of meat before cooking, its behaviour during cooking, its capacity to hold moisture during processing and juiciness upon mastication (Lawrie, 1998; Barge *et al.*, 1991; Honikel, 1998; Onyango *et al.*, 1998).

Muscle is mainly composed of water (approximately 75%), protein (approximately 20%), lipids (approximately 5%), carbohydrates (approximately1%) and vitamins and minerals (approximately 1%), often analysed as ash (Huff-Lonergan & Lonergan, 2005). Water is held within the myofibril, between myofibrils, between myofibrils and the sarcolemma, between muscle cells and between muscle groups (Offer & Cousins, 1992), and is bound by proteins. Meat proteins first bind a small quantity of water, (5-10 g/100 g protein) termed "bound water" directly to the charged amino acid groups (Sebranek, 2004; Huff-Lonergan & Lonergan, 2005). Bound water is resistant to freezing and is not driven off by conventional heating. Another 2-3-molecule layer forms around protein groups (50 – 60 g/100 g protein) (Sebranek, 2004) and it is termed immobilized (also referred to as entrapped) water. This water fraction may be held in place by either steric effects or by attraction to bound water and does not flow freely from tissue but is easily removed by drying and can be converted to ice during freezing. The rigor process mostly affects it during the conversion of muscle to meat (Huff-Lonergan & Lonergan, 2005). Free water is attracted weakly to both bound and immobilized water, and is held loosely and is very depended upon capillary spaces between and within proteins.

When meat is cut, a red aqueous solution (which affects the value of the meat negatively), known as weep in uncooked meat, which has not been frozen and drip in uncooked thawed meat, seeps from the surface over time (Lawrie, 1998). Drip loss is a combination of water, salt-soluble proteins and water-soluble proteins such as sarcoplasmic proteins (Swatland, 1995). The amount of weep lost from muscle depends on the quantity of fluid released from its association with muscle proteins on shrinkage of the lattice of thin and thick filaments (Lawrie, 1998). Water- and salt-soluble proteins decrease over time (Offer & Trinick, 1983). Muscle pH and the rate of pH decline influence the WHC of meat (Swatland, 1995; Warris, 2000). An increased final pH increases the WHC of meat, thus lowering moisture losses (Onyango *et al.*, 1998). A high WHC leads to the surface of the meat appearing dry, less moisture being lost during cooking resulting in an unfavourable impression of meat juiciness during mastication. Loss in WHC due to elevated temperatures is likely to increase denaturation of the muscle proteins partly because of the enhanced movement of water into the extracellular spaces (Lawrie, 1998).

A decrease in the WHC of cooked meat is manifested by the exudation of fluid known as shrink (Lawrie, 1998). The different meat proteins denature during cooking of meat (Honikel, 1980), causing structural changes (cell membrane destruction, shrinkage of muscle fibres and aggregation of sarcoplasmic proteins

and shrinkage of connective tissue) that result in cooking loss. A high WHC results in low cooking loss (Onyango *et al.*, 1998).

Meat tenderness

The overall impression of meat tenderness involves three aspects; ease of penetration by teeth, ease with which meat breaks into fragments and the amount of residue that is left after chewing (Lawrie, 1998; Forrest *et al.*, 1975; Gillespie, 1960). Meat tenderness is influenced by the myofibrillar component (ultrastructure of the myofibrillar proteins) and the stromal components (content, composition and structure of connective tissue proteins) (Muir *et al.*, 1998). Finer muscle fibres of young animals are more tender than coarser muscle fibres of older or large framed animals (Lawrie, 1998). Collagen is the major protein in connective tissue and constitutes about 25-30% of the total protein in muscles. Tenderness caused by connective tissue is due to cross-linkages between collagen molecules. Young, growing animals' meat is tender upon the first bite because the connective tissue is characterized by the increased soluble collagen percentage linked to a lower amount of cross-bond connective tissue. An increase in animal age is related to a reduction in the proportion of salt and acid soluble collagen, an increase in the extent of intra and intermolecular cross-linking between polypeptide chains of collagen and a decrease of collagen solubility on heating and decreasing susceptibility to attack by enzymes (Lawrie, 1998).

In general, tenderization is the direct result of the ability of calpain to degrade Z-disks in skeletal muscle. The bulk of muscle protein is then degraded through other pathways such as the lysosomal pathway. Calpain activity is inhibited by calpistatin (Quali, 1990). The ratio of calpain to calpastatin could also be considered as an indicator of the activity of calpain and possibly tenderization. Inhibition of calpains by calpastatin is pH depended. Calpastatin activity measured under optimal conditions (pH 7.5) always exceeds the activity of μ-calpain. Under post-mortem pH conditions (pH <5.8), calpain activity is reduced but the effectiveness of calpastatins are reduced even more. Other proteinases such as cathepsins have been isolated and may be involved in long-term aging. They are active at more acidic levels (pH 5.4 – 5.6). Cathepsin B has been shown to have activity against collagen and proteoglycans (Devine, 2004). Calpains are responsible for 90% or more of the tenderization that occurs during postmortem storage (Goll *et al.*, 1992). The major enzyme involved in post mortem proteolysis is μ-calpain (Geesink & Koohmaraie, 1999).

Pre-slaughter feeding and animal growth rate have a direct effect on meat tenderness (Fishell *et al.*, 1985). Rapid growth rates, due to high energy diets, result in higher proportions of less cross-linked collagen and an increased protein turnover. This results in higher concentrations of proteolytic enzymes in carcass tissues at slaughter which increases meat tenderness (Fishell *et al.*, 1985). Free-range animals have been shown to produce tougher meat than feedlot animals because of higher levels of exercise of free-range lambs during their grazing activity (French *et al.*, 2001; Vestergaard *et al.*, 2000; Schroeder *et al.*, 1980). Also,

larger and fatter carcasses of feedlot lambs insulate the carcasses (better than lean free-range carcasses) and slow down post mortem chilling which in turn improves meat tenderness by decreasing the extent of cold-shortening. Slow post mortem chilling may also enhance post mortem muscle autolysis. Contradictory results show that meat from lambs fed a low energy diet is more tender than meat from lambs fed high energy diets (Solomon *et al.*, 1986). When feedlot- and free-range cattle grow at a similar rate prior to slaughter at the same weight or age, no differences in either shear force values or tenderness evaluated by a taste panel are observed (Mc Intyre & Ryan, 1984).

Lamb gender seems to influence meat tenderness. Scientific investigations concur that meat from ram lambs is less tender than that of castrates (Field, 1971), despite the existence of reports that show no differences in tenderness between ram and castrates lambs (Bradford & Spurlock, 1964). Ruminant studies involving cattle observed that meat from bull carcasses is less tender and less palatable than meat from steer carcasses (Seideman *et al.*, 1982; Field, 1971). This is because μ-calpain and calpastatin activity tends to be higher in bulls than in steers. Greater calpastatin activity decreases the amount of protein proteolysis by μ-calpain. After puberty, testosterone levels increase in males. This increase in testosterone also leads to an increase in the amount of collagen in the muscles and reduces the tenderness of meat (Pommier *et al.*, 1989).

Meat from heavier lambs is more tender than meat from lighter lambs, this difference being associated with fatter carcasses of heavy lambs (Kemp *et al.*, 1976). Other investigations indicate that slaughter weight had no effect on the Instron shear values of *longissimus*, *semimembranosus* and *biceps femoris* muscles of lambs (Solomon *et al.*, 1980). Kemp *et al.* (1976) noted that shear force values decreased as weight increased.

The rate and extent of post-mortem glycolysis affects beef, lamb and pork tenderness. Tenderness appears to decrease when the ultimate pH increases from 5.5 to 6.0 but increases above 6.0. In sheep and beef, tenderness is minimal at pH values between 5.8 and 6.2. At pH 6.8 meat tenderness is excessive and is associated with jelly-like consistency, which lowers overall product acceptability. The rate and extent of post-mortem proteolysis is temperature dependent (Lawrie, 1998).

Temperature has a major influence on the rate of ageing. Calpains are inactivated at high rigor temperatures (i.e. 35°C) and meat does not age to its full potential. At lower temperatures there is a shift to slower but longer and more effective tenderization. Cooking temperatures have a final bearing on meat tenderness. At temperatures between 40-65°C, denatured myofibrillar proteins aggregate and this is accompanied by a loss of fluid and shrinkage of the muscle fibres within the endomysial sheath. This leads to an increase in toughness of meat. As temperatures rise from 65-80°C, additional shrinkage of the collagen in the endomysium and perimysium occurs and more water is squeezed out. This could lead to an increase in the shear force values. Further increases in temperature above 80°C and prolonged heating leads to collagen solubilisation and ultimately leads to a reduction in shear force values (Lawrie, 1998).

Pre-rigor ionic compound infusions are a feasible means of improving meat tenderness. It alters the rate of glycolysis, rate and state of contraction and the rate at which proteolysis proceeds. Calcium chloride has proven particularly useful in this regard but negative effects on colour (Lawrence *et al.*, 2003a; Kerth *et al.*, 1995; Wheeler *et al.*, 1993) and flavour (Lawrence *et al.*, 2003b; Wheeler *et al.*, 1997) are well documented.

Where tenderness differences exist among animals of either the same breed, age or slaughter weight of a given muscle, the difference cannot be linked to total collagen content or the amount of mature or immature collagen cross links present. In this case, differences may be explained by factors that control the rate of post-mortem glycolysis or autolysis or physiological factors (Lawrie, 1998).

CHEMICAL COMPOSITION OF MEAT

The chemical composition of meat provides nutrional information. It seems that production system indeed influences the proximal composition of meat.

Moisture

Muscle contains approximately 75% moisture (Huff-Lonergan & Lonergan, 2005) which is held within the myofibril, between myofibrils, between myofibrils and the sarcolemma, between muscle cells and between muscle groups (Offer & Cousins, 1992). Muscle moisture content is high when fat content of lambs is low and the opposite is also applicable (Theriez *et al.*, 1981). Numerous scientific investigations report differences in carcass fatness levels due to production system (Díaz *et al.*, 2002; Santos- Silva *et al.*, 2002). Free-range diets allow skeletal and muscle tissue growth without excess fattening while energy dense diets associated with feedlot diets lead to greater carcass fatness. Leaner carcasses of free-range relate to higher muscle moisture content (Rowe, 1999). Schroeder *et al.* (1980), on the other hand, found no difference in moisture content between forage- and grain-finished beef.

Sex hormones influence carcass fatness levels, which in turn have a bearing on muscle moisture percentage. Intact males produce leaner carcasses than castrates and ewe lambs (Arnold & Meyer, 1988; Seideman *et al.*, 1982; Crouse *et al.*, 1981; Field *et al.*, 1971). Leaner carcasses of intact males are associated with increased moisture levels. Castration affects the chemical composition of muscle by inducing a decrease in the moisture content and an increase in fat content, this effect being more marked in late castrated animals (Destefanis *et al.*, 2003; Monin & Quali, 1991). Gender studies involving cattle show that steers have lower muscle moisture content than bulls.

Solomon *et al.* (1980) and Kemp *et al.* (1976) observed that lambs slaughtered at heavier weights contained less moisture and more protein and less ether extract. Kemp *et al.* (1976) report that whether carcasses contain more moisture and protein and less fat than ewe carcasses (Kemp *et al.*, 1976).

Protein

Proteins have the ability to support rapid growth when consumed by animals and are thus of high biological value (Arbele *et al.*, 2001). Red meat in particular is considered a high value animal protein (MacRae *et al.*, 2005) because it contains all the essential amino acids in amounts equivalent to human requirements, is highly digestible and easily absorbable (Arbele *et al.*, 2001). Lean portions of red meat contain 19 to 23 percent protein. This is in agreement with Huff-Lonergan & Lonergan (2005) who found that the protein content of meat is approximately 20%. This content varies inversely with the amount of fat present, and because of moisture and fat losses during cooking, increases to 25 to 30 percent in cooked meat (Arbele *et al.*, 2001). Similarly, muscle protein content decreases when fat content increases (Theriez *et al.*, 1981).

Rowe at al. (1999) found that muscle protein was not affected by production system. Gender studies involving cattle show that steers have lower muscle protein than bulls. Higher protein contents in bull beef are due to the presence of testosterone, as the presence of this hormone is related to a greater muscle growth capacity (Field, 1971).

Solomon *et al.* (1980) and Kemp *et al.* (1976) observed that lambs slaughtered at heavier weights contained less protein.

Lipid

The amount of lipid in meat cuts depends on the amount of trimmed fat within and between muscles and the amount of subcutaneous fat remaining after cutting and trimming. Lipids of major importance from a nutritional point of view are triglycerides, phospholipids, cholesterol and limited quantities of fat-soluble vitamins (Arbele *et al.*, 2001). Lipids comprise approximately 5% of muscular tissue (Huff-Lonergan & Lonergan, 2005). The effect of production system and gender on muscle lipid content has been discussed previously (see Moisture section). Solomon *et al.* (1980) and Kemp *et al.* (1976) observed that lambs slaughtered at heavier weights contained a higher ether extract.

Fatty acid composition of muscle and depot fat

Although the fatty acid composition of fat has no influence on the market value of a carcass, it affects the eating and keeping quality of meat. It is well known that the fatty acid composition of fat influences meat flavour (Melton, 1990). Saturated fatty acids (SFA) are known to increase the hardness of fat, the later

being easily solidified upon cooling, which influences meat palatability (Banskalieva *et al.*, 2000). Unsaturated fatty acids on the other hand increase potential for oxidation which influences shelf-life (Banskalieva *et al.*, 2000).

Meat fat comprises mostly monounsaturated fatty acids (MUFA) and saturated fatty acids (SFA). Oleic acid (C18:1), palmitic acid (C16:0) and stearic acid (C18:0) are the most abundant fatty acids (Valsta *et al.*, 2005). Linoleic acid (C18:2) is the predominant PUFA (0.5-7%) followed by α-linolenic (up to 0.5%). Trans-fatty acids comprise about 1-2% of total fatty acids across all types of meat; in ruminant meat they represent 2-4%. Palmitic and stearic acids are the main saturated fats in red meat (Higgs, 2000). Meat is one of the best sources of MUFA in the diet. Oleic acid is the main monounsaturated fatty acid (40%) in meat (Higgs, 2000). A diet that is rich in oleic acid is associated with improved health such as a lower risk of cardiovascular disease.

It is generally accepted that plasma cholesterol concentration is influenced by the fatty acid composition of dietary fat. The ratio of polyunsaturated to saturated fatty acids is more important for health reasons than the total fat content (Higgs, 2000). A decrease of saturated fatty acids, especially myristic and palmitic acid is associated with lower blood serum cholesterol which ultimately leads to a decrease in the risk of cardiovascular heart disease. Myristic acid is thought to be the most atherrogenic and has four times the cholesterol elevating effect of palmitic acid. Stearic acid has a neutral effect. Research results however indicate that not all PUFA are equally beneficial in terms of preventing non-communicable diseases. Immunologists demonstrated that n-6 PUFA were less beneficial than n-3 PUFA. The n-3 fatty acids are able to modulate inflammation by competing with the n-6 metabolites for incorporation into the immune cells membrane phospholipids (Calder & Grimble, 2002).

Muscle lipids

The principal fatty acids of intramuscular fat for ruminants finished on either pasture or concentrate are stearic (C18:0), oleic (C18:1) and palmitic acid (C16:0) (Valera *et al.*, 2004). In muscle lipids of goats, oleic (C18:1), palmitic (C16:0), stearic (C18:0) and linoleic acid (C18:2) are the major fatty acids (Banskalieva *et al.*, 2000). Futhermore, SFA mainly include mystyric, palmitic (C16:0) and stearic acid (C18:0). As for MUFA, it includes mainly palmitoleic (C16:1) and oleic acid (C18:1) and PUFA consists largely of linoleic (C18:2), linolenic (C18:3) and arachidonic acid (C20:4). The results presented by Banskalieva *et al.* (2000), indicate that the percentages of palmitic (C16:0) and stearic acid (C18:0) in goat muscles are similar to those for other ruminant species. The mean concentration of SFA in goat muscles from numerous studies also indicates that it is not different from that in lamb and beef (Banskalieva *et al.*, 2000). As for monounsaturated fatty acids, palmitelaidic acid (C16:1) is higher in goat muscle than in lamb muscle. Furthermore, goat muscles are higher in PUFA (i.e., C18:2, C18:3 and C20:4) than lamb and beef, but

lower compared to pork (Banskalieva *et al.*, 2000). In general *M. longissimus dorsi* in beef is lower in PUFA compared with hind limb *gluteus medius* muscle (Enser *et al.*, 1998).

Other depots

In goats, the main fatty acids regardless of location of adipose tissues in the body are oleic (C18:1), stearic (C18:0) and palmitic acid (C16:0) followed by myristic (C14:0), palmitelaidic (C16:1), heptadecenoic (C17:0) and linoleic acid (C18:2) in lower concentrations. Goat lipids mainly consist of SFA (30-71%) and MUFA (20-57%) (Banskalieva *et al.*, 2000).

Sheep kidney fat is higher in mystyric acid (C16:0), MUFA and PUFA and lower in stearic (C18:0) acid compared to goat kidney fat. Sheep and goat kidney fat are similar in their concentration of palmitic acid. Subcutaneous fat depots in sheep are more saturated, relatively lower in MUFA and contain more linoleic (C18:2) and linolenic (C18:3) compared to goats (Banskalieva *et al.*, 2000). When Gaili & Ali (1985) compared subcutaneous, kidney and intermuscular fat depots in fattening sheep and goats they found that sheep kidney fat was lower in stearic acid (C18:0) and relatively higher in oleic acid (C18:1) compared to goats. When kids and lambs are slaughtered at the same age, the subcutaneous and kidney fat of lambs is softer than that of goats, owing it to a higher unsaturated fatty acid content (Zygoyiannis *et al.*, 1992). On the other hand, Webb & Casey (1995) indicated that subcutaneous adipose tissue of lambs was high in stearic acid (C18:0). Banskalieva *et al.* (2000) reported that the mean percentage of stearic acid (C18:0) in subcutaneous tissue of lambs and goats is similar. Results of several scientific investigations indicate that internal depots in goats and lambs are more saturated than subcutaneous fat (Banskalieva, 1996; Zygoyiannis *et al.*, 1985; Kemp *et al.*, 1981). In agreement, Belibasakis *et al.* (1990) and Leat (1976) also concluded that subcutaneous fat is more unsaturated (i.e., softer) in sheep, cattle and pigs than internal depots. However, data compiled by Banskalieva *et al.* (2000) suggest that some internal depots in kids are less saturated than other subcutaneous fat depots.

Production/feeding system effect on muscle and depot fat

Numerous scientific investigations involving ruminants show that different nutritional regimes can change muscle fatty acid composition, PUFA level and the n-3:n-6 PUFA ratio (Enser *et al.*, 1998; Melton, 1990). Santos-Silva *et al.* (2002) observed that *longissimus* muscles of pasture raised lambs presented higher concentrations of mystiric (C14:0) and pentadecanoic (C15:0) acid and lower proportions of palmitic (C16:0), palmitoleic (C16:1cis-9) and oleic (C18:1cis-9) acids compared to concentrate fed lambs. Rowe *et al.* (1999) found that *longissimus* muscle of grazing lambs had higher proportions of saturated long chain fatty acids in the form of stearic (C18:0) and arachidic acids (C20:0). Pasture feeding increases n-3 fatty acids in *longissimus* muscle while concentrate feeding leads to higher proportions of n-6 fatty acids (Nuernberg *et al.*, 2005 Piasentier, 2003; Santos-Silva *et al.*, 2002; Enser *et al.*, 1998). Nuernberg *et al.*

(2005) found that the long chain PUFA docosahexaenoic acid (DHA, C22:6n-3) was significantly accumulated by grass feeding. Santos-Silva *et al.* (2002) observed that linoleic acid (C18:2n-6) decreased for pasture raised lambs while it remained unchanged for concentrate fed lambs. Grass contains high levels of linolenic fat (C18:3n-3), the precursor of n-3 fatty acids while concentrates are high in C18:2n-6, the precursor of the n-6 fatty acids. When Russo *et al.* (1999) fed three different diets; *ad libitum* lucerne hay and concentrate supplemented with barley flakes (9%), *ad libitum* lucerne hay and concentrate supplemented with maize oil (5%) and solely concentrate fed in diet 2 to three groups of lambs, oleic acid was the most abundant fatty acid found in both the *M. longismuss lumbarum* and *M. semitendinosus*, while palmitic acid was second and stearic acid was third highest. Lambs on diet 3 had high proportions of palmitic acid (C16:0) that were significantly higher when compared to the other diets. There was however a reduction in the n-3 fatty acids and an overall increase in the amount of saturates (eg. mystiric and palmitic). Depot and intramuscular fat in diet 3 showed an increase in the level of unsaturation.

Diaz *et al.* (2002) noted that subcutaneous fat of pasture raised lambs have greater proportions of saturated fatty acids than concentrate fed lambs. Greater proportions of saturated fatty acids may be due to forage intake which stimulates ruminal activity and thus the biohydrogenation of fatty acids, increasing the concentration of fatty acids (Choi *et al.*, 1997). Concentrate feeds on the other hand lead to a higher quantity of available carbohydrates, which shortens the residence time in the rumen and decreases the biohydrogention of fatty acid (Diaz *et al.*, 2002). Casey & Webb (1995) reported that the pelleting of high density feeds causes greater accumulation of pentadecanoic and oleic acid while diets presented in loose form are characterised by greater proportions of stearic and linoleic acid in the subcutaneous adipose tissue of whethers. There seems to be a significant shift in the proportions SFA towards USFA with increasing dietary energy which is characterized by a decline in firmness of subcutaneous adipose tissue (Casey & Webb, 1995). Subcutaneous fat of pasture raised lambs presented lower and adequate n-6:n-3 polyunsaturated fatty acid ratios compared to concentrate fed lambs (Diaz *et al.*, 2002).

Gender effect on muscle and depot fat

Gender studies involving cattle show that the most abundant fatty acids in bull beef is oleic acid, stearic acid and palmitic acid (Padre *et al.*, 2006). Castration seems to affect the proportions of palmitic, stearic and oleic acids, indicating that steer beef contained higher palmitic acid (C16:0) and oleic acid (C18:1) while bull beef had higher stearic acid (C18:0). Ruiz *et al.* (2005) reported that there are no differences in the C16:0 and C18:1 content in steers and bulls and that the latter have a higher PUFA: SFA ratio compared to steers. According to Padre *et al.* (2006) the ratio of n-6: n-3 and PUFA: SFA were similar for steers and bulls. Gender studies involving goats showed that despite using different goat breeds and tested meats, total muscle lipid content was lower and that PUFA level and the PUFA: SFA ratio were greater in males compared to females (Matsuoka *et al.*, 1997). Waldman *et al.* (1968) and Marchello *et al.* (1967) observed that does and heifers present higher percentages of C18:1 and lower levels of C14:0 and

C18:0. Levels of branched chain fatty acids (saturated C14:0, C15:0, C16:0) in the subcutaneous fat of intact males was higher than that of castrated kids (Bas *et al.*, 1982). Rojas *et al.* (1994) did not find any effect indicative of gender on the fatty acid composition of kidney fat of goat kids.

Age effect on muscle and depot fat

Increased age at slaughter of unweaned kids changed the fatty acid composition of depot fats with decreasing proportions of stearic acid but increasing proportions of all other acids (Zygoyiannis *et al.*, 1992). Bas *et al.* (1987b) pointed out that increasing age of weaned kids receiving a concentrate based diet decreases the MUFA level in kidney and subcutaneous adipose tissue.

Live weight effect on muscle and depot fat

Earlier investigations indicate that kids at heavier live weights have higher stearic acid concentrations for fat depots except sternal and inguinal fat while the content of SFA increased and the level of MUFA decreased in all depots (Sauvant *et al.*, 1979). Kids receiving milk replacer and concentrates and slaughtered at 12, 16 or 19 kg live weight, in both inguinal and sternal adipose tissue show that there was a constant decrease in the ratio SFA: USFA as live weight increased. Banskalieva (1996) and Webb & Casey (1995) reported similar results for subcutaneous and perirenal fat for lambs slaughtered at different live weights.

Cholesterol

Cholesterol is also a nutritionally important component of meat. The cholesterol content of meat varies between about 30 and 120 mg/100 g of meat and is even higher in offal. Muscle total cholesterol varies from 61 to 63.5 mg/100 g while adipose total cholesterol levels are between 113 and 121 mg/100 g. Lean meat would therefore probably have an almost negligible effect on cholesterol levels and might even positively influence lipid biochemistry levels by lowering saturated and increasing polyunsaturated fatty acids. The later result was confirmed when lean beef was consumed as part of a low saturated fat diet (Higgs, 2000). Nutritional guidelines stipulate that cholesterol intake should not exceed 300 mg per day. This is because exceeding amounts of cholesterol can raise serum cholesterol, the latter having long being associated with chronic heart disease although it was recently shown that dietary cholesterol had little effect on serum and low density lipoprotein cholesterol levels (Nelson *et al.*, 1995). It is thought that the changes in blood cholesterol levels can be ascribed to the ratio of fatty acids in the diet.

Gender does not seem to affect the cholesterol concentration of bovine skeletal muscle (Rule *et al.*, 1997). It seems that differences in muscle cholesterol concentration may be associated with marked changes in muscle cell structure. Altering cholesterol concentration in muscle may require a marked redistribution of membrane fatty acids (Rule *et al.*, 1997).

Conjugated linoleic acid (CLA) content

Conjugated linoleic acid (CLA) are produced in the rumen from the bioconversion of linoleic acid and are intermediary metabolites in the production of stearic acid. The rumen bacterium, *Butyrivibrio fibrosolvens* shows specificity towards the biohydrogenation of linoleic acid (Kepler *et al.*, 1996). CLA are widely defined as a combination of several positional and geometric isomers with double bonds predominantly at the 9, 11, 10 and 12 or 11 and 13 carbon atoms with various combinations of cis- and trans- configurations.

Meat and milk from ruminant animals contain more CLA than products from monogastrics (Jiang *et al.*, 1999). Supplementing ruminant diets with high quality sources of linoleic acid has been shown to increase the CLA concentration in meat (Kott *et al.*, 2003). It therefore seems that the CLA content of ruminant products is depended on the nature of the feed fed to them. CLA have been shown by several researchers to have beneficial effects on human health and disease prevention. Health benefits from the inclusion of CLA in human diets involve the reduction in body fat accumulation (Park *et al.*, 1999), enhanced immune function (Sugano *et al.*, 1998), reductions in the development of arteriosclerosis and antidiabetic effects, and antioxidant activity (Pariza & Ha, 1990b).

Ash

The ash content of a meat sample represents the total mineral content of that sample, albeit a crude estimate. Minerals are vital in human nutrition (Biesalki, 2005; Mac Rae *et al.*, 2005; Higgs, 2000). Red meat has high iron content as well as high potassium and phosphorus contents (Higgs, 2000; Lawrie, 1998).

It seems that production system does not have an effect on ash content (Rowe et al, 1999). Gender studies involving cattle show that steers have lower muscle ash content than bulls (Rowe et al, 1999). Kemp *et al.* (1976) reported a larger ash percentage in ewe carcasses compared to castrates.

In their investigation, Solomon *et al.* (1980) found that percentage ash is not affected by slaughter weight.

SENSORY MEAT QUALITY

The sensory quality of meat refers to the aroma, juiciness, tenderness and flavour of meat. Aroma is perceived as an odour passing into the nasal area from the mouth when it volatiles, or is sniffed through the nostrils (Teff, 1996). Meat flavour is a complex sensation, which consists of aroma and taste (Charley & Weaver, 1998). Meat juiciness is related to the WHC of meat (Offer & Trinick, 1983). Tenderness is the predominant quality determinant and probably the most important quality characteristic of red meat.

Sensory meat quality attributes are influenced by many factors. In this thesis the effect of production system and gender are considered.

Juiciness

In analytical sensory analysis two sensory components are used to measure meat juiciness (AMSA, 1978). The first sensory component, initial meat juiciness, refers to the amount of fluid exuded on the meat surface when pressed between thumb and forefinger. Initial meat juiciness is related to the WHC of meat (Offer & Trinick, 1983). The second component, sustained juiciness refers to the impression that is formed after the first two to three bites between the molar teeth. Sustained juiciness is affected by the presence of fat because intramuscular fat stimulates the secretion of saliva, thus improving juiciness (Lawrie, 1998).

Fatter carcasses that stem from feedlot finishing improve meat juiciness through an increase in the intramuscular fat compared to leaner free-range carcasses (Priolo *et al.*, 2002; Arnold & Meyer, 1998; Notter *et al.*, 1991; Summers *et al.*, 1978; Oltjen *et al.*, 1971). Gender studies show that leaner carcasses of intact males are associated with less juicy meat compared to ewes and castrate lambs (Priolo *et al.*, 2002; Lawrie, 1998). Kemp *et al.* (1976) however did not note any differences in juiciness due to castration in lamb. Research results indicate that lamb juiciness improved significantly when lambs were slaughtered at heavier weights although the differences were small and the values were acceptable (Kemp *et al.*, 1976).

Flavour

Lamb fat has a very unique aroma and flavour (Duckett & Kubert, 2001; Jamora & Rhee, 1998). Flavour is associated with two components; precursors and flavour volatiles. Flavour precursors are the water soluble compounds (sugars, amino acids and nucleotides which are common to different species) and myofibrillar proteins. Although myofibrillar proteins do not produce flavour, small peptides, carbohydrates and some inorganic ions do produce aroma. Species specific flavours are located in the lipid-soluble (fat) fraction. The proportions of the different fatty acids in the fat, particularly the unsaturated fatty acids which are more susceptible to oxidation into volatile compounds of low molecular weight such as aldehydes, ketones and hydrocarbons and alcohols, contribute to the aroma of the meat. Phospholipids which are rich in polyunsaturated fatty acids also play a fundamental role in the flavour of meat. Branched chain fatty acids, carbonyl compounds, sulphur containing compounds, lipid oxidation products, phenols and basic compounds are all believed to impact on lamb flavour (Duckett & Kubert, 2001).

Meat from free-range animals has a more intense flavour than meat from feedlot animals (Priolo *et al.*, 2001; Kemp *et al.*, 1979). Feedlot diets alter the fat composition and reduce the lamb flavour intensity (Rousset-Akrin *et al.*, 1997). Crouse *et al.* (1981) showed that flavour of ground meat of lambs fed a low energy diet was more intense than that of ground meat from lambs fed a high energy diet. Increases in

live weight are also associated with flavour and odour increases that may even be undesirable (Quali, 1990). When feedlot and free-range animals are slaughtered at the same weight and/ or fat cover, no differences in flavour has been observed (Muir *et al.*, 1998). However, differences between sensory panelists and/or high quality pastures may be the reason why no differences in flavour between feeding systems are detected (Melton, 1990). Kemp *et al.* (1976) found that flavour was significantly ($P < 0.05$) more desirable in wethers than in rams. Kemp *et al.* (1976) did not observe any flavour differences attributable to slaughter weight.

CONCLUSION AND OBJECTIVES

Modern day consumers are concerned about diet/health relationships. They believe that free-range meat is healthier because it is lean, natural and free of hormones. Animal welfare issues also seem to motivate purchasing behaviour. To meet consumer demands, free-range animal production presents itself as an attractive means to restore consumer confidence. It would therefore be of great value to the meat industry to gain more information about the effect of production system on animal growth, meat quality and the fatty acid profiles of muscular and fat depots. In South Africa, the Dorper is the second most abundant sheep breed that was specifically selected for adaptability under South Africa's harsher conditions. It is an early maturing breed that has the inherent characteristics of performing well under both extensive and intensive feeding conditions. Information on the effect of production system on Dorper lamb growth, carcass characteristics, meat quality (physical, chemical and sensory) and fatty acid profiles of fat depots is lacking and would be valuable to producers and traders alike.

REFERENCES

AMSA . 1978. Guidelines for cookery and sensory evaluation of meat. Chicago, IL: American Meat Science Association, National Livestock and Meat Board.

Arbele, E.D., Forrest, J.C., Gerrard, D.E. & Mills, E.W. 2001. Principles of Meat Science. Fourth Edition. Kendall/ Hunt Publishing Company. Dubuque, Iowa.

Arnold, A. M. & Meyer, H. H. 1988. Effects of gender, time of castration, genotype and feeding regime on lamb growth and carcass fatness. Journal of Animal Science, 66, 2468-2475.

Baardseth, P., Skrede, G., Naes, T., Thomassen, M.S., Iversen, A. & Kaaber, L. 1988. A comparison of the CIE L*A*B values obtained from two different instruments on several food commodities. Journal of Food Science, 53, 1737-1742.

Banskalieva, V., Sahlu, T. & Goetsch, A.L. 2000. Fatty acid composition of goat muscles and fat depots: a review. Small Ruminant Research, 37, 255-268.

Banskalieva, V. 1996. Effect of age, physiological state, and nutrition on fatty acid composition in depot fat and ruminal volatile fatty acids in sheep. Small Ruminant Research, 24, 37-42.

Barge, M.T., Destefanis, G., Pagano Toscano, G. & Brugiapaglia, A. 1991. Two reading techniques of the filter press method for measuring meat water holding capacity. Meat Science, 29, 183-198.

Bas, P., Gallion, F., Morand-Fehr, P., Rouzeaau, A. & Hervieu, J. 1987b. Variations de composition et d' activite LPL des tissues adipeux abdominaux selon le lieu de prelevement chez la chevre en de gestation. Reproductive Nutrition and Development, 27 (1 B), 311-312.

Bas, P., Hervieu, J., Morand-Fehr, P. & Sauvant, D., 1982. Factors influencing the composition of fat in slaughater kids: effects on quality of carcass fat. Nutrition et systemes d'alimentation de chervre, 1, 90-100.

Belibasakis, N., Koudifis, D., Psomas, J., Zygoyiannis, D. 1990. Effect of olive cake pulp feeding on the growth performance and some carcass characteristics of finishing bulls. In: Proceedings of VI International Confrence on goats. Being, China. P.685.

Bennet, R.M. 1996. People's willingness to pay for farmed animal welfare. Animal Welfare, 5, 3-11.

Bickerstaffle, R., Palmer, B.R., Geesink, G.H., Bekhit, A.E.D. & Bellington, C. 2000. The effect of gender on meat quality of lamb longissimus dorsi. Proceedings of the International Congress of Meat Science and Technology, 46, 104-105.

Bidner, T.D., Schupp, A.R., Montgomery, R.E. & Carpenter, J.C. 1981. Acceptability of beef finished on all forage, forage-plus-grain or high energy diets. Journal of Animal Science, 53, 1181-1187.

Biesalski, H.K. 2005. Meat composition of a healthy diet-are there any risks or benefits if meat is avoided in the diet? Meat Science, 70, 509-524.

Boccard, R., Naude, D.E., Cronje, D.E., Smit, M.C., Venter, H.J. & Rossouw, E.J. 1979. The influence of age, sex and breed of cattle on their muscle characteristics. Meat Science, 4, 261-281.

Boer, J., Zonderland, J. & De Boer, J. 1996. as cited by Diaz, M.T., Velasco, S., Caneque, V., Lauzurica, S., de Huidobro, F. R., Perez, C., Gonzalez, J. & Manzanares, C. 2002. The use of concentrate or pasture for fattening lambs and its effect on carcass and meat quality. Small Ruminant Research, 43, 257-268.

Bowling, R.A., Smith, G.C., Carpenter, Z.N., Dutson, T.R. & Oliver, W.M. 1977. Production, carcass and palatability characteristics of steers produced by different management systems. Journal of Animal Science, 46, 333-341.

Bradford, G.E. & Spurlock, G.M. 1964. Effect of castrating lambs on growth and body composition. Journal of Animal Production, 6, 291-299.

Brewer, S. 2004. Irridation effects on meat colour: A review. Meat Science, 68, 1-17.

Calder, P.C. & Grimble, R.F. 2002. Polyunsaturated fatty acids, inflammation and immunity. European Journal of Clinical Nutrition. 56, S14-S19.

Carpenter, C.E., Cornforth, D.P. & Whittier, D. 2001. Consumer preferences for beef colour and packaging did not affect eating satisfaction. Meat Science, 57, 359-363.

Casey, N. H & Webb, E. C. 1995. Influence of dietary energy levels and form of diet on composition of fatty acid in subcutaneous adipose tissue of wethers. Small Ruminant Research 18, 125-132.

Charley, H. & Weaver, C. 1998. Foods: A scientific approach, Third Edition. New Jersey, Upper Saddle River: Prentice-Hall.

Choi, N.J., Kim, E.J., Maeng, W.J., Neville, M.A., Enser, M., Wood, D.J. & Scollan, N.D. 1997. Rumen biohydrogenation of fatty acids of different sources of fat: as cited by: Diaz, M.T., Velasco, S., Caneque, V., Lauzurica, S., de Huidobro, F. R., Perez, C., Gonzalez, J. & Manzanares, C. 2002. The use of concentrate or pasture for fattening lambs and its effect on carcass and meat quality. Small Ruminant Research, 43, 257-268.

Cloete, S.W.P., Snyman, M.A. & Herselman, M.J. 2000. Productive performance of Dorper sheep. Small Ruminant Research, 36, 119-135.

Crouse, J. D., Busboom, J. R., Field, R. A. & Ferrell, C. L. 1981. The effects of breed, diet, sex, location and slaughter weight on lamb growth, carcass composition and meat flavour. Journal of Animal Science, 53, 376-381.

Crouse, J.D. & Field, R.A. 1978. Effect of dietary energy intake on carcass composition and palatability of different weight carcasses from ewe and ram lambs. Journal of Animal Science, 47, 1207-1218.

Davies, A., Titterington, A.J. & Cochrane, C. 1995. "Who buys organic food? A profile of the purchasers of organic food in Northern Ireland. *British Food Journal*, 97, (10), 17-23.

Destefanis, G., Brugiapagliar, A., Barge, M.T. & Lazzaroni, C. 2003. Effect of castration on meat quality in Piemontese cattle. Meat Science, 64,215-218.

Devine, C.E. 2004. Ageing *In*: Encyclopaedia of Meat Sciences. Volume One. First Edition. Elsevier Ltd., The Boulevard, Langford Lane, Kidlington, Oxford, OX5 1gb, UK.

Díaz, M.T., Velasco, S., Perez, C., Lauzurica, S., Huidoboro, F. & Caneque, V. 2003. Physio-chemical characteristics of carcass and meat Manchego-breed suckling lambs slaughtered at different weights. Meat Science, 65, 1085-1093.

Díaz, M.T., Velasco, S., Caneque, V., Lauzurica, S., de Huidobro, F. R., Perez, C., Gonzalez, J. & Manzanares, C. 2002. The use of concentrate or pasture for fattening lambs and its effect on carcass and meat quality. Small Ruminant Research, 43, 257-268.

Dransfield, E. 2001. Consumer issues and acceptance of meat. In: Proceedings of the International Congress of Meat Science and Technology, 1, 72-79. Kraków, Poland.

Dransfield, E., Nute, G.R., Hogg, B.W., & Walters, B.R. 1990. Carcass and eating quality of ram, castrated ram and ewe lambs. Animal Production, 50, 291- 299.

Duckett, S.K. & Kuber, P.S. 2001. Genetic and nutritional effects on lamb flavour. Journal of Animal Science, 79, E249-E259.

Enser, M., Hallet, K.G., Hewwett, B., Fursey, G.A.J., Wood, J.D., & Harrington, G. 1998. Fatty acid and composition of UK beef lamb muscle in relation to production system and implications for human nutrition. Meat Science, 49, 329-341.

Field, R.A. 1971. Effect of castration on meat quality and quantity. Journal of Animal Science, 32, 849.

Fishell, V.K., Aberle, E.D., Judge, M.D. & Perry, T.W. 1985. Palatability and muscle properties of beef as influenced by preslaughter growth rate. Journal of Animal Science, 61, 151-157.

Forrest, J.C., Arbele, E.D., Hedrick, H.B., Judge, M. D. & Merkel, R.A. 1975. Principles of meat science. San: W.H. Freeman and Company.

French, P., O'Riordan, E.G., Monahan, F.J., Caffrey, P.J., Mooney, M.T., Troy, D.J. & Moloney, A.P. 2001. The eating quality of steers fed grass and/or concentrates. Meat Science, 57 379-386.

Gaili, E.S. & Ali, A.E. 1985. Meat from Sudan desert sheep and goats: Part 2. Composition of muscular and fatty tissues. Meat Science, 13, 229-236.

Geesink, G.H. & Koohmaraie, M. 1999. Postmortem proteolysis and calpain/calpastatin activity in callypige and normal lamb *Bbiceps femoris* during extended postmortem storage. Journal of Animal Science, 77, 1490–1500.

Gillespie, E.L. 1960. The science of meat and products: San Francisco: W.H. Freeman and Company.

Goll D.E., Taylor, R.G., Christiansen, J.A, & Thompson, V.F. 1992. Role of proteinases and protein turnover in muscle growth and meat quality. Proceedings of the Reciprocal Meat Conference, Knoxville.

Grunert, K.G. 2006. Future trends and consumer lifestyles with regard to meat consumption. Meat Science, 74, 149 – 160.

Grunert, K.G. 1997. What's in a steak? A cross-cultural study on the quality perception of beef. Food quality and Preferance, 8, 157-174.

Harper, G.C. & Henson, S.J. 1999. "The nature of consumer concerns about animal welfare". Department of Agricultural Economics, The University of Reading, Reading.

Harper, G.C. & Makatouni, A. 2002. Consumer perception of organic food production. British Food Journal, 104, 287-299.

Higgs, J.D. 2000. The changing nature of red meat: 20 years of improving nutritional meat quality. Trends in Food Science and Technology, 11, 85-95.

Honikel, K.O. 1998. Reference methods for assessment of physical chracteristics of meat. Meat Science, 49, 447-457.

Huff- Lonergan, E., & Lonergan, S. M. 2005. Mechanisms of water holding capacity in meat: The role of post-mortem biochemical and structural changes. Meat Science, 71, 194 - 204.

Hunt, M. C., Macini, R. A., Hachmeister, K. A., Kropf, D. H., Merriman, M. & Delduca, G. 2004. Carbon monoxide in modified atmosphere packaging effects colour, shelf life and micro-organisms of beef steaks and ground beef. Journal of Food Science, 69, C45-C52.

Immonen, K., Ruusunen M., Hissa, K. & Puolanne, E. 2000. Bovine muscle contraction in relation to finishing diet, slaughter and ultimate pH. Meat Science, 55, 25-31.

Jamora, J.J. & Rhee, S.K. 1998. The uniqueness of lamb: nutritional and sensory properties. Sheep and Goat Research Journal, 14, 53-64.

Jayasingh, P., Cornforth, D. P., Brennand, C. P., Carpenter, C. E. & Whittier, D. R. 2002. Sensory evaluation of ground beef stored in high oxygen modified atmosphere packaging. Journal of Food Science, 67, 3493-3496.

Jayasingh, P., Cornforth, D. P., Carpenter, C. E. & Whittier, D. R. 2001. Evaluation of carbon monoxide treatment in modified atmosphere packaging or vacuum packaging to increase colour stability of fresh beef. Meat Science, 59 (3), 317-324.

Jeremiah, L.E., Tong, A.K.W. & Gibson, L.L. 1997. The influence of chronological age, slaughter weight and gender on carcass meat quality. Sheep and Goat Research Journal, 13, 157-166.

Jiang, J.W. & Vessby, B. 1999. Relation between the intake of milk fat and the occurance of conjugated linoleic acid in human adipose tissue. American Journal of Clinical Nutrition, 70, 21-27.

Jimenez-Colmenero, F., Carballo, J. & Cofrades, S. 2001. Healthier meat and meat products: their role as functional foods, Review. Meat Science, 59, 5-13.

Johnson, P.L., Purchas, R.W., McEwan, J.C. & Blair, H.T. 2005. Carcass composition and meat quality differences between pasture raised ewe and ram lambs. Meat Science Thesis, University of Stellenbosch, South Africa.

Kemp, Y.D., Mahyuddin, M., Ely, J.D.Woody, W.G. 1981. Effect of feeding systems, slaughter weight and sex on organoleptic properties and fatty acid composition of lamb. Journal of Animal Science, 51, 321-330.

Kemp, J.D., ShelleyJ.M., Ely, D.G., & Moody, W.G. 1979. Effects of castration and slaughter weight on fatness, cooking losses and palatability of lamb. Journal of Animal Science, 34, 560- 571.

Kemp, J.D., Johnson, A.E., Stewart, D.F., Ely, D.G. & Fox, J.D. 1976. Effect of dietary protein, slaughter weight and sex on carcass composition, organoleptic properties and cooking losses of lamb. Journal of Animal Science, 42 (3), 575-583.

Kepler, C.R., Hirons, P.K., McNeill, J.J. & Tove, S.B. 1996. Intermediate and products of biohydrogenation of linoleic acid by *Butyivibrio fibrosolvens.* Journal of Biological Chemistry, 241, 1350-1354.

Kerth, C.R., Miller, M.F. & Ramsey, C.B. 1995. Improvement of beef tenderness and quality traits with calcium chloride injection in beef loins 48 hours post mortem. Journal of Animal Science, 73, 750-756.

Koohmaraie M. 1988. The role of endogenous proteases in meat tenderness. Reciprocal Meat Conference Proceedings, 41, 89-100.

Kott, R.W., Hatfield, P.G., Bergman, J. W., Flynn, C.R., Van Wagoner, H., & Boles., J.A. 2003. Feedlot performance, carcass composition, and muscle fat, CLA concentration of lambs fed diets supplemented with safflower seeds. Small Ruminant Research, 49, 11-17.

Kropf, D. H., 2004. Vacuum *In*: Encyclopaedia of Meat Sciences. Volume Three. First Edition. Elsevier Ltd., The Boulevard, Langford Lane, Kidlington, Oxford, OX5 1gb, UK.

Lawrence, T.E., Dikeman, M.E., Hunt, M.C., Kastner, C.L. & Johnson, D.E. 2003a. Effect of calcium salts on beef longissimus quality. Meat Science, 64, 299 – 308.

Lawrence, T.E., Dikeman, M.E., Hunt, M.C., Kastner, C.L., & Johnson, D.E. 2003b. Staged injection marination with calcuim lactate, phosphate and salt may improve beef water – binding ability and palatability traits. Meat Science, 67, 967 – 972.

Lawrie, R.A. 1998. Meat Science, 6th edition. Cambridge England: Woodhead Publishing Ltd.

Leat, W.F.M. 1976. The control of fat absorption, deposition and mobilization in farm animals, Pg 177-193 In: Meat Animals, Volume 8. Plenum Press. New York and London.

Longdell, G. 1997. 42nd International Congress of Meat Science and Technology. Trends in Food Science and Technology, 8, 57-60.

MacRae, J., O'Reilly, L. & Morgan, P. 2005. Desirable characteristic of animal product from a human health perspective. Livestock Production Science, 94, 95-103.

Mancini, R.A. & Hunt, M.C. 2005. Current Research in meat colour. Review. Meat Science, 71, 100-121.

Marchello, J.A., Cramer, D.A. & Miller, L.G. 1967. Effects of ambient temperature on certain ovine fat characteristics. Journal of Animal Science, 26, 294-298.

Matsuoka, A., Furokawa, N., Takahashi, T. 1997. Carcass traits and chemical composition of meat in male and female goats. Journal of Agricultural Science, Tokyo, Nogyo Daigaki 42(2), 127-135.

McEachern, M.G. & Willock, J. 2004. Producers and consumers of organic meat: A focus on attitudes and motivations. British Food Journal, 7, 534-552.

McIntyre, B.L. & Ryan, W.J. 1984. The influence of type of diet and electrical stimulation on the eating quality of beef. Animal Production in Australia, 15, 468-471.

Melton, S.L. 1990. Effect of feeds on flavour of red meat, a review. Journal of Animal Science, 68, 4421-4435.

Miller, M. F., Carr, M.A., Ramsey, C.B., Crockett, K.L. & Hoover, L.C., 2001. Consumer thresholds for establishing the value of beef tenderness. Journal of Animal Science, 79, 3062-3068.

Milne, C. 2000. The history of the Dorper sheep. Small Ruminant Research, 36, 99-102.

Monin, C. & Quali, A. 1991. Muscle differentiation and meat quality. In R. Lawrie (Ed.), Developments in meat science, 5, (pp 89-157). London: Elsevier Applied Science.

Morris, L. 1996. The ethical consumer: A new force in the food sector? Market Intelligence Section, April.

Muir, P. D., Beaker, J. M. & Bown, M. D. 1998. Effects of forage and grain feeding systems on beef quality. Journal of Agricultural Research, 41, 623-635.

Nel, J.A. 1993. The History of the Dorper sheep (Afrikaans). Dorper Breeders Society of South Africa, Middelburg 5900.

Nelson, G.J., Schimdt, P.C. & Kelly, D.S. 1995. Low fat diets do not lower plasma cholesterol levels in healthy men compared to high fat diets with similar fatty acid composition and constant caloric intake. Lipids, 30, 969-979.

Notter, D.R., Kelly, R.F. & McClaugherty, F.S. 1991. Effects of ewe breed and management system on efficiency of lamb growth production: II. Lamb growth, survival and carcass characteristics. Journal of Animal Science, 69, 22-33.

Nuernberg, K., Dannenberger, D., Nuernber, G. & Ender., K., R.I. 2005. Effect of grass based Feeding system on meat quality characteristics and fatty acid composition of *longissimus* muscle in different cattle breeds. Livestock Production Science, 94, 137– 147.

Offer, G. & Cousins, T. 1992. The mechanisms of drip production – formation of 2 compartments of extracellular space in muscle postmortem. Journal of Science of Food and Agriculture, 58, 107-116.

Offer, G. & Trinick, J. 1983. On the mechanism of water holding capacity in meat, the swelling and shrinking of myofibrils. Meat Science, 8, 245-281.

Oltjen, R.R., Rumsey, T.S. & Putman, P.A. 1971. All forage diets for finishing beef steers. Journal of Animal Science, 46, 716-724.

Onyango, C.A., Izumimoto, M. & Kutima, P.M. 1998. Comparison of some physical and chemical properties in selected game meats. Meat Science, 49, 117-125.

Padre, R.G., Aricetti, J.A., Moreira, F.B., Mizubuti, I.Y., Do Prado, I.N., Visentainer, J.V., De Sousa, N.E. & Matsushita, M. 2006. Fatty acid profile, and chemical composition of *Longissimus* muscle of bovine steers and bulls finished in pasture system. Meat Science, 74, 242-248.

Pariza, M.W. & Ha, Y.L. 1990. Newly recognized carcinogenic fatty acids. Basic Life Science, 52, 16-170.

Pethick, D.W., Daidson, R., Hopkins, D.L., Jacob, R.H., D'Souza, D.N., Thompson, J.M. & Walker, P.J. 2005. The effect of dietary treatment on meat quality and on consumer perception of sheep meat eating quality. Australian Journal of Experimental Agriculture, 45, 517, 524.

Piasentier, E. 2003. The effect of grazing on the quality of meat. Internationale Fachtagung für Schafhaltung. p1-5 http://www.gumpenstein.at/publikationen/fachtagungschaf/piasenti.pdf accessed 8 January 2008.

Piertisik, Z & Shand, P. J. 2004. Effect of blade tenderization and tumbling time on the processing characteristics and tenderness of injected cooked roast beef. Meat Science, 66, 871-879.

Pommier, S.A., Fahmy, M.H., Poste, L.M. & Butler, G. 1989. Effect of sex, electrical stimulation and conditioning time on carcass and meat characteristics of Romanov lambs. Food Quality and Preference, 1, 127-132.

Priolo, A., Micol, D., Agabrie, J., Prache, S and Dransfield, E. 2002. The effect of grass or concentrate feeding system on lamb carcass and meat quality. Meat Science, 62, 179-185.

Priolo, A., Micol, D. & Agabriel, J. 2001. Effects of grass feeding systems on ruminant meat colour and flavour. A review. Animal Research, 50, 185-200.

Purchas, A.W. 1978. Some effects of nutrition and castration on meat production from male Suffolk cross (Border Leicester-Romney cross) lambs. New Zealand Journal of Agricultural Research, 22, 375-383.

Quali, A. 1990. Meat tenderization: possible causes and mechanisms: A review. Journal of Muscle Foods, 1, 129–165.

Richardson, N. J. 1994. UK consumer perceptions of meat. Proceedings of the Nutrition Society, 53, 281-287.

Risvik, E. 1994. Sensory properties and preferences. Meat Science, 36, 67-77.

Rojas, A., Lopez-Bote, C., Rota, A., Martin, L., Rodriquez, P.L., Tovar, J.J. 1994. Fatty acid composition of Verata goat kids fed either goat milk or commercial milk replacer. Small Ruminant Research, 14, 61-66.

Rousset-Akrim, S., Young, O.A. & Berdague, J.L.. 1997. Diet and growth effects in panel assessment of sheepmeat odour and flavour. Meat Science, 45, 169-181.

Rowe, A., Macedo, F.A.F., Visentainer, J.V., Souza, N.E. & Matsushita, M. 1999. Muscle composition and fatty acid profile in lambs fattened in drylot or pasture. Meat Science, 51, 283-288.

Ruiz, M.R., Matsushita, M., Visentainer, J.V., Hernandez, J.A. & Ribeiro, E.L.A. 2005. Proximate chemical composition and fatty acid profiles of *Longissimus thoracis* from pasture fed LHRH immunocastrated and intact Bos indicus bulls. Journal of Animal Science, 1 (35), 13-18.

Rule, D.C., Macneil, M.D. & Short, R.E. 1997. Influence of sire growth potential, time on feed and growing finishing strategy on cholesterol and fatty acids of ground carcass and Longissimus muscle of beef steers. Journal of Animal Science, 75(6), 1525-1533.

Russo, C., Prezuiso, G., Casarosa, L., Campondi, G., & Ciani, D. 1999. Effect of dietary energy source on the chemical- physical characteristics of meat and depot fat of lamb carcasses. Small Ruminant Nutrition, 33, 77– 85.

Sales, J. 1999. Slaughter and products. In: The Ostrich, biology, production and health (edited by D.C. Deeming). Pp.231-274. Wallinford, Oxon:CABIbPublishing.

Sales, J. 1996. Histological, biophysical, physical and chemical characteristics of different ostrich muscles. Journal of the Science of Food and Agriculture, 70, 109-114.

Salim, H.M., Shahjalal, M., Tareque, A.M.M. & Akter, N. 2003. Intake and growth performance of female goats and sheep given concentrate supplement under grazing condition. Pakistan Journal of Biological Sciences, 6 , 1304-1309.

Santos-Silva, J., Mendes, L.A. & Bessa, R.J.B. 2002. The effect of genotype, feeding system and slaughter weight on the quality of light lambs 1. Growth, carcass composition and meat quality. Livestock Production Science, 76, 17-25.

Sauvant, D., Bas, P. & Morand-Fehr, P. 1979. Heavy kids production. II. Influence of milk ingestion and weaning on performance of adipose tissue composition of kids. Ann. Zootech, 28, 73-92.

Schanbacher, B.D., Crouse, D.J. & Ferrel, L.C. 1980. Testosterone influences on growth, performance and carcass characteristics and composition of market young lambs. Journal of Animal Science, 51, 685-691.

Schoeman, S.J. 2000. A comparative assessment of Dorper sheep in different production environment and systems. Small Ruminant Research, 137-146.

Schroeder, J.W., Cramer, D.A., Bowling, R.A & Cook, C.W. 1980. Palatability, shelf-life and chemical differences between forage- and grain- finished beef. Journal of Animal Science, 50, 852-859.

Sebraneck, J. 2004. Meat Chemistry – Importance of compositional components and chemistry of each in processed meats. Iowa State University.

Seideman, S. C., Cross, H. R, Oltjen, R. R. & Scanbacher, B. D. 1982. Utilization of intact male for red meat production. Journal of Animal Science, 55, 826- 840.

Snowder, G.D. & Duckett, S.K. 2003. Evaluation of the South African Dorper as a terminal sire breed for growth, carcass, and palatability characteristics. Journal of Animal Science, 81, 368-375.

Solomon, M.B., Lynch, G.P. & Berry, B.W. 1986. Influence of animal diet and carcass electrical stimulation on the quality of meat from youthful ram lambs. Journal of Animal Science, 62, 139-146.

Solomon, M.B., Kemp, J.D., Moody, W.G., Ely, D.G. & Fox, J.D. 1980. Effect of breed and slaughter weight on physical, chemical and organoleptic properties of lamb carcasses. Journal of Animal Science, 15(5), 1102-1107.

Sugano, M., Tsuijita, A., Yamaski, M., Noguchi, M. & Yamada, K. 1998. Conjugated linoleic acid modulates tissue levels of chemical mediators and immunoglobulins in rats. Lipids, 33, 521-527.

Summers, R.L., Kemp, J.D., Ely, D.G. & Fox, J.D. 1978. Effects of weaning, feeding systems and sex on lamb characteristics and palatability. Journal of Animal Science, 47, 622-631.

Swatland, H.J. 1995. On-line evaluation of meat. USA, Lancaster: Technomic Publishing Company Inc.

Teff, K.L. 1996. Physiological effects of flavour perception. Trends in Food Science in Technology, 7, 448-452.

Theriez, M., Tissier, M. & Robelin, J. 1981. The chemical composition of the intensively fed lamb. Animal production, 32, 29-37.

Valera, A., Oliette, B., Moreno, T., Portela, C., Monserrat, L., Carballo, J.A. & Sánchez, L. 2004. Effect of pasture finishing on the meat characteristics and intramuscular fatty acid profile of steers of the Rubia Gallega breed. Meat Science, 67 (3), 515- 522.

Valsta, L.M., Tapanainen, H. & Mannisto, S. 2005. Meat fats in nutrition. A review. Meat Science, 70, 525-530.

Verberke, W.A.J., & Viaene, J. 2000. Ethical challenges for livestock Production: Meeting consumer concerns about meat safety and animal welfare. Journal of Agricultural and Environmental Ethics, 12, 141-151.

Vergara, H., Molina, A. & Gallego, L. 1999. Influence of sex and slaughter weight on carcass and meat quality in light and medium weight lambs produced in intensive systems. Meat Science, 52, 221-226.

Vestergaard, M., Oksberg, N. & Henckel, P. 2000. Influence of feeding intensity, grazing and finishing feeding on muscle fibre characteristics and meat colour of *semitendenosus, longissimus dorsi* and *supraspinatus* muscles in young bulls. Meat Science, 54, 177-185.

Vitamin Information Centre. 2005. Facing polyunsaturated fatty acids: where do we stand? Medical Update N0.45. Islando, South Africa.

Waldman, R.C., Suess, G.G. & Brunngardt, V.H. 1968. Fatty acids of certain bovine tissue and their association with growth, carcass and palatability traits. Journal of Animal Science, 27, 632-635.

Warris, P.D. 2000. Meat Science: An Introductory Text, 1st ed. Bristol UK: Biddles LTD CABI Publishing

Webb, E.C. & Casey, N.H. 1995. Genetic differences in fatty acid composition of subcutaneous adipose tissue in Dorper and South African Mutton Merino whethers at different live weights. Small Ruminant Research, 18, 81-88.

Wellington, G.H., Hogue, D.E. & Foote, R.H. 2003. Growth, carcass characteristics and androgen concentrations of gonad-altered ram lambs. Small Ruminant Research, 48, 51-59.

Wheeler, T.L., Koohmaraie, M. & Schackelford, S.D. 1997. Effect of postmortem injection time and post mortem-injection aging time on the calcium activated tenderization process in beef. Journal of Animal Science, 75, 2652-2660.

Wheeler, T.L., Koohmaraie, M., Lansdell, J.L., Siragussa, G.R. & Miller, M.F. 1993. Effects of postmortem injection time, injection level, and concentration of calcium chloride on beef quality traits. Journal of Animal Science, 71, 2965 – 2974.

Wolf, B.T., Jones, D.A. & Owen, M.G. 2001. Carcass composition, conformation and muscularity in Texel lambs of different breeding history, sex and leg shape score. Animal Science, 72, 465-475.

Zygoyiannis, D., Kufidis, D., Katsaounis, N., Phillips, P. 1992. Fatty acid composition of carcass fat of indigenous (*Capra prisca*) suckled Greek kids and milk of their does. Small Ruminant Research, 104, 360-365.

Chapter 3

Effect of production system on the growth rate and carcass characteristics of Dorper lambs

Abstract

An investigation on the effect of production system on growth rate and carcass characteristics of Dorper lambs was carried out under South African conditions. The study involved a total number of sixty lambs which were divided into two production/feeding groups (feedlot {FL-} or free-range {FR-}) at weaning. Each group consisted of 10 lambs from three gender classes (ewes, rams and castrates). The feedlot lambs were fed a commercial pelleted ration while the free-range group grazed natural pastures until slaughter. Within each production group, half of the lambs were slaughtered after five weeks (slaughter date 1) while the other half were slaughtered after six weeks (slaughter date 2). The production system x gender interaction indicated that male lambs (castrates and rams) grew twice as fast as ewes under FL-conditions. Differences between gender groups were much smaller in FR-lambs. Furthermore, results indicated that FL-lambs generally produced heavier carcasses, higher dressing percentages and greater carcass fatness levels than FR- lambs. This effect was more pronounced for lambs slaughtered on date 2. Ram lambs attained higher slaughter weights and produced heavier carcasses than ewe lambs, castrates being intermediate. It was concluded that the FL-diets were generally associated with better lamb growth rates. FL-diets resulted in greater carcass fatness and an improved dressing percentage.

INTRODUCTION

Consumer attitudes and behavioural changes/choices are based on both personal experiences and information acquired through various media (Richardson, 1994). In today's era of information overload, consumers are not only concerned about the kind of food they consume (Jimenez-Colmenero *et al.*, 2001) but also about the treatment the animal receives ante mortem. Issanchou (1996) summarised the hypothesis set forth by Van Trijp (1995) that animal welfare issues would gain importance as far as future consumer behavioural changes are concerned. Concluding remarks by Verbeke & Viaene (2000) supported this hypothesis when they assessed the relative importance attached by consumers to product safety and animal welfare. Although their results indicated that animal welfare issues were ranked among the less important fresh meat attributes, Verbeke & Viaene (2000) stated that since it is associated with consumption decisions that were unfavourable for beef and pork in the past, it should be considered important. Animal production systems should therefore be geared towards meeting emerging consumer decisions whilst remaining competitive on major target markets. Although health and food safety concerns

are paramount to animal welfare issues, the later should enjoy equal attention. It is the prerogative of every affected country, including South Africa to ensure that animal welfare issues are addressed.

Increasing animal welfare concerns create the perfect market for free-range animal production. Free-range animal production emanates from a philosophy that involves holistically "working with natural systems rather than seeking to dominate them", as may be the case with some conventional farming systems (McEachern & Tregear, 2000). The free-range system is often viewed as a superior system for the environment, soil, livestock and humans who work in it and utilize its products (Raven, 2001). Free-range products are thus perceived as natural food products without chemicals and growth hormones (Davies *et al.*, 1995) that are produced in favourable environments pertaining to animal health and welfare (McEachern & Willock, 2004).

Numerous investigations report differences in lamb growth rate, carcass composition and carcass fatness levels due to feeding system (Díaz *et al.*, 2002; Santos- Silva *et al.*, 2002). Free-range diets are generally associated with slower lamb growth rates compared to faster growth rates achieved with feedlot diets (Notter *et al.*, 1991). Nonetheless, free-range diets allow skeletal and muscle tissue growth without excess fattening. Sex hormones also influence the growth pattern of lambs. It is known that intact males grow faster and reach a greater ultimate size than castrates and ewe lambs. Intact males also produce leaner carcasses than castrates and ewe lambs (Arnold & Meyer, 1988; Seideman *et al.*, 1982; Crouse *et al.*, 1981; Field, 1971). The fast growth rate of ram lambs is attributed to their ability to utilize feed more efficiently (Notter *et al.*, 1991). Feedlot diets enable ram lambs to fully exhibit their superiority in growth potential over castrates and ewe lambs (Field, 1971). However, the growth advantage of rams over castrates is less pronounced when nutritional levels are reduced or when diets are of poorer quality (Crouse *et al.*, 1981). Feedlot lambs generally produce heavier carcasses than free-range lambs (Díaz *et al.*, 2002; Priolo *et al.*, 2002). Carcasses from ram lambs are commonly heavier than carcasses from castrates and ewe lambs (Dransfield *et al.*, 1990) although ewe lambs usually display higher dressing percentages than rams and castrate lambs (Vergara *et al.*, 1999) when slaughtered at the same age. Fat deposition is influenced by the energy concentration of a diet. Feedlot diets yield carcass of greater fatness compared to free-range carcasses (Díaz *et al.*, 2002; Murphy *et al.*, 1994; Crouse *et al.*, 1981).

Although there is literature on the effect of free-range and feedlot feeding on lamb growth, this has not yet been reported under South African conditions. The Dorper sheep is an early maturing breed selected for adaptability under South Africa's harsher conditions (Milne, 2000; Schoeman, 2000). In this experiment, Dorper lambs of the same age were finished off in a feedlot or under free-range conditions and slaughtered after a pre-determined period. Therefore the main aims of this study were to investigate the effect of system (free-range or feedlot) on Dorper lamb growth rate and carcass characteristics under South African conditions. In addition, the effect of gender on lamb growth and carcass characteristics was also reported.

MATERIALS AND METHODS

Lamb management

Dorper lambs were born between May and June, 2005, at the Nortier experimental farm, situated approximately 10 km north of Lamberts Bay to the North-west of the Western Cape Province. Every second ram lamb that was born was castrated by means of rubber rings. Dates of birth of all lambs were recorded. The lambs were weaned at approximately four months of age in September, 2005, when they weighed approximately 36.3 ± 3.2 kg. At weaning, sixty lambs weighing 35-40 kg (20 ewes, 20 castrated and 20 ram lambs) were selected from the larger population (n = 336) to minimize variation in starting weight. These lambs were stratified according to their live weight within gender groups, and randomly allocated to one of two production systems (feedlot - FL or free-range - FR). Each group consisted of 10 ewes, 10 castrates and 10 rams. Lambs in each production system were kept together during the trial period. The average starting weight (± s.d.) of lambs was 36.3 ± 0.4 kg. Lambs were dosed against internal parasites and vaccinated against pulpy kidney before entering the feeding phase of the trial.

The vegetation at Nortier is a combination of Strandveldt and Sandveldt (Cloete & De Villiers, 1987). Free-range lambs were observed feeding primarily on *Exomis microphyla*, *Atriplex mumelaria*, *Felicia bergeriana* and *Manochlamys albicans* and did not receive any supplements. Pasture was abundant and was not a limiting factor to growth. Feedlot lambs were fed a commercial pelleted ration(Complete Sheep Finisher, Veekos batch number 4442; see Table 1 for bag minimum and maximum specifications). Both groups had *ad libitum* access to water. Lamb weights were recorded individually at the beginning of every week. After the 5 week trial period, the average daily gain (ADG) was calculated for each lamb. For this purpose live weight was regressed on weighing date (in weeks) for each lamb. The regression coefficient was divided by 7 in order to obtain the average daily gain to account for the fact that weekly weights were recorded.

Lamb slaughter

Based on the weaning weight records and average growth to that stage, it was estimated that these early maturing Dorper lambs would have reached an ideal slaughter weight and fat cover of A2 after an additional growth period of 5-6 weeks post-weaning. After 5 weeks, 15 lambs from each of the two production groups (each group represented by 5 lambs from each gender class) were randomly selected, weighed and transported approximately 250 km to the abattoir. The last weight recorded on the farm before the lambs were transported was regarded as the slaughter weight. Lambs slaughtered after five weeks were approximately 156 days old. Upon arrival at the abattoir, all lambs were grouped together in lairage overnight. The next morning, the lambs were electrically stunned and slaughtered using standard South African methods. Most of the carcasses were classified as A2 according to the South African classification system (Government Notice No. 1748, 26 June 1992). An A2 lamb has no permanent

incisors and has a lean fat cover (1.0-4.0 mm subcutaneous fat depth measured at the ninth rib, 50 mm from the midline). The abdominal fat was removed from each carcass and weighed. After forty-eight hours of refrigeration at 4°C, individual cold carcass weights were recorded and expressed relative to the slaughter weight to derive dressing percentage. *Longissimus dorsi* (LD) muscles, excised from between the 8th to 11th ribs from both sides of each carcass were transported to the laboratory for further analyses. The LD muscles from the right side of the carcass were used for subcutaneous fat thickness measurements. A dial clipper was positioned 1.5 cm from the midline and 1.5 cm from the edge of the last rib to determine the subcutaneous fat thickness. Measurements taken from the midline were recorded as subcutaneous fat 1 and measurements from the edge were recorded as subcutaneous fat 2. The LD muscle samples were vacuum sealed and stored at -18°C until required for sensory meat quality evaluation (Chapter 5). LD muscles from the left side of the carcass were used for physical meat quality analysis. The remaining portions were vacuum sealed and stored at -18°C and later used for chemical meat quality analysis (Chapter 4). The kidney fat from each carcass was removed, weighed, vacuum sealed and stored at -18°C for later use. The remaining 30 lambs in the investigation were slaughtered six weeks after feeding commenced when they were approximately 163 days old and underwent exactly the same procedures outlined above.

Table 1. Composition of the commercial pelleted ration fed to the feedlot lambs as determined from the specifications on the bag.

COMPOSITION (G/ KG)	MIN	MAX
Protein	130	
Protein excluding NPN		22.3%
Ammonia sulphate	2.5	
Ammonia chloride	7.5	
Moisture		120
Fat	25	
Fibre		200
Calcium		10
Phosphorus	3	
Magnesium	0.25	
Sulphur	2	
Potassium	4.5	
Sodium	0.7	
Chlorine	4.5	
Manganese	30	
Zinc	50	
Cobalt	1	
Iodine	1	
Ca:P	1:1	4 : 1

Statistical analysis

The growth and slaughter data of the animals was tested for normality and homogeneity of variance before being subjected to analysis. The basic analysis involved a 2 (production system: FL- vs. FR) x 3 (gender: ewe vs. castrate vs. ram) x 2 (slaughter date: 1 vs. 2) experimental design.

Growth differences between the treatment groups were established by subjecting the data to Proc GLM of SAS (1999). Preliminary analysis involved the full model, i.e. the effects of production system, gender, slaughter date and the interactions among main effects. The slaughter date effect and its interactions were removed from the final analysis, because results indicated that these were not significant ($P > 0.05$). The final model used to establish growth differences between treatment groups included production system and gender as the main effects as well as a two way interaction between these main effects.

Preliminary analysis of carcass characteristics also involved the full model, i.e. the effects of production system, gender, slaughter date and the interactions among the main effects. All the interaction effects were removed from the final analysis, because results indicated that these were not significant ($P > 0.05$). The final model used to establish carcass differences between treatment groups included production system, gender and slaughter date.

The contribution of either a main effect or an interaction to a response was defined as the sum of squares for a specific main or interaction divided by the corrected total sum of squares. This value was multiplied by 100 to express the contribution as a percentage.

RESULTS AND DISCUSSION

The two way interaction between gender and production system on lamb ADG is presented in Table 2. Production system did not affect lamb ADG but significance ($P<0.05$) was noted for gender and its interaction with production system. The interaction contributed to most (17.8%) of the variation accounted for by the model, compared to gender (12.7%) and production system (0.23%). The significant interaction will therefore be discussed.

The average growth of male lambs (castrates and rams) was twice that of ewes in the FL-production system ($P < 0.05$). Much smaller gender differences were observed in the FR-production system, and ram lambs fared the worst in absolute terms. It is generally accepted that male lambs grow faster than ewes because they utilize feed more efficiently (Seideman *et al.*, 1982). Moreover, feedlot diets are associated with faster growth rates (Santos-Silva *et al.* 2002; Arnold & Meyer, 1988; Crouse *et al.* 1981) and enable male lambs to fully exhibit their superiority in growth over ewe lambs (Arnold & Meyer, 1988; Notter *et al.*,

1991; Seideman *et al.*, 1982; Crouse *et al.*, 1980; Bradford & Spurlock, 1964). The growth advantage of male lambs is attributed to the presence of testicular hormones, particularly testosterone (Scanbacher *et al.*, 1980). Although the FL-gender growth pattern observed in this study concurs with previously reported results, a difference of this magnitude was not expected. In the FR-production system, ram lambs grew the slowest. The contention that ram lambs may not show clear growth advantages over castrates on pasture (Purchas, 1978) is supported by the absolute growth rate in favour of the castrate FR-lambs in the present study. Furthermore, results seem to indicate that FR-feeding may have been sufficient for ewe lamb growth. The slow growth rate of FL-ewes can be attributed to insufficient energy intake as a result of them being dominated during feeding times by the more aggressive male lambs that were also frequently observed mounting them. On the other hand, Salim *et al.* (2003) observed that ewe and doe growth performance may be optimized with concentrate supplementation (under FR conditions), a system that was not considered in the present experiment.

Table 2. Means (± s.e.) depicting the two way interaction between production system and gender of lamb ADG (kg/dag).

PRODUCTION SYSTEM						P-VALUE
FEEDLOT			FREE-RANGE			
Ewe	Castrate	Ram	Ewe	Castrate	Ram	
0.09 ± 0.03	0.23 ± 0.03	0.25 ± 0.03	0.17 ± 0.03	0.18 ± 0.02	0.14 ± 0.02	0.002

The results pertaining to the effect of production system on slaughter weight, dressing percentage, abdominal fat, kidney fat and subcutaneous fat of Dorper lambs excluding gender effect are presented in Table 3, while the effect of gender on the same attributes of Dorper lambs is given in Table 4.

Table 3. Means (± s.e.) depicting the effect of production system on slaughter weight, dressing percentage, abdominal fat and subcutaneous fat of Dorper lambs slaughtered on date 1 and 2, respectively.

CARCASS CHARACTERISTIC	SLAUGHTER DATE 1		SLAUGHTER DATE 2		P-VALUE
	Production system		Production system		
	Feedlot	Free-range	Feedlot	Free-range	
Slaughter weight (kg)	42.80 ± 1.23	41.20 ± 1.02	44.70 ± 1.49	43.87 ± 1.14	0.4966
Cold carcass weight (kg)	19.15 ± 0.60	17.40 ± 0.47	20.32 ± 0.77	18.34 ± 0.57	0.0003
Dressing percentage (%)	44.72 ± 0.75	42.29 ± 0.72	45.37 ± 0.38	41.77 ± 0.53	<.0001
Abdominal fat (g)	0.34 ± 0.05	0.25 ± 0.04	0.33 ± 0.03	0.24 ± 0.03	0.0173
Kidney fat (g)	0.28 ± 0.04	0.20± 0.02	0.30 ± 0.03	0.19 ± 0.02	0.0004
Subcutaneous fat 1 (cm)	0.98 ± 0.10	0.63 ± 0.09	0.57 ± 0.08	0.37 ± 0.05	0.0015
Subcutaneous fat 2 (cm)	0.32 ± 0.05	0.22 ± 0.04	0.27 ± 0.04	0.17 ± 0.02	0.0125

Table 4. Means (± s.e.) depicting the effect of gender on slaughter weight, dressing percentage, abdominal fat and subcutaneous fat of Dorper lambs slaughtered on date 1 and 2.

	SLAUGHTER DATE 1			SLAUGHTER DATE 2			P-VALUE
	GENDER			GENDER			
	Ewes (n=10)	Castrates (n=10)	Rams (n=10)	Ewes (n=10)	Castrates (n=10)	Rams (n=10)	
Slaughter weight (kg)	38.45 ± 1.25	42.7 ± 1.19	44.85 ± 0.88	38.85 ± 1.17	46.00 ± 1.06	48.00 ± 0.86	< .0001
Cold carcass weight (kg)	16.95 ± 0.64	18.33 ± 0.62	19.54 ± 0.67	16.80 ± 0.72	20.28 ± 0.63	20.91 ± 0.68	<.0001
Dressing percentage (%)	44.14 ± 1.05	42.96 ± 1.04	43.49 ± 0.88	43.14 ± 0.85	44.06 ± 0.73	43.50 ± 0.86	0.9790
Abdominal fat (g)	0.35 ± 0.07	0.32 ± 0.06	0.22 ± 0.03	0.27 ± 0.05	0.33 ± 0.02	0.26 ± 0.03	0.1481
Kidney fat (g)	0.28 ± 0.05	0.24 ± 0.04	0.19 ± 0.01	0.20 ± 0.01	0.31 ± 0.02	0.23 ± 0.03	0.4395
Subcutaneous fat 1 (cm)	0.81 ± 0.12	0.86 ± 0.14	0.75 ± 0.13	0.34 ± 0.08	0.55 ± 0.10	0.53 0.08	0.4395
Subcutaneous fat 2 (cm)	0.31 ± 0.07	0.29 ± 0.05	0.21 ± 0.05	0.19 ± 0.04	0.28 ± 0.05	0.17 ± 0.02	0.1257

Slaughter date, production system and gender all had significant ($P<0.05$) effects on the cold carcass weight of Dorper lambs. Gender contributed more (31.2%) to the variation accounted for by the model compared to production system (13.56%) and slaughter date (4.36%). Gender effect indicated that male lambs (rams and castrates) produced heavier carcasses than ewe lambs. Moreover, male lamb carcasses were heavier on slaughter date 2 than on slaughter date 1. For ewe lambs, carcasses of slaughter date 1 were heavier than those of slaughter date 2. Slaughter weights of male lambs were significantly higher than that of ewe lambs, resulting in heavier carcasses. Similar studies indicate that carcasses of entire males are heavier than carcasses of castrates and ewe lambs (Dransfield *et al.*, 1990). McClure *et al.* (1994) also found that ram lambs produced heavier carcasses than ewe lambs in a study that did not include castrates. As for production system, FL-lambs produced heavier carcasses than FR- lambs on both slaughter dates. Furthermore as expected, carcasses for both FL- and FR-lambs slaughtered on date 2 were heavier ($P = 0.0342$) than carcasses of lambs slaughtered on date 1. Lower carcass weights of FR-lambs can be attributed to reduced carcass fatness in these lambs. McClure *et al.* (1994) also found that lambs finished on forage had less fat than concentrate fed lambs.

Production system had a significant ($P<0.05$) effect on the dressing percentage of lambs and contributed to 30.22% of the variation accounted for by the model. On the other hand, gender and slaughter date did not have any significant ($P>0.05$) effect on the dressing percentage, and contributed only 0.54% and 0.005% respectively to the variation accounted for by the model. The dressing percentage of FL-lambs was higher than that of FR-lambs on both slaughter dates. Furthermore, FL-lambs slaughtered on date 2 had higher dressing percentages than FL-lambs slaughtered on date 1. The opposite was observed for FR-lambs. It seems probable that carcass fatness had an influence on dressing percentage as fatter FL-carcasses had higher dressing percentages. Cañeque *et al.* (1990) and Díaz *et al.* (2002) reported higher dressing values

for feedlot lambs than for lambs raised under free-range conditions. Part of the difference in dressing percentage between FL- and FR-lambs possibly stems from a smaller alimentary tract in the former, fed concentrates. FR-lambs, consuming herbage have larger alimentary tracts and thus weigh more (Owens *et al.*, 1993). Slaughter weight was also suggested to play a role in the higher dressing percentage of FL-lambs compared to FR-lambs (Díaz *et al.*, 2002). This effect could not be confirmed in the present study, since no significant differences in slaughter weight were found between FL- and FR-lambs slaughtered on either date ($P > 0.22$; Table 3). Contrary to the present results, Santos-Silva *et al.* (2002) found that FL- and FR-lambs showed similar dressing values.

Production system was significant for abdominal fat ($P<0.05$) and contributed 9.45% of the variation accounted for by the model for abdominal fat. Gender and slaughter date were non-significant ($P>0.05$) and respectively contributed 6.17% and 0.16% to the model. According to the results FL-lambs had greater abdominal fat deposition than FR-lambs on both slaughter dates. For both FL- and FR-lambs, lambs slaughtered on date 1 had greater fat deposition than lambs slaughtered on date 2. Lower abdominal fat deposition in FR-lambs may be attributed to (1) changes in the metabolism caused by physical activity during foraging or (2) due to a substantially lower energy intake (3) or a combination of lower energy intake and higher energy expenditure. Find references to back your hypothesis. Physical activity leads to greater muscular development at the cost of fat deposition. Furthermore, an increase in slaughter weight is marked by an increase in carcass fatness which corresponds to the standard lamb growth pattern. Heavier carcasses of FL-lambs presented significantly greater fatness than FR-carcasses. Crouse *et al.* (1978) also observed greater fat deposition in lambs fed a high energy diet.

Production system had a significant effect ($P<0.05$) on kidney fat deposition and accounted for 19.24% of the variation accounted for by the model. Gender and slaughter date contributed 4.85% and 0.04% respectively. For both slaughter dates, FL- lambs had greater kidney fat deposition than FR-lambs. For FL-lambs, lambs slaughtered on date 2 had greater kidney fat deposition than lambs slaughtered on date 1. As for FR-lambs, lambs slaughtered on date 1 had greater kidney fat deposition than lambs slaughtered on date 2. Greater kidney fat deposition in FL-lambs slaughtered on date 2 could be the result of greater energy intake than required for maintenance. The lower kidney fat deposition observed in FR-lambs slaughtered on date 2 as opposed to lambs slaughtered on date 1 was unexpected and therefore cannot be explained.

Slaughter date and production system had a significant effect ($P<0.05$) on subcutaneous fat 1 (taken at the midline) while gender had no significant effect ($P>0.05$). Slaughter date contributed to most (19.16%) of the variation accounted for by the model compared to production system (13.36%) and gender (1.98%). Results indicated that FL-lambs had greater subcutaneous fat deposition than FR-lambs for both slaughter dates. For both FL- and FR-lambs, lambs slaughtered on date 1 had greater fat deposition than lambs slaughtered on date 2. Diaz *et al.* (2002) also observed higher subcutaneous fat in FL-lambs compared to those raised under free-range conditions. Contrary to results of this investigation, Díaz *et al.* (2002) found

that the proportion of fat was greater in lambs slaughtered at 28 kg live weight, than in lambs slaughtered at 24 kg.

Production system had an effect ($P<0.05$) on subcutaneous fat 2 and contributed to most (9.74%) of the variation accounted for by the model. Gender and slaughter date did not effect subcutaneous fat 2 (taken at the edge) deposition and accounted for 6.29% and 3% of the variation accounted for by the model respectively. The same phenomena as that observed for subcutaneous fat 1 was observed for subcutaneous fat 2.

CONCLUSIONS

Dorper ewe lambs reared under FL-conditions grew much slower than males (castrates and rams). No similar trend was found in lambs reared under FR-conditions. It is not sure if this result was coincidental, and further research is required to confirm or refute these findings. The study also confirmed research published elsewhere and the finding that FL-lambs were generally fatter with a higher dressing percentage than FR-lambs also applies to South African Dorper sheep. However, FR-lambs performed satisfactorily and showed much less variation between gender groups than FL-lambs. This in itself could be an advantage to FR-production systems. The combination of leaner meat with a growing-out environment perceived by consumers to be beneficial to animal welfare, weighs heavily in favour of the FR-management system. The lack of adverse effects on growth and slaughter traits under FR-conditions needs to be confirmed for Dorper lambs in future studies.

REFERENCES

AOAC. 1997. Official Methods of Analysis. 15th ed. Arlington,VA. USA: Association of Official Analytical Chemists.

Arnold, A. M. & Meyer, H. H. 1988. Effects of gender, time of castration, genotype and feeding regime on lamb growth and carcass fatness. Journal of Animal Science, 66, 2468-2475.

Bradford, G.E. & Spurlock, G.M. 1964. Effect of castrating lambs on growth and body composition. Journal of Animal Production, 6, 291-299.

Caneque, V., Huidobro, F., Hernandez, J.A. & Dolz, J.F. 1990. Comparison between four fattening systems for lambs and their effects on carcass quality. As cited by: Diaz, M.T., Velasco, S., Caneque, V., Lauzurica, S., de Huidobro, F. R., Perez, C., Gonzalez, J. & Manzanares, C. 2002. The use of concentrate or pasture for fattening lambs and its effect on carcass and meat quality. Small Ruminant Research, 43, 257-268.

Cloete, S.W.P. & De Villiers, T.T. 1987. Production parameters for a commercial Dorper flock on extensive pastures. South African Journal of Animal Science, 27, 121-127.

Crouse, J. D., Busboom, J. R., Field, R. A. & Ferrell, C. L. 1981. The effects of breed, diet, sex, location and slaughter weight on lamb growth, carcass composition and meat flavour. Journal of Animal Science, 53, 376-381.

Davies, A., Titterington, A.J. & Cochrane, C. 1995. "Who buys organic food? A profile of the purchasers of organic food in Northern Ireland. *British Food Journal*, 97, (10), 17- 23.

Díaz, M.T., Velasco, S., Caneque, V., Lauzurica, S., de Huidobro, F. R., Perez, C., Gonzalez, J. & Manzanares, C. 2002. The use of concentrate or pasture for fattening lambs and its effect on carcass and meat quality. Small Ruminant Research, 43, 257-268.

Dransfield, E., Nute, G.R., Hogg, B.W., & Walters, B.R. 1990. Carcass and eating quality of ram, castrated ram and ewe lambs. Animal Production, 50, 291- 299.

Field, R.A. 1971. Effect of castration on meat quality and quantity. Journal of Animal Science, 32, 849.

Issanchou, I. 1996. Consumer expectations and perceptions of meat and meat product quality. Review article. Meat Science, 43, S5-S19.

Jimenez-Colmenero, F., Carballo, J. & Cofrades, S. 2001. Healthier meat and meat products: their role as functional foods, Review. Meat Science, 59, 5 – 13.

Mc Eachern, M. G. & Willock, J. 2004. Producers and consumers of organic meat: A focus on attitudes and motivations. British Food Journal, 106 (7), 534-552.

McClure, K.A., Van Keuren, R.W. & Althouse, P.G. 1994. Performance and carcass characteristics of weaned lambs either grazed on orchard grass, ryegrass or alfafa or fed all concentrate diets in drylots. Journal of Animal Science, 72, 3230-3237.

McEachern, M.G. & Tregear, A. 2000. Farm Animal Welfare in the UK: A Comparison of Assurance Schemes. Farm Management, 10 (11). University of Reading, Reading.

Milne, C. 2000. The history of Dorper sheep. Small Ruminant Research, 36, 99-102.

Murphy, T.A., Loerch, S.C., McClure, K.E. & Solomon, M.B. 1994. Effects of restricted feeding on growth performance and carcass composition of lambs subjected to different nutritional treatments. Journal of Animal Science, 72, 3131-3137.

Notter, D.R., Kelly, R.F. & McClaugherty, F.S. 1991. Effects of ewe breed and management system on efficiency of lamb growth production: II. Lamb growth, survival and carcass characteristics. Journal of Animal Science, 69, 22-33.

Owens, F.N., Dubeski, P. & Hanson, C.F. 1993. Factors that alter the growth and development of ruminants. Journal of Animal Science, 71, 3138-3150.

Priolo, A., Micol, D., Agabrie, J., Prache, S & Dransfield, E. 2002. The effect of grass or concentrate feeding system on lamb carcass and meat quality. Meat Science, 62, 179-185.

Purchas, A.W. 1978. Some effects of nutrition and castration on meat production from male Suffolk cross (Border Leicester-Romney cross) lambs. New Zealand Journal of Agricultural Research, 22, 375-383.

Raven, H. 2000. New voice for Scotland's organic farmers. The Scottish Farmer, ABC Bussiness Publication Ltd, Glasgow, 8 April.

Richardson, N. J. 1994. UK consumer perceptions of meat. Proceedings of the Nutrition Society, 53, 281-287.

Salim, H.M., Shahjalal, M., Tareque, A.M.M. & Akter, N. 2003. Intake and growth performance of female goats and sheep given concentrate supplement under grazing condition. Pakistan Journal of Biological Sciences, 6 (15), 1304-1309.

Santos-Silva, J., Mendes, L.A. & Bessa, R.J.B. 2002. The effect of genotype, feeding system and slaughter weight on the quality of light lambs 1. Growth, carcass composition and meat quality. Livestock Production Science, 76, 17-25.

SAS Institute, Inc. 1999. SAS/STAT User's Guide, Version 8, 1st printing, Volume 2. SAS Institute, Inc, SAS Campus Drive, Cary, North Carolina 27513.

Schanbacher, B.D., Crouse, D.J. & Ferrel, L.C. 1980. Testosterone influences on growth, performance and carcass characteristics and composition of market young lambs. Journal of Animal Science, 51, 685-691.

Schoeman, S.J. 2000. A comparative assessment of Dorper sheep in different production environments and systems. Small Ruminant Research, 36, 137- 146.

Seideman, S. C., Cross, H. R, Oltjen, R. R. & Scanbacher, B. D. 1982. Utilization of intact male for red meat production. Journal of Animal Science, 55, 826- 840.

Van Trijp, H. 1995. Variety Seeking in Product Choice Behavior: Theory with Application in the Food Domain, Ph.D. Dissertation, Wageningen Agricultural University, the Netherlands.

Verberke, W.A.J., & Viaene, J. 2000. Ethical challenges for livestock Production: Meeting consumer concerns about meat safety and animal welfare. Journal of Agricultural and Environmental Ethics, 12, 141-151.

Chapter 4

The effect of production system on the physical and chemical characteristics of meat from Dorper lambs

Abstract

The effect of a feedlot (FL-) versus a free-range (FR-) production system was investigated as pertaining to the physical and chemical meat quality characteristics of Dorper lambs. Sixty lambs were divided into two groups at weaning. Each group consisted of 10 lambs from each of three gender classes (ewes, rams and castrates). Feedlot lambs were fed a commercial pelleted diet while the FR-lambs grazed natural pastures until slaughter. Physical meat quality characteristics were assessed on the *Longissimus dorsi* (LD) muscle while chemical characteristics were measured on the LD and *Biceps femoris* (BF) muscles. This study showed that production system significantly lowered pH45 of FL-lambs (6.68 ± 0.056) compared to that of FR lambs (6.89 ± 0.049). Production system also affected meat colour by reducing the redness (a*) and intensity (chroma) parameters of FR-lambs. No differences attributable to production system were found on meat tenderness, as indicated by Warner-Bratzler shear force values. The physical meat quality attributes were independent of gender, apart from tendencies for carcass temperature 45 minutes after slaughter to be slightly higher in castrate lambs than in ewes and rams, with cooking loss being slightly lower. Results further indicated that production system did not have a significant effect on intramuscular lipid concentration. Neither production system nor gender had a significant effect on muscle myoglobin concentration. Age at slaughter only affected the moisture content of BF muscles while it also affected the protein and ash concentrations of LD muscles. Based on the results of this investigation, it can be concluded that consumers are unlikely to discriminate against FR-meat especially as pertaining to colour, fat content and tenderness.

INTRODUCTION

Ruminant meat quality is influenced by intrinsic factors and extrinsic factors (Priolo *et al.*, 2001). Among the extrinsic factors, feeding plays an important role in the determination of meat quality (Priolo *et al.*, 2001). Modern consumers are particularly concerned about the treatment the animal receives ante mortem and the kind of food they consume (Jimenez-Colmenero *et al.*, 2001). Several research results indicate that some segments of the larger consumer population prefer to buy free-range products because meat produced in such systems is perceived to adhere to high quality standards while being subject to animal friendly production practices (McEachern & Wilcock, 2004; Harper & Makatouni, 2002; Davies *et al.*, 1995).

The appearance of meat, especially during shopping, determines how consumers perceive quality and

indeed influences purchasing behaviour (Grunert, 1997). Lamb meat colour is commonly used by consumers as an indicator of freshness while visible fat content is associated with health aspects (Grunert, 2006). During consumption, meat tenderness is regarded as the most important palatability trait (Gonzalez *et al.*, 2001; Boleman *et al.*, 1997) and seems to affect the re-purchasing intent of consumers.

As far as meat colour is concerned, it is well documented that meat from free-range animals is darker than meat from feedlot animals (Piansentier, 2003; Diaz *et al.*, 2002; Priolo *et al.*, 2002; Baardseth *et al.*, 1988; Bidner *et al.*, 1981). Darker meat of free-range animals is due to a higher haemic pigment concentration in muscles as a result of exercise (Piansentier, 2003; Diaz *et al.*, 2002; Priolo *et al.*, 2002). As for gender, ewe lamb muscles are reported to be less red than ram lamb muscles (Johnson *et al.*, 2005). However, other investigations report no colour differences between gender groups (Diaz *et al.*, 2003; Vergara *et al.*, 1999). Feedlot diets normally result in fatter carcasses that have been noted to improve meat tenderness through an increase in the intramuscular fat content (Crouse & Field, 1978; Summers *et al.*, 1978). Free-range diets on the other hand allow skeletal and muscle tissue growth without excess fattening, and is often associated with less juicy and less tender meat. Gender studies indicate that intact males produce leaner carcasses than castrates and ewe lambs, and are also associated with less juicy and less tender meat compared to the fatter carcasses of ewes and castrate lambs (Seideman *et al.*, 1982; Field, 1971).

Studies on the proximate chemical composition of meat indicate that muscle moisture content decreases when fat content increases, as is the case with feedlot diets and fatter carcasses (French *et al.*, 2001). However, other investigations did not find moisture differences between different production systems (Schoeder *et al.*, 1980). According to Theriez & Tissier (1981), muscle protein content decreases as muscle fat percentage increases. As mentioned, animals on feedlot diets have higher fat concentrations than animals on free-range diets (Diaz *et al.*, 2002; Schoeder *et al.*, 1980). Gender studies also indicate that muscles of castrates and ewe lambs have a higher concentration of intramuscular fat than those of ram contemporaries. It seems that production system does not have an appreciable effect on muscle ash (mineral) content (Theriez & Tissier 1981).

In South Africa there is lack of literature on the comparisons of production systems and gender on physical and chemical meat quality characteristics of lamb produced by local breeds. In addition, the comparison of free-range with feedlot finishing for Dorper sheep under South African conditions has not yet been made. In this experiment, Dorper lambs of the same age were finished off either in a feedlot or under free-range conditions and slaughtered after a pre-determined period to investigate the effect of production/feeding system (free-range or feedlot) on physical and chemical meat quality characteristics. Moreover, the effect of gender on physical and chemical meat quality characteristics was also investigated.

MATERIALS AND METHODS

Lamb management

Sixty Dorper lambs were divided into two production groups (feedlot {FL-} or free-range {FR-}) at weaning (36.3 ± 3.2 kg). Each production group consisted of 10 lambs from each gender class (ewes, rams and castrates). The feedlot lambs were fed a commercial pelleted ration (Veekos, batch number 44442: see Chapter 3 bag minimum and maximum specifications) while the free-range group grazed natural pastures without provision of any energy/production supplements until slaughter. The experimental outlay (age of the lambs, selection of the lambs, description of the production system, diet composition, plants grazed, etc.) is detailed in Chapter 3. After five weeks, 15 lambs from each of the two production systems (each group represented by five lambs from each gender class) were randomly selected, weighed and transported approximately 250 km to the abattoir. Lambs slaughtered after five weeks weighed 42.0 ± 4.4 kg. Upon arrival at the abattoir, all lambs were grouped together in lairage overnight. The next morning, the lambs were electrically stunned and slaughtered using standard South African methods (Cloete *et al.*, 2004a, b). The remaining 15 lambs on each diet were slaughtered in week six when they weighed 44.0 ± 5.1 kg.

Physical characteristics

Muscle temperature and pH readings were measured and recorded 45 minutes (temp45 and pH45, respectively) and 48 hours (temp48 and pH48, respectively) postmortem by inserting a portable pH meter equipped with pH and temperature probe into the left *Longissimus dorsi* (LD) muscle in the loin (at the last rib) of each carcass. The pH meter was calibrated using standard buffers at pH 4.0 and 7.0 that were held at the specific temperatures of the carcasses prior to their use. After pH and temperature readings were taken and recorded 48 hours postmortem, LD muscles from the left side of each carcass were excised from the 8^{th} to the 11^{th} thoracic vertebrae. The right hind legs were also removed from each carcass. The LD muscles and hind legs were placed individually in coded bags and transported to the Meat Science laboratory at Stellenbosch University in an insulated cool box.

Before any physical or chemical analyses were carried out, all visible fat (including subcutaneous fat) was trimmed off the muscles. Muscle colour was recorded according to the method described by Honikel (1998) with the use of a Colour guide 45º/0 º colorimeter. Muscle slices (1.5 to 2 cm thick) were allowed to bloom for thirty minutes at room temperature (18-19ºC). Colour measurements were recorded in triplicate for each sample at randomly selected positions and expressed by the coordinates L*, a* and b* of the CIELab colorimetric space (Minolta, 1998). In the colour space, L* is the lightness value and a* and b* are chromacity coordinates. The a* coordinate measures red-greenness and the b* coordinate measures yellow-blueness. The a* and b* coordinates were used to calculate the Hue angle (h^{ab}) and Chroma values as follows:

Hue angle (h^{ab}) = $\tan^{-1}(b^*/a^*)$
Chroma (C^*) = $\sqrt{(a^{*2} + b^{*2})}$

To determine drip loss, weighed muscle slices (1.5 to 2 cm thick) were suspended in plastic bags and left in a chiller (4ºC) for 24 hours. After 24 hours, muscle samples were blotted dry with tissue paper and weighed. Drip loss was then expressed as a percentage of the initial weight of the muscle sample. Cooking loss (%) of the muscle slices were determined by placing a raw, weighed sample (1.5 to 2 cm thick), sealed in a plastic bag in a preheated water bath (80ºC) for 1 hour (Cloete *et al.*, 2005). The cooked meat samples were then allowed to cool under running water. Excess water was blotted with tissue paper before the weight was recorded. Cooking loss was expressed as a percentage of the initial weight of the muscle sample. The same muscle samples that were used to determine cooking loss were used for the assessment of tenderness. Muscle samples were stored overnight (4ºC) before tenderness was determined the following day. Tenderness assessment was done as described by Honikel (1998) by using a Warner-Bratzler device, with a load cell of 2.000 kN, attached to a model 4444 Instron texture machine (Apollo Scientific cc, South Africa). Six cores (the samples were big enough to remove six cores) were removed parallel to the muscle fibre axis from the cooked muscle slice and placed in the Warner Bratzler device, so that the knife blade of the device cut across the fibres at a right angle. Mean shear force values were calculated from the recorded shear force values for six cylindrical cores from each muscle sample and used in the statistical analysis.

The remaining portions of the raw LD samples were minced and vacuumed sealed (in two bags) prior to storing at -20ºC. One portion was later used for proximate chemical analysis and the remaining portion was used for fatty acid and cholesterol analysis (Chapter 6).

Biceps femoris (BF) muscles were excised from the right hind leg of each carcass. Connective tissue and all visible fat were trimmed off all muscles where after they were minced and vacuum sealed, stored at –20ºC until required for chemical, fatty acid and cholesterol concentration analysis (Chapter 6).

Chemical characteristics

Raw, finely minced, thawed LD and BF muscle samples were used for proximate composition analysis, which is described in terms of percentages moisture, protein, lipid and ash. Total moisture was determined according to procedures prescribed by the AOAC (2002). Weighed muscle samples were dried in an oven for 24 hours at 100ºC and the moisture percentage calculated. The moisture free muscle previously used to determine muscle moisture content was used for the determination of ash content according to the methodology outlined by the AOAC (2002). The muscle samples were ashed in an oven at 500ºC for 6 hours and the ash percentage calculated. The total lipid concentration was determined by extracting lipids with chloroform: methanol (2:1 v/v) solution as described by Lee *et al.* (1996). Total crude protein fraction

(N x 6.250) was determined by the Dumas combustion method (AOAC method 968.06; AOAC, 1997) using the Leco FP 528 on the same samples (fat-free) used for lipid content determination.

Myoglobin determination

Thawed, homogenized meat samples were used to extract myoglobin according to the method described by Krzywicki (1982). Duplicate minced samples of approximately 5 grams of meat were weighed and placed in 50 ml polypropylene centrifuge tubes. Twenty five milliliters of ice cold phosphate buffer was added to each tube and the sample homogenized for 40-45 seconds at a low speed. Samples were then held on ice (4ºC) for one hour. Samples were then centrifuged at 9000 RPM for 45 min at 4 ^{0}C. Thereafter, the supernatant was filtered through Whatman no.1 filter paper. Individual absorbencies were then taken at 525 and 700 nm. Myoglobin concentration was calculated as:
Myoglobin (mg/ml) = ((A x 525) x (A x 700)) x 2.303 x 6 where A represents the absorbency of muscle sample.

Statistical Analysis

A 2 x 3 x 2 factorial analysis was performed in a randomized complete block design with two treatments replicated in 60 blocks (animals). The factors were two productions systems (FL and FR), gender (ewe, ram and castrate lambs) and date of slaughter (slaughter date 1 and slaughter date 2). The data were subjected to factorial analysis using Proc GLM of SAS version 9.1 (SAS, 1999). Before the data was subjected to analysis, the data was tested for normality and homogeneity of variance.

Preliminary analysis indicated that; (1) the two-way interactions between production system and gender, (2) date of slaughter (week 5 or 6) and (3) all the date of slaughter interactions were not significant ($P > 0.05$) for the any of the physical meat quality attributes. Therefore the final model for the analysis of the dependent variables pH45, pH48, temp45, drip loss %, cooking loss %, L* lab, a* Lab, b* Lab, chroma and hue, and Warner-Bratzler shear force included production system and gender as the main effects.

Preliminary statistical analysis on chemical composition indicated that the interaction effects were also not significant ($P > 0.05$). The final model for the analysis of the chemical characteristics of both the BF and the LD muscles therefore included production system, gender and slaughter date as main effects.

RESULTS AND DISCUSSION

The effect of production system on the physical quality characteristics of the LD muscle is presented in Table 1. Production system had a significant effect ($P < 0.05$) on pH45, Temp45, a* lab, and chroma. As for the other characteristics, no differences due to production system were observed.

FL-lambs had a significantly lower pH45 than FR-lambs ($P < 0.01$). It can be argued that the fatter carcasses of FL-lambs (as indicated by the significantly thicker subcutaneous fat of FL-lambs compared to FR-lambs slaughtered on both slaughter date 1 and 2 in Chapter 3) cooled down at a slower rate than the leaner carcasses of FR-lambs (French *et al.*, 2001; Lawrie, 1998) and therefore had a more rapid post mortem glycolysis, which resulted in a lower pH. This slower cooling rate was also shown by the higher (approximately 3ºC) Temp45 of the FL-lambs compared to the FR-lambs (Table 1). Contrary to the results of this investigation, Diaz *et al.* (2002) found that feeding system had no effect on muscle pH, possibly because there was an adequate food supply and minimal animal stressors in their experiment. Results of this investigation further indicate that lambs from both production systems had similar means for pH48, a result that seems to suggest that overnight lairage may have been sufficient for muscle glycogen reserves to be replenished after the stress of transport and other stressors. Higher carcass Temp45 of FL-lambs is consistent with previous results (Priolo *et al.*, 2001).

The results for muscle colour show a significant ($P < 0.05$) reduction of the a* and chroma values for the meat of FR-lambs, indicating that the meat was less red and less intense in colour. This was an unexpected result for two reasons. Firstly, it is known that meat of FR-lambs is generally accepted to be darker than meat of FL-lambs because of greater physical activity undertaken by FR-animals during grazing (Piansentier, 2003; Diaz *et al.*, 2002; Priolo *et al.*, 2002). Secondly, since the pH 48 of FR-lambs was above 5.8 it was expected that the meat would be dark since it is accepted that the darkening of colour becomes more noticeable above this pH. Diaz *et al.* (2002) also found a reduction in a* lab meat colour for FR-lambs. On the other hand, Pethick *et al.* (2005) found that meat from lambs fed a high energy pelleted diet was less red and less intense in colour and associated it with an elevated pH.

Production system had no effect ($P > 0.05$) on meat tenderness as indicated by the Warner-Bratzler shear force values. Although it has been noted that exercise leads to tougher meat (Vestergaard *et al.*, 2000), this did not occur in the present study. This unexpected result could most probably be attributed to two aspects applicable to this investigation. Firstly the animals were slaughtered as lambs and it is known that meat from young, growing animals is more tender upon the first bite because their connective tissue is characterized by an increased soluble collagen percentage linked to a lower quantity of cross-bond connective tissue. An increase in animal age is related to a decrease in the proportion of salt and acid soluble collagen, an increase in the extent of intra- and intermolecular cross-linking between polypeptide chains of collagen, a decrease of collagen solubility on heating and decreasing susceptibility to attack by enzymes, all of which relates to meat toughness (Lawrie, 1998). Secondly, the feedlot lambs had only been maintained in the feedlot for 5-6 weeks. Prior to that they had also been exposed to FR-conditions, and it could be argued that this was too short a period for exercise or the lack thereof to have any meaningful contribution. The same arguments would also apply to the colour characteristics. The index of yellowness (b* lab) revealed a tendency towards a difference ($P = 0.068$) for feeding system and tended to be higher in FL-lambs. In support of this trend, Priolo *et al.* (2002) noted that grass fed lambs had a lower

b* value than concentrate fed lambs. Temperature, drip loss, cooking loss, tenderness, L* lab and hue values were not affected by production system (Table 1).

Table 1. Means (± s.e.) depicting the effect of production system on the physical quality characteristics of Dorper *longissimus dorsi* muscle.

ATTRIBUTE	PRODUCTION SYSTEM		P-VALUE
	Feedlot	Free-range	
pH45	6.68 ± 0.056	6.89 ± 0.049	0.006
pH48	5.78 ± 0 .053	5.88 ± 0 .099	0.374
Temp45 (ºC)	30.46 ± 0.541	27.71 ± 0.611	0.001
Temp48 (ºC)	1.52 ± 0.052	1.69 ± 0.099	0.222
Drip loss (%)	2.40 ± 0.003	2.21 ± 0.002	0.646
Cooking loss (%)	36.23 ± 0.006	36.77 ± 0.005	0.452
Warner-Bratzler (N)	50.0 ± 0.200	60.0 ± 0.300	0.318
L* lab	36.96 ± 0.003	40.63 ± 3.861	0.348
a * lab	12.90 ± 0.226	11.92 ± 0.246	0.005
b * lab	10.45 ± 0.171	9.85 ± 0.263	0.068
Chroma	16.62 ± 0.230	15.51 ± 0.290	0.004
Hue	0.66 ± 0.008	0.67 ± 0.012	0.634

The effect of gender on the physical quality characteristics of the LD muscle is presented in Table 2. In this study, the results show that although no differences ($P > 0.05$) due to gender were observed on the physical quality characteristics of the LD muscle, there were tendencies for the Temp45 ($P = 0.06$) and the cooking loss percentages ($P = 0.0819$) to differ. These results could be linked to the thicker fat cover of the castrates (See Chapter 3). However, comparable studies have also found that gender had no effect on muscle pH (Diaz *et al.*, 2003; Jeremiah *et al.*, 1997; Dransfield *et al.*, 1990), muscle colour (Diaz *et al.*, 2003; Vergara *et al.*, 1999; Jeremiah *et al.*, 1997) and meat tenderness (Vergara *et al.*, 1999). The present results therefore accord with these literature findings.

Table 2. Means (± S.E.) depicting the effect of gender on the physical quality characteristics of Dorper *longissimus dorsi* muscle.

ATTRIBUTE	GENDER			P-VALUE
	Castrates	Ewes	Rams	
pH45	6.78 ± 0.066	6.80 ± 0.064	6.79 ± 0.080	0.971
pH48	5.76 ± 0.101	5.76 ± 0.071	5.98 ± 0.110	0.177
Temp45	30.45 ± 0.643	28.53 ± 0.735	28.28 ± 0.850	0.057
Temp48	1.55 ± 0.129	1.64 ± 0.119	1.63 ± 0.209	0.864
Drip loss (%)	2.53 ±. 0.002	2.18 ± 0.003	2.21 ± 0.005	0.738
Cooking loss (%)	35.37 ± 0.005	37.33 ± 0.007	36.81 ± 0.006	0.0819
Warner-Bratzler (N)	60.0 ± 0.300	50.0 ± 0.300	70.0 ± 0.500	0.318
L* lab	36.45 ±.0.346	42.53 ± 5.777	37.42 ± 0.508	0.394
A* lab	12.77 ± 0.275	12.35 ± 0.242	12.09 ± 0.384	0.257
B* lab	10.29 ± 0.270	10.14 ± 0.208	10.02 ± 0.348	0.775
Chroma	16.43 ± 0.311	16.00 ± 0.247	15.75 ± 0.015	0.322
Hue	0.67 ± 0.012	0.68 ± 0.	0.68 ± 0.005	0.799

The effect of production system on chemical meat quality characteristics of the BF and LD muscles is presented in Table 3. Significant ($P < 0.05$) differences due to production system were observed for both the moisture and protein concentrations of both the BF and LD muscles between FR- and FL-lambs. For both muscles, the average muscle moisture concentration of FR-lambs was higher than that of FL-lambs. Although the intramuscular fat concentrations of both muscles did not differ between feeding systems, the FL-systems had higher fat concentrations in absolute terms, especially as pertaining to the BF where there was a tendency towards significance ($P = 0.094$). It could be argued that this difference may have become more pronounced and been similar to those reported in the literature (Kemp *et al.*, 1976) if the period that the lambs were in the feedlot were extended. Summers *et al.* (1978) also found that the average moisture concentration was higher in unweaned, pasture raised lambs compared to weaned, concentrate fed lambs. Similar studies involving cattle show that steers fed concentrate ad libitum had lower LD moisture concentrations than steers fed either only grass or grass supplemented with concentrate (French *et al.*, 2001). Theriez & Tissier (1981) found that moisture and protein concentration decreased when fat concentration of lamb increased. Schoeder *et al.* (1980), on the other hand, found no difference in moisture concentrations between forage- and grain-finished beef.

The protein percentage of both the BF and LD muscles of FL- lambs was higher than that of FR- lambs. Findings by Theriez & Tissier (1981) that muscle protein content decreases when fat content increases does not agree with the results of this investigation. On the other hand, Rowe *et al.* (1999) found that

muscle protein was not affected by production system. Production system did not affect (P > 0.05) ash percentages or muscle myoglobin concentrations.

The effect of gender on the chemical meat quality characteristics of the BF and LD muscles is presented in Table 4. Significant (P < 0.05) gender differences were found for the moisture content of both muscles. Muscles of ram lambs had a higher moisture percentage than muscles from castrates and ewe lambs. The highest moisture content was observed for the BF muscle of FR ram lambs. It is well known that ram lambs produce leaner carcasses than castrates and ewes (Arnold & Meyer, 1988; Seideman *et al.*, 1982; Crouse *et al.*, 1981) as was also observed in this investigation (Chapter 3). In this investigation, the tendency towards lower lipid concentration of meat from the ram lambs (although this was not statistically different from castrates or ewes related to higher moisture content ( ). Gender had a significant effect on the lipid content of the LD muscle. *Longissimus dorsi* muscles of castrate lambs contained more (P < 0.05) intramuscular lipid than those of ewes and rams.

Table 3. Means (± s.e.) depicting the effect of production system on the chemical composition of the *Biceps femoris* and *Longissimus dorsi* muscles of Dorper lambs.

CHEMICAL COMPOUND	*Biceps femoris* (BF)			*Longissimus dorsi* (LD)		
	Production system		P-value	Production system		P-value
	Feedlot	Free-range		Feedlot	Free-range	
Moisture (%)	74.97± 0.15	76.29 ± 0.16	<0.0001	74.49± 0.15	75.54 ± 0.20	<0.0001
Protein (%)	22.58 ± 0.17	21.78 ± 0.85	0.002	23.08 ± 0.11	22.44 ± 0.17	0.0005
Lipid (%)	3.61 ± 0.15	3.28 ± 0.13	0.094	3.64 ± 0.17	3.43 ± 0.18	0.386
Ash (%)	1.26 ± 0.03	1.19 ± 0.03	0.177	1.38 ± 0.07	1.23 ± 0.07	0.105
Myoglobin (mg/g)	2990 ± 81	2873 ± 82	0.330	2705 ± 81	2687 ± 88	0.883

Table 4. Means (± s.e.) depicting the effect of gender on the chemical meat quality characteristics of the *Biceps femoris* and *Longissimus dorsi* muscles of the Dorper.

	Biceps femoris				*Longissimus dorsi*			
	Gender			P-value	Gender			P-value
	Castrate	Ewe	Ram		Castrate	Ewe	Ram	
Moisture (%)	75.28 ± 0.23	75.59 ± 0.27	76.03 ± 0.20	0.02	74.71 ± 0.22	74.79 ± 0.22	75.54 ± 0.24	0.006
Protein (%)	22.44 ± 0.17	22.29 ± 0.25	21.81 ± 0.21	0.07	22.90 ± 0.18	22.92 ± 0.18	22.47 ± 0.19	0.101
Lipids (%)	3.69 ± 0.15	3.34 ± 0.19	3.32 ± 0.18	0.20	3.80 ± 0.17	3.66 ± 0.216	3.08 ± 0.227	0.03
Ash (%)	1.26 ± 0.03	1.23 ± 0.05	1.19 ± 0.03	0.46	1.24 ± 0.10	1.25 ± 0.05	1.42 ± 0.108	0.221
Myoglobin (mg/g)	2943 ± 66	3010 ± 118	2842 ± 171	0.50	2700 ± 71	2680 ± 129	2707 ± 110	0.984

The two batches of lambs were slaughtered a week apart as it was not logistically possible to slaughter all lambs in a single batch, resulting in the lambs slaughtered a week later being heavier and fatter (Chapter 3). Date of slaughter exerted a significant (P = 0.0362) effect upon moisture percentage of the BF muscle, as well as on the protein (P = 0.0126) and ash (P = 0.0133) percentages of the LD muscle. Lambs slaughtered on date 2 generally had lower moisture concentrations than lambs slaughtered on date 1. The same was noted for the FR-lambs. An interaction effect was observed for percent ash. Ash concentration of the LD muscle of FL-lambs slaughtered at date 1 was higher than FL-lambs slaughtered at date 2. Ash results for FR-lambs indicated that lambs slaughtered at date 2 had a higher ash concentration. However, Theriez & Tissier (1981) found that weight gain had no appreciable effect on ash concentration. For LD protein concentration, FL- and FR-lambs slaughtered at date 2 had higher protein concentrations than their counterparts slaughtered at date 1. Protein results of this investigation are contradictory to those reported by Theriez & Tissier (1981). Gender had no effect on the myoglobin concentration of both the BF and LD muscles.

CONCLUSIONS

The lower pH45 of FL-lambs compared to FR-lambs was expected since the greater subcutaneous fat cover of FL-lambs resulted in a slower cooling rate (nearly 3ºC when measured at 45 mins post mortem), thus impacting on muscle pH. It was impossible to explain the reduced redness and colour intensity of lambs finished under FR-conditions. However, the L* value is often seen as the best predictor of consumer colour acceptance. The importance of colour differences in this study is therefore unclear when related to consumer acceptance. Production system had no effect (P > 0.05) on meat tenderness as indicated by the Warner-Bratzler shear force values. This is an important result particularly since consumers consider tenderness as the most important meat palatability trait. Meat from FR-lambs can thus compete favourably with meat from FL-lambs. No conclusive evidence could be found that gender had an effect on any of the physical meat quality attributes. Meat from the BF muscle of FL-lambs tended (P = 0.09) to have a greater intramuscular lipid concentration. Albeit not significant, this tendency is supported by results indicating that meat from FR-animals generally had relatively less fat (Diaz *et al.*, 2002; Schoeder *et al.*, 1980). The latter system could therefore be regarded as a better choice from a human health perspective, although there is no clear evidence in this study as results weren't significant. Neither production system nor gender had a significant effect (P>0.05) on muscle myoglobin concentration.

REFERENCES

AOAC International, 2002. Official methods of analysis (17th edition). Arlington, Virginia, USA: Association of Official Analytical Chemists Inc. Ash of Animal Feed./ AOAC Official method 942.05

AOAC. 1997. Official methods of Analysis. 15th edition. Arlington, VA. USA: Association of Official Analytical Chemists.

Arnold, A. M. & Meyer, H. H. 1988. Effects of gender, time of castration, genotype and feeding regime on lamb growth and carcass fatness. Journal of Animal Science, 66, 2468-2475.

Baardseth, P., Skrede, G., Naes, T., Thomassen, M.S., Iversen, A. & Kaaber, L. 1988. A comparison of the CIE L*A*B values obtained from two different instruments on several food commodities. Journal of Food Science, 53, 1737-1742.

Bidner, T.D., Schupp, A.R., Montgomery, R.E. & Carpenter, J.C. 1981. Acceptability of beef finished on all forage, forage-plus-grain or high energy diets. Journal of Animal Science, 53, 1181-1187.

Boleman, S.J., Boleman, S.L., Miller, R.K., Taylor, J.F., Cross, H.R., Wheeler, T.L., Koohmaraie, M., Shackleford, S.D., Miller, M.F., West, R.L., Johnson, D.D. & Savell, J.W. 1997. Consumer evaluation of beef of known categories of tenderness. Journal of Animal Science, 75, 1521–1524.

Cloete, J.J.E., Cloete, S.W.P. & Hoffman, L.C. 2005. Behaviour of Merinos divergently selected for multiple rearing ability in response to external stimuli. Small Ruminant Research, 60, 227-236.

Cloete, J.J.E., Cloete, S.W.P., Hoffman, L.C. & Fourie, J.E. 2004a. Slaughter traits of Merino sheep divergently selected for multiple rearing ability. South African Journal of Animal Science, 34, 189-196.

Cloete, J.J.E., Hoffman, L.C., Cloete, S.W.P. & Fourie, J.E. 2004b. A comparison between body composition, carcass characteristics and retail cuts of South African Mutton Merino and Dormer sheep. South African Journal of Animal Science, 34, 44-51.

Crouse, J. D., Busboom, J. R., Field, R. A. & Ferrell, C. L. 1981. The effects of breed, diet, sex, location and slaughter weight on lamb growth, carcass composition and meat flavour. Journal of Animal Science, 53, 376-381.

Crouse, J.D. & Field, R.A. 1978. Effect of dietary energy intake on carcass composition and palatability of different weight carcasses from ewe and ram lambs. Journal of Animal Science, 47, 1207-1218.

Davies, A., Titterington, A.J. & Cochrane, C. 1995. “Who buys organic food? A profile of the purchasers of organic food in Northern Ireland”. British Food Journal, 97 , 17-23.

Díaz, M., Velasco, S., Perez, C., Lauzurica, S., Huidoboro, F. & Caneque, V. 2003. Physio-chemical characteristics of carcass and meat Manchego-breed suckling lambs slaughtered at different weights. Meat Science, 65, 1085-1093.

Díaz, M.T., Velasco, S., Caneque, V., Lauzurica, S., de Huidobro, F. R., Perez, C., Gonzalez, J. & Manzanares, C. 2002. The use of concentrate or pasture for fattening lambs and its effect on carcass and meat quality. Small Ruminant Research, 43, 257-268.

Dransfield, E., Nute, G.R., Hogg, B.W., & Walters, B.R. 1990. Carcass and eating quality of ram, castrated ram and ewe lambs. Animal Production, 50, 291- 299.

Field, R.A. 1971. Effect of castration on meat quality and quantity. Journal of Animal Science, 32, 849-858.

French, P., O’Riordan, E. G., Monahan, F.J., Caffrey, P.J., Mooney, M.T., Troy, D.J. & Moloney, A.P. 2001. The eating quality of steers fed grass and/or concentrates. Meat Science, 57, 379-386.

Gonzalez, C. B., Salitto, V.A. & Carduza, F.J. 2001. Effect of calcium chloride marination on bovine Cutaneus trunci muscle. Meat Science, 57, 251–256.

Grunert, K.G. 2006. Future trends and consumer lifestyles with regard to meat consumption. Meat Science, 74, 149 – 160.

Grunert, K.G. 1997. What's in a steak? A cross-cultural study on the quality perception of beef. Food quality and Preferance, 8, 157-174.

Harper, G.C. & Makatouni, A. 2002. Consumer perception of organic food production. British Food Journal, 104, 3/4/5, 287-299.

Honikel, K.O. 1998. Reference methods for the assessment of physical characteristics of meat. Meat Science, 49 (4), 447 – 457.

Jeremiah, L.E., Tong, A.K.W. & Gibson, L.L. 1997. The influence of chronological age, slaughter weight and gender on carcass meat quality. Sheep and Goat Research Journal, 13, 157-166.

Jimenez-Colmenero, F., Carballo, J. & Cofrades, S. 2001. Healthier meat and meat products: their role as functional foods, Review. Meat Science, 59, 5 – 13.

Johnson, P.L., Purchas, R.W., McEwan, J.C. & Blair, H.T. 2005. Carcass composition and meat quality differences between pasture raised ewe and ram lambs. Meat Science, 71, 383-391.

Krzywicki, K. 1982. The determination of haem pigment in meat. Meat Science, 7, 29-36.

Lawrie, R.A. 1998. Meat Science, 6th edition. Pergamon Press. New York.

Lee, C.M., Trevino, B. & Chaiyawat, M. 1996. A simple and rapid solvent extraction method for determining total lipids in fish tissue. Journal of AOAC International volume 79, no 2.

McEachern, M.G. & Willock, J. 2004. Producers and consumers of organic meat: A focus on attitudes and motivations. British Food Journal, 7, 534-552.

Pethick, D.W., Davidson, R., Hopkins, L.D., Jacob, R.H., ´Souza, D.N.D., Thompson, J.M. & Walker, P.J. 2005. The effect of dietary treatment on meat quality and consumer perception of sheep meat eating quality. Australian Journal of Experimental Agriculture, 45, 517-524.

Piasentier, E. 2003. The effect of grazing on the quality of meat. Internationale Fachtagung für Schafhaltung. p1-5 http://www.gumpenstein.at/publikationen/fachtagungschaf/piasenti.pdf accessed 8 January 2008.

Priolo, A., Micol, D. and Agabriel, J., Prache, S. & Dransfield, E. 2002. Effect of grass or concentrate feeding systems on lamb carcass and meat quality. Meat Science, 62, 179-185.

Priolo, A., Micol, D. & Agabriel, J. 2001. Effects of grass feeding systems on ruminant meat colour and flavour. A review. Animal Research, 50, 185-200.

Rowe, A., Macedo, F.A.F., Visentainer, J.V., Souza, N.E. & Matsushita, M. 1999. Muscle composition and fatty acid profile in lambs fattened in drylot or pasture. Meat Science, 51, 283-288.

SAS Institute Inc. 1999. SAS Procedures Guide. SAS Institute INC., Cary, NC, USA.

Schroeder, J.W., Cramer, D.A., Bowling, R.A & Cook, C.W. 1980. Palatability, shelf-life and chemical differences between forage- and grain- finished beef. Journal of Animal Science, 50, 852-859.

Seideman, S. C., Cross, H. R, Oltjen, R. R. & Scanbacher, B. D. 1982. Utilization of intact male for red meat production. Journal of Animal Science, 55, 826- 840.

Summers, R.L., Kemp, J.D., Elly, D.G. & Fox, J.D. 1978. Effects of weaning, feeding system and sex of lamb on lamb characteristics and palatability. Journal of Animal Science, 47, 622-629.

Theriez, M. & Tissier, M. 1981. The chemical composition of intensively fed lambs. Animal Production, 32, 29-37.

Vergara, H.,Molina, A. & Gallego, L. 1999. Influence of sex and slaughter weight on carcass and meat quality in light and medium weight lambs produced in intensive systems. Meat Science, 52, 221-226.

Vestergaard, M., Oksberg, N. & Henckel, P. 2000. Influence of feeding intensity, grazing and finishing feeding on muscle fibre characteristics and meat colour of *semitendenosus, longissimus dorsi* and *supraspinatus* muscles in young bulls. Meat Science, 54, 177-185.

Chapter 5

The effect of production system on the sensory quality characteristics of Dorper lamb

Abstract

This investigation analyses the effect of production systems on sensory quality characteristics of Dorper lambs under South African conditions. Sixty lambs were divided into two production groups (feedlot-{FL} or free-range {FR}) at weaning. Each group consisted of 10 lambs from each gender class (ewes, rams and castrates) resulting in a 2 (production system) x 3 (gender) experimental outlay. Lambs were blocked according to weaning weight and were fed for 5 (slaughter day 1) or 6 (slaughter day 2) weeks. Feedlot lambs were fed a commercial pelleted diet while the free-range group utilized natural pastures until slaughter. Samples were evaluated by a trained sensory panel (7 assessors) during ten sessions. For each session, panel members were offered six different meat samples and the attributes (initial juiciness, sustained juiciness, tenderness and flavour) were recorded individually. The production system effect was significant for sustained juiciness and tenderness, with the meat from FL-lambs being juicier and more tender than meat from FR-lambs. A tendency was observed for initial meat juiciness with meat of FL-lambs being juicier than that of FR-lambs. No aroma and flavour differences attributable to production system were observed. Meat from FR-ram lambs slaughtered on slaughter day 1 was the least tender when the production system by gender by slaughter date interaction was considered. Lamb flavour was compromised in ram lambs in the FR-production system when the feeding system by gender interaction was considered. The gender effect indicated that meat tenderness was compromised in ram lambs, when compared to the other gender groups. It is concluded that free-range meat may not necessarily be distinguished from feedlot meat as far as the attributes of aroma and flavour are concerned.

INTRODUCTION

Eating satisfaction of meat is mainly derived from meat tenderness, juiciness and flavour. Consumers consider meat tenderness the most important palatability trait (Pietrasik & Shand, 2004; Whipple *et al.*, 1990), with some consumers expressing willingness to pay a higher price for meat that could be certified as tender (Miller *et al.*, 2001). Juicy meat is generally preferred over meat that is less juicy (Risvik, 1994). Meat flavour is also important in overall product acceptability. In order to satisfy consumer satisfaction, these quality attributes therefore need to be taken into consideration when raising animals.

In recent years a number of consumers have been quite vocal about their preference for animal products of free-range origin (Verbeke & Viaene, 2000). Free-range products are perceived as natural, healthier and of higher quality than products from more intensive animal production systems (McEachen & Wilcock, 2004; Davies *et al.*, 1995). Scientific investigations report differences between carcasses from feedlot and free-range systems (Díaz *et al.*, 2002; Murphy *et al.*, 1994; Crouse *et al.*, 1981). High planes of nutrition often associated with feedlot diets result in lambs that are generally fatter at slaughter compared to lambs on

free-range diets. These fatter carcasses from feedlot diets show an improvement in meat tenderness through an increase in the intramuscular fat content relative to the muscle collagen (Crouse & Field, 1978) Moreover, higher juiciness scores are associated with meat from lambs fed feedlot diets (Priolo *et al.*, 2002; Arnold & Meyer, 1988; Notter *et al.*, 1991; Oltjen *et al.*, 1971). Fatter carcasses are also better insulated than lean carcasses, thus slowing down post mortem chilling and improving meat tenderness by decreasing the extent of cold-induced muscle shortening and also by prolonging post mortem proteolysis (Muir *et al.*, 1998). Also, animals that grow rapidly before slaughter, as is commonly found when high quality feedlot diets are fed, have been found to produce tender meat (Koohmaraie *et al.*, 2002). The tenderness of meat is attributed to an increased protein turnover that results in higher concentrations of proteolytic enzymes in carcass tissues (Fishell *et al.*, 1985). In addition muscles from these faster growing animals tend to have less cross-linked collagen (Lawrie, 1998). In contrast, lambs fed low energy diets have also been reported to produce more tender meat than lambs fed a higher energy diet (Solomon *et al.*, 1986). Some studies have shown that lamb gender has an effect on carcass composition, juiciness, tenderness and flavour (Priolo *et al.*, 2002; Lawrie, 1998). In particular, intact male lambs produce leaner carcasses than castrates and ewes. Leaner carcasses are associated with less juicy and less tender meat compared to fatter carcasses of ewes and castrate lambs (Seideman *et al.*, 1982; Field, 1971). However, investigations on cattle have been unable to detect significant differences in meat tenderness between bulls and steers. At the same age, meat from males is less tender than meat from females and this phenomenon is attributed to higher calpastatin and μ-calpain activity at 24 hours post mortem in the meat from males (Morgan *et al.*, 1993). According to Pommier *et al.* (1989) testosterone levels in males increase after puberty, causing an increase in the quantity of collagen in the muscle, which reduces the tenderness of meat.

Flavour volatiles may be affected by feeding system (Melton, 1990; Crouse *et al.*, 1981). Feedlot diets have been noted to alter fat composition and reduce flavour intensity while free-range diets produce lamb with a more intense flavour (Rousset-Akrin *et al.*, 1997). However, Muir *et al.* (1998) observed no flavour differences when free-range and feedlot lambs were slaughtered at the same weight and/or fat cover. In addition, high quality pastures may also result in no flavour differences between free-range and feedlot meat (Melton, 1990). Sheep meat odour and flavour are also affected by gender as well as its interactions with feeding system (Priolo *et al.*, 2002; French *et al.*, 2001; Rousset-Akrim *et al.*, 1997).

Literature which compares the effect of production/feeding system on the sensory meat characteristics of all three gender groups is scarce in Southern Africa. Most literature compares either feeding system on the sensory meat quality characteristics between ewes and rams or rams and castrates. The comparison of a free-range finishing regime with feedlot finishing for Dorper sheep under South African conditions has not yet been reported. The Dorper sheep breed is the second most abundant sheep breed in South Africa and has been selected for its hardiness and adaptability under harsh conditions (Milne, 2000; Schoeman, 2000). In this experiment Dorper lambs of all gender groups of the same age were finished off in the feedlot or under free-range conditions and slaughtered after a predetermined period. The main objectives of this study were to investigate the effect of production system (free-range or feedlot) on the sensory

quality characteristics of Dorper lamb. The effect of gender on lamb sensory quality characteristics was also investigated.

MATERIALS AND METHODS

Sixty Dorper lambs were divided into two production groups, namely feedlot (FL-) and free-range (FR-) at weaning. Each production group consisted of 10 lambs from each gender class (ewes, rams and castrates). The FL-lambs were fed a commercial pelleted diet (Complete Sheep Finisher; Veekos, batch number 44442; see Chapter 3 for bag minimum and maximum specifications) while the FR-group grazed natural pastures until slaughter. The experimental outlay (age of the lambs, selection of the lambs, description of the production system, diet composition, plants grazed, etc.) is detailed in Chapter 3. After a predetermined period of five weeks, 15 lambs from each of the two production groups (each group represented by five lambs from each gender class) were randomly selected, weighed and transported approximately 250 km to the abattoir. Lambs slaughtered after five weeks were approximately 156 days old. Upon arrival at the abattoir, all lambs were grouped together in overnight lairage. The next morning, lambs were electrically stunned and slaughtered using standard South African procedures. The remaining 15 lambs were slaughtered in week six when they were approximately 163 days old. Both week 5 and week 6 lambs were used for the sensory analysis.

After forty-eight hours of refrigeration at 4^{o}C, *Longissimus dorsi* (LD) muscles were excised between the 8th to 11th ribs from both sides of each carcass. Excised LD muscles were placed in individually coded bags, in an insulated cool box, and transported to the Meat Science laboratory at Stellenbosch University for further analysis. The LD muscles from the right side of each carcass were used for subcutaneous fat thickness measurements (Chapter 3). The LD muscle samples from the left side of the carcass (with the subcutaneous fat layer still intact) were vacuum sealed and stored at -18^{o}C until required for sensory meat quality evaluation.

Preparation of samples

Twenty-four hours before every sensory evaluation session, six LD muscles (one from each sex of each treatment) were removed from the freezer and defrosted in a refrigerator at 2-4^{o}C. After twenty-four hours each sample was removed from its packaging and placed on a metal rack (covered with foil paper with the reflective side up) in a coded bag. A probe was inserted into the centre of each sample and samples were roasted to an internal temperature of 68^{o}C in a preheated oven at 160^{o}C. The meat was roasted in two Defy ovens connected to a computerized electronic temperature system. At a core temperature of 68^{o}C, meat samples were removed from the oven and allowed to cool for five minutes. All the visible fat and meat surfaces exposed to the cooking environment were then trimmed off. Each sample was cut into

cubes, perpendicular to the fibre direction. Thereafter, the cubes were individually wrapped in aluminum foil and reheated at 100^{o}C for 10 minutes before the commencement of each session.

Sensory analysis

The sensory panel consisted of seven trained assessors previously selected for their flavor and texture sensitivity according to the guidelines of the American Meat Science Association (AMSA, 1995). The panel was further trained using the consensus method described by Lawless & Heymann (1998). Attributes were rated on the basis of 100 mm unstructured lines with anchor points at each end, zero (left anchor point) representing minimum and hundred (right anchor point) representing maximum. Scores were considered as the distance from the left anchor point. For all the sensory attributes analysed, except flavour, a higher value depicted a better score. One sample from each gender group in each production system was used to train the panel for sensory attributes. The judges agreed on a consensus list of attributes for describing lamb which included intensity of lamb aroma, impression of initial juiciness, sustained juiciness, impression of tenderness and overall lamb flavour. Verbal definitions of the sensory attributes evaluated for the lamb are given in Table 1.

Sensory procedure

Samples were served and evaluated during ten sessions, During each session, every panel member received six meat samples i.e. three (ram, ewe, castrate) samples from the free-range system and three (ram, ewe, castrate) samples from the feedlot system. The panelists were seated in individual sensory booths in a temperature controlled room (natural day light at 22^{o}C). Meat samples (individually wrapped in aluminum foil) were placed in coded glass ramekins, preheated at 100 ^{o}C and presented in a completely randomized order as pertaining to production system and gender. The meat was evaluated using the standard questionnaire of the American Meat Science Association (AMSA, 1995). The aroma of the samples was assessed immediately after unwrapping the aluminum foil. Initial juiciness was assessed by pressing the sample between the forefinger and the thumb. Sustained juiciness, tenderness and flavour attributes were assessed by tasting the sample. For each session, panel members were offered six different meat samples and the attributes were individually recorded. Wafer biscuits, apple slices and distilled water were used by the assessors to cleanse their palates between samples.

Table 1. Verbal definitions used to describe the sensory attributes of Dorper lamb.

ATTRIBUTE	DEFINITION	SCALE
Lamb aroma	Aroma associated with lamb.	0 = No lamb aroma 100 = strong lamb aroma
Initial juiciness	The amount of fluid that exudates on the cut surface when pressed between thumb and fore finger.	0 = extremely dry 100 = extremely juicy
Sustained juiciness	The degree of juiciness perceived after the first two to three chews between the molar teeth.	0 = extremely dry 100 = extremely juicy
Tenderness	Impression of tenderness after the first two to three chews between the molar teeth.	0 = extremely tender 100 = extremely tough
Flavour	Flavour associated with lamb as a combination of taste and swallowing.	0 = bland flavour 100 = intense flavour

Statistical analysis of data

The sensory data were subject to analysis of variance (ANOVA) using SAS version 8.2 statistical software to evaluate different sources of variation in sensory attributes: lamb aroma, initial juiciness, sustained juiciness, tenderness and overall flavour. Production system, gender and slaughter date were the main effects and all the interactions between the main effects were also considered. The Shapiro-Wilk test was performed to test for non-normality (Shapiro & Wilk, 1965). The sensory experiment consisted of three treatment combinations, each replicated ten times by seven panel members in a completely randomized design. The treatment combinations involved a 2 x 3 x 2 factorial design, arising from the combination of two production systems (feedlot and free-range) and three gender groups (ewes, castrates and ram lambs) and two slaughter dates (slaughter date 1 and 2). A P-value smaller than 5% ($P<0.05$) was considered significant. Where applicable, Pearsons' correlations were calculated between the various sensory attributes and the physical and chemical characteristics reported in previous Chapters.

RESULTS AND DISCUSSION

The analysis of variance (ANOVA) of the lamb attributes: lamb aroma, initial meat juiciness, sustained meat juiciness, tenderness and flavour are presented in Table 2. Production system had no effect on lamb aroma, although a tendency ($P = 0.06$) for an effect on initial meat juiciness was noted. Differences ($P< 0.05$) attributable to production system were observed for sustained meat juiciness and tenderness. Gender only had a significant effect on the lamb attributes; tenderness and flavour. The two way interaction between production system and gender was significant for lamb flavour. Slaughter date had no effect on any of the sensory attributes but, the three-way interaction between production system, gender

and slaughter date was significant for meat tenderness. The significant main effects are therefore discussed further while the significant interactions will be discussed in more detail.

On average, results of this investigation revealed that meat from FL-lambs tended (P = 0.06) to have higher initial juiciness scores than meat from FR-lambs (Table 3). Moreover, a negative correlation was observed between initial meat juiciness and drip loss (P= 0.002; r=-0.54), while a positive correlation was observed between initial meat juiciness and sustained meat juiciness (P<0.0001; r=0.800). On the other hand, a negative correlation was observed between initial meat juiciness of FR-lambs and cooking loss (P=0.02; r=-0.418) while a positive correlation between initial meat juiciness and sustained meat juiciness was noted (P<0.0001; r=0.80). It is well known that initial meat juiciness is related to the waterholding capacity (WHC) of meat. Higher WHC values indicate higher initial juiciness scores whereas lower WHC values indicate lower initial juiciness scores. Higher sustained juiciness scores were also noted for meat from FL-lambs compared to meat from FR-lambs (P<0.05). Sustained meat juiciness depends on the amount of liquid released during mastication, both from the food and saliva. The higher intramuscular lipid content (Chapter 4, Table 3) of meat from FL-lambs (in absolute terms) compared to that of FR-lambs might have affected the perception of meat juiciness through stimulating saliva flow (P= 0.02; r=0.43). Piasentier (2003) also noted higher sustained juiciness scores for FL-lambs compared to FR-lambs.

Less tender meat of FR-lambs may be attributed to the higher level of exercise of these lambs during grazing activity (Shroeder *et al.*, 1980). This result is in agreement with that of Vestergaard *et al.* (2000) who also suggested physical activity as the reason for lower tenderness scores observed in bulls raised on pasture compared to tie-stalled bulls that were fed a concentrate based diet. The different energy intake of the animals on the two production systems might also have have contributed to different muscle lipid content and therefore juiciness and tenderness. Lowe (2002) did not find any significant differences in tenderness between FR- and FL- lambs, based on mechanical shear force values, probably because nutrition was adequate and stress levels were low in that experiment. Meat from ewe lambs tended to be more tender (86.98 ^{a} ± 8.63) than meat from castrates although the difference was not statistically significant (86.56 ^{a} ± 8.42) . Moreover, meat from ram lambs had the lowest tenderness score compared to meat from castrates and ewes (Table 3). It is known that at the same age (as was the case in this investigation), meat from male lambs is less tender than that from female lambs (Morgan *et al.*, 1993). This is because, after puberty, the amount of testosterone in males increases the amount of collagen in muscles, resulting in reduced tenderness of the meat (Pommier at al., 1989). Other research results indicate that meat from male animals have higher calpastatin activity 24 h postmortem which most likely decreases the quantity of myofibrillar protein proteolysis thus resulting in less tender meat (Morgan *et al.*, 1993). Studies involving beef cattle also show that meat from bull carcasses is less tender and hence less palatable than meat from steer carcasses (Dikeman *et al.*, 1986; Seideman *et al.*, 1982; Field, 1971). However, some investigations have been unable to detect significant differences between meat from bulls and steers (Vanderwert *et al.*, 1986). The three-way interaction between production system, gender and slaughter date was significant (P < 0.05) for meat tenderness. Meat from FR-ram lambs slaughtered on

slaughter date 1 (FR-ram1) had the lowest tenderness scores compared to all the other means contained in the three-way interaction (Table 5). This was an expected result for a number of reasons. Firstly, it is well known that intact males generally produce leaner carcasses (than ewes and castrates) that are associated with less tender meat (Dikeman *et al.*, 1986; Seideman *et al.*, 1982; Schroeder *et al.*, 1980; Field, 1971). Furthermore, it is also known that at the same age, meat from males is less tender than that of ewes or castrates, a phenomenon that is attributed to testicular hormones (Pommier *et al.*, 1989). In addition, low energy diets such as free-range diets are often associated with less tender meat although contradictory results have been reported (Solomon *et al.*, 1986). Ram lambs produced meat with a more intense flavour. This attribute was affected (P = 0.01) by the two-way interaction between feeding system and gender (Table 4). The flavour of FL-lambs was largely independent of gender while meat from FR-rams had a less desirable flavour than meat from all the other groups. This includes meat obtained from the FR-ewe and –castrate lambs. In general lambs finished off under free-range conditions were found to produce meat with more intense flavours (and less desirable flavour) than lambs stemming from feedlot conditions (Priolo *et al.*, 2001). Similarly, ram lambs produced meat with more intense flavours than meat from ewe lambs, most probably due to testicular hormones. A study by Rousset- Akrim *et al.* (1997) also showed that lambs raised under free-range conditions had a more intense flavour than lambs raised under feedlot conditions although their difference applied across gender groups. In this study, flavour was compounded in the FR-system x ram lamb combination, resulting in the observed interaction.

Table 2. Analysis of variance (ANOVA) for the attributes; aroma, initial juiciness, sustained juiciness, tenderness and flavour for Dorper lambs (rams, ewes, castrates) reared either under free-range condition or feedlot system.

		Lamb aroma		Initial juiciness		Sustained juiciness		Tenderness		Flavour	
Source	**dF**	**MS**	**P-value**	**MS**	**P-value**	**MS**	**P-value**	**MS**	**P-value**	**MS**	**P-value**
Production system	1	32.89	0.350	289.63	0.064	486.27	0.015	549.38	0.024	2.67	0.599
Gender	2	48.35	0.280	22.40	0.756	122.15	0.211	640.02	0.004	35.77	0.031
Slaughter date	1	74.41	0.160	96.03	0.278	169.69	0.141	145.80	0.234	0.02	0.965
Production system x Gender	2	16.99	0.640	175.81	0.123	18.95	0.779	137.59	0.264	46.09	0.013
Production system x Slaughter date	1	0.01	0.990	0.04	0.982	0.49	0.936	3.67	0.850	0.74	0.780
Gender x slaughter date	2	36.50	0.380	30.96	0.680	7.64	0.900	10.53	0.900	7.77	0.450
Production system x Gender x Slaughter date	2	35.50	0.390	53.81	0.514	7.73	0.903	347.62	0.040	15.37	0.210

Table 3. Means (± s.d) depicting the effect of slaughter date, production system and gender on the sensory attributes of Dorper lamb.

Attribute	Slaughter date		Production system		Gender		
	1	2	Feedlot	Free-rage	Castrates	Ewes	Rams
Aroma	81.83 [b] ± 8.91	83.14 [a] ± 7.92	82.82 [a] ± 8.52	82.15 [a] ± 8.37	82.17 [a] ± 8.07	83.02 [a] ± 8.76	82.26 [a] ±8.52
Initial juiciness	81.72 [b] ± 8.16	84.25 [a] ± 7.08	83.94 [a] ± 7.58	82.02 [b] ± 7.80	83.25 [a] ± 7.42	83.70 [a] ± 7.95	82.33 [a] ± 7.86
Sustained juiciness	79.38 [b] ± 9.31	81.63 [a] ± 8.69	81.67 [a] ± 8.82	79.33 [b] ± 9.18	80.75 [a] ± 8.36	81.38 [a] ± 9.88	79.40 [a] ± 8.84
Tenderness	85.48 [a] ± 8.53	85.48 [a] ± 8.74	86.69 [a] ± 8.19	84.21 [b] ± 8.90	86.56 [a] ± 8.42	86.98 [a] ± 8.63	82.85 [b] ± 8.29
Flavour	82.20 [a] ± 8.21	82.67 [a] ± 8.05	82.57 [a] ± 8.46	82.30 [a] ± 7.78	82.65 [a] ± 7.72	82.82 [a] ± 8.51	81.84 [b] ± 8.13

[ab] Different subscripts differ at P< 0.05

Table 4. Means (± s.d) depicting the effect of the two way interaction between production system x gender on the flavour of Dorper lambs.

Attribute	Production system x Gender					
	FL-castrate	FL-ewe	FL-ram	FR-castrate	FR-ewe	FR-ram
Flavour	82.37 [a] ± 7.92	82.64 [a] ± 8.77	82.71 [a] ± 8.81	82.95 [a] ± 7.56	82.98 [a] ± 8.32	80.98 [b] ± 7.39

[ab] Different subscripts differ at P< 0.05

Table 5. Means (± s.d) depicting the effect of the three way interaction between production system x gender x slaughter date on the tenderness of Dorper lambs.

Attribute	Production system x Gender x Slaughter date											
	FLcast1	FLcast2	FLewe1	FLewe2	FLram1	FLram2	FRcast1	FRcast2	FRewe1	FRewe2	FRram1	FRram2
Tenderness	87.87 ± 8.02	85.57 ± 9.00	89.04 ± 6.62	87.67 ± 9.47	84.83 ± 8.90	85.33 ± 6.31	85.31 ± 8.66	87.48 ± 8.08	86.50 ± 7.75	84.87 ± 10.03	79.38 ± 8.24	81.73 ± 8.43

CONCLUSIONS

Results from this investigation indicate that production system affects some sensory characteristics of Dorper lambs. The advantage of FL-feeding appears to be its ability to produce juicier and more tender meat compared to FR-feeding – phenomena attributed to the higher lipid content of the former. Meat tenderness was compromised in ram lambs in the FR-production system for lambs slaughtered on slaughter day 1 when the production system by gender by slaughter date interaction was considered. Overall, production system had no effect on either the aroma or flavour of Dorper lamb. However, lamb flavour was more intense in ram lambs in the FR-production system when the feeding system by gender interaction was considered. Furthermore, the gender effect suggested that meat tenderness was compromised in ram lambs compared to the other gender groups.

REFERENCES

AMSA. 1995. Research guidelines for Cookery, Sensory Evaluation and Instrumental Tenderness Measurements of Fresh Meat. Pp. 1-33. Chicago: National Livestock and Meat Board.

Arnold, A.M. & Meyer, H.H. 1988. Effects of gender, time of castration, genotype and feeding regime on lamb growth and carcass fatness. Journal of Animal Science, 66, 2468-2475.

Crouse, J.D. & Field, R.A. 1978. Effect of dietary energy intake on carcass composition and palatability of different weight carcasses from ewe and ram lambs. Journal of Animal Science, 47, 1207-1218.

Crouse, J.D., Busboom, J.R., Field, R.A. & Ferrell, C.L. 1981. The effects of breed, diet, sex, location and slaughter weight on lamb growth, carcass composition and meat flavour. Journal of Animal Science, 53, 376-381.

Davies, A., Titterington, A.J. & Cochrane, C. 1995. "Who buys organic food? A profile of the purchasers of organic food in Northern Ireland. *British Food Journal*, 97, (10), 17-23.

Díaz, M.T., Velasco, S., Caneque, V., Lauzurica, S., de Huidobro, F. R., Perez, C., Gonzalez, J. & Manzanares, C. 2002. The use of concentrate or pasture for fattening lambs and its effect on carcass and meat quality. Small Ruminant Research, 43, 257-268.

Dikeman, M.E., Reddy, G.B., Arthaud, V.H., Tuma, H.J., Koch, R.M., Mandigo, R.W., Axe, J.B. 1986. Longissimus muscle quality, palatability and connective tissue histological characteristics of bulls and steers fed different energy levels and slaughtered at four ages. Journal of Animal Science, 63, 92-113.

Field, R.A. 1971. Effect of castration on meat quality and quantity. Journal of Animal Science, 32, 849.

Fishell, V.K., Aberle, E.D., Judge, M.D. & Perry, T.W. 1985. Palatability and muscle properties of beef as influenced by preslaughter growth rate. Journal of Animal Science, 61,151-157.

French, P., O'Riordan, E.G., Monahan, F.J., Caffrey, P.J., Mooney, M.T., Troy, D.J. & Moloney, A.P. 2001. The eating quality of steers fed grass and/or concentrates. Meat Science, 57, 379-386.

Koohmaraie, M., Kent, Matthew, P.K., Schackelford, S.D., Veiseth, E. & Wheeler, T.L. 2002. Meat tenderness and muscle growth: is there any relationship? Meat Science, 62, 345-352.

Lawless, H.T. & Heymann, H. 1998. Sensory evaluation of food: principles and practices. Gaithersburg, MD, USA: Aspen Publishers.

Lawrie, R.A., 1998. Meat Science, 6th edition. Pergamon Press. New York.

Lowe, T.E., Peachy, B.M. & Devine, C.E. 2002. The effect of nutritional supplements on growth rate, stress responsiveness, muscle glycogen and meat tenderness in pastoral lambs. Meat Science, 62(4), 391-397.

McEachern, M.G. & Willock, J. 2004. Producers and consumers of organic meat: A focus on attitudes and motivations. British Food Journal, 7, 534-552.

Melton, S.L. 1990. Effect of feeds on flavour of red meat, a review. Journal of Animal Science, 68, 4421-4435.

Miller, M.F., Carr, M.A., Ramsey, C.B., Crockett, K.L. & Hoover, L.C. 2001. Consumer thresholds for establishing the value of beef tenderness. Journal of Animal Science, 79, 3062-3068.

Milne, C. 2000. The history of Dorper sheep. Small Ruminant Research, 36, 99-102.

Morgan, J.B., Wheeler, M., Koohmaraie, M., Savell, J.W. & Crouse, J.D. 1993. Meat Tenderness and Calpain Proteolytic System in Longissimus Muscle of Young Bulls and Steers. Journal of Animal Science, 71, 1471-1476.

Muir, P.D., Beaker, J.M. & Bown, M.D. 1998. Effects of forage and grain feeding systems on beef quality. Journal of Agriculture Research, 41, 623-635.

Murphy, T.A., Loerch, S.C., McClure, K.E. & Solomon, M.B. 1994. Effects of restricted feeding on growth performance and carcass composition of lambs subjected to different nutritional treatments. Journal of Animal Science, 72, 3131-3137.

Notter, D.R. Kelly, R.F. & McClaugherty, F.S. 1991. Effects of ewe breed and management system on efficiency of lamb growth production: II. Lamb growth, survival and carcass characteristics. Journal of Animal Science, 69, 22-33.

Oltjen, R.R., Ramsey, T.S. & Putman, P.A. 1971. All forage diets for finishing beef steers. Journal of Animal Science, 46, 716-724.

Piasentier, E. 2003. The effect of grazing on the quality of meat. Internationale Fachtagung für Schafhaltung. p1-5 http://www.gumpenstein.at/publikationen/fachtagungschaf/piasenti.pdf accessed 8 January 2008.

Piertisik, Z. & Shand, P.J. 2004. Effect of blade tenderized and tumbling time on the processing characteristics and tenderness of injected cooked roast beef. Meat Science, 66, 871-879.

Pommier, S.A., Fahmy, M.H., Poste, L.M. & Butler, G. 1989. Effects of sex, electrical stimulation and conditioning time on carcass and meat characteristics of Roman lambs. Food Quality and Preference, 1: 127-132.

Priolo, A., Micol, D., Agabrie, J., Prache, S & Dransfield, E. 2002. The effect of grass or concentrate feeding system on lamb carcass and meat quality. Meat Science, 62, 179-185.

Priolo, A., Micol, D. & Agabrie, J. 2001. Effect of grass feeding system on ruminant meat colour and flavour. A review. Animal Research, 50, 185-200.

Risvik, E. 1994. Sensory properties and peferences. Meat Science, 36, 67-77.

Rousset-Akrim, S., Young, O.A. & Berdague, J.L. 1997. Diet and growth effects in panel assessment of sheepmeat odour and flavour. Meat Science, 45, 169-181.

Schoeman, S.J. 2000. A comparative assessment of Dorper sheep in different production environments and systems. Small Ruminant Research, 36, 137- 146.

Schroeder, J.W., Cramer, D.A., Bowling, R.A. & Cook, C.W. 1980. Palatability, shelf-life and chemical differences between forage- and grain- finished beef. Journal Animal Science, 50, 852-859.

Seideman, S.C., Cross, H.R. Oltjen, R.R. & Scanbacher, B.D. 1982. Utilization of intact male red meat production. Journal of Animal Science, 55, 826-840.

Shapiro, S.S. & Wilk, M.B. 1965. An analysis of variance test for normality (complete samples). Biometrika, 52, 591-611.

Solomon, M.B., Lynch, G.P. & Berry, B.W. 1986. Influence of animal diet and carcass electrical stimulation on the quality of meat from youthful ram lambs. Journal of Animal Science, 62, 139-146.

Vanderwert, W.F.K., McKeith, P.J.B. & Berger, L.L. 1986. Influence of zeranol implants and electrical stimulation on the palatability traits of five muscles in Angus and Limousin bulls and steers. Journal of Animal Science, 63, 114-120.

Verberke, W.A.J. & Viaene, J. 2000. Ethical challenges for livestock Production: Meeting consumer concern about meat safety and animal welfare. Journal of Agriculture and Environmental Ethics, 12, 141-151.

Vestergaard, M., Therkilsen, M., Henckel, P., Jensen, L.R., Anderson, H.R. & Sejrsen, K. 2000. Influence of feeding intensity, grazing and finishing feeding on meat and eating quality of young bulls and the relationship between muscles fibre characteristics, fibre fragmentation and meat tenderness. Meat Science, 54, 187-195.

Chapter 6

The effect of production system on the fatty acid composition of Dorper lamb

Abstract

This study investigated the effect of feeding/production systems and gender on the cholesterol and fatty acid profile of abdominal, subcutaneous, kidney, intermuscular and intramuscular (*Longissimus dorsi*-{LD} and *Biceps femoris*-{BF}) fat depots of Dorper lambs finished off under South African conditions. Sixty lambs were divided into two production groups (feedlot-{FL} or free-range {FR}) at weaning. Each group consisted of 10 lambs from each gender class (ewes, rams and castrates) slaughtered on two different dates resulting in a 2 (production system) x 3 (gender) x 2 (slaughter date) experimental outlay. Feedlot lambs were fed a commercial pelleted ration while the free-range group grazed natural pastures until slaughter. Results indicated that for intermuscular fat, FL-lambs slaughtered on date 2 had the highest cholesterol levels. Palmitic acid (C16:0) was higher (P = 0.0375) in the LD muscles of FL-lambs. Oleic acid (C18:1n-9c) and the sum of SFA were higher in intramuscular LD for lambs slaughtered on date 2. Results for intramuscular LD further indicated that the sum of TUFA was higher for lambs slaughtered on date 1 while sum of PUFA and the P: S ratio tended to be higher for lambs slaughtered on date 1. For intramuscular fat from the BF muscle, g-linolenic acid (C18:3n-6) was higher (P < 0.0001) in FL- lambs. Results for intramuscular BF further indicated that ram lambs had the highest palmitic acid (C16:0) and sum of TUFA, casrates had the highest α-linolenic acid (C18:3n-3) and g-linolenic acid (C18:3n-6) and ewes lambs had the highest sum of SFA. Intramuscular BF concentrations of mystyric (C14:0) and palmitic acid as well as the sum of SFA was higher for lambs slaughtered on date 1 while α-linolenic acid (C18: 3n-3) was higher for lambs slaughtered on date 2. For abdominal fat, mystyric (C14:0) was higher for lambs slaughtered on date 2 for abdominal fat. Results for subcutaneous, kidney and intermuscular fat show that FR-feeding increased α-linolenic acid (C18:3n-3) concentrations. FL-feeding increased linoleic acid (C18:2n-6c) concentrations for subcutaneous and kidney fat.

INTRODUCTION

Consumer food choices are based on personal experiences as well as information acquired through the media (Richardson, 1994). The modern consumer's interest in food choices became more evident after information about food safety scares and diet/ health relationships surfaced (Higgs, 2000; Verbeke & Viaene, 2000, Vitamin Information Centre, 2005). During earlier years, the consumption of meat was associated with dietetic goodness (Higgs, 2000). Today, the consumption of red meat, particularly its fat content, is linked to considerable levels of fat and saturated fatty acids (SFA) which when consumed in excess is believed to lead to the development of high levels of cholesterol in circulating lipoproteins (MacRae *et al.*, 2005). Lately, it has become clear that the inappropriate consumption of red meat (relatively high in protein and fat) coupled with insufficient dietary fibre, fruits and vegetables (Higgs, 2000)

is responsible for the escalating incidence of lifestyle and dietary induced diseases (Vitamin Information Centre, 2005). It is therefore recommended that people replace saturated and trans- fatty acids with unsaturated fat, especially n-3 fatty acids, which lower the risk of coronary heart disease (Hu & Willet, 2003; Sanders, 2003).

In an attempt to help combat the negative image of meat attributed to its highly saturated fat, recent scientific studies involving animal feeding strategies were aimed at reducing the saturated fat content and enhancing the n-3 fatty acids of meat (Nuernberg *et al.*, 2005; Scollan *et al.*, 2001; Lough *et al.*, 1992). Some scientific investigations involving ruminants show that different nutritional regimes can alter the fatty acid composition, PUFA level and the n-3: n-6 PUFA ratio of animal tissues (Enser *et al.*, 1998).

Forage intake is known to stimulate ruminal activity and thus the biohydrogenation of fatty acids, with an ultimate increase in the concentration of saturated fatty acids (SFA) (Okeudo *et al.*, 1994). Nuernberg *et al.* (2005) observed that pasture feeding reduces the percentage of palmitic acid (C16:0). Lambs finished off under feedlot conditions present intramuscular and subcutaneous fat with lower concentrations of stearic acid (18:0) and higher palmitic (C16:0) and linoleic acid (C18:2) compared to lambs raised on pasture (Díaz *et al.*, 2002). Subcutaneous and intramuscular fats of pasture-raised lambs present lower PUFA ratios than concentrate fed lambs (Díaz *et al.*, 2002). Overall, feedlot lambs seem to present greater total unsaturated fatty acids (TUFA) in their subcutaneous fat (Díaz *et al.*, 2002), a phenomenon which may be related to a greater concentrate intake (Aurousseau, 1981).

The effect of age on fatty acid profile is related to body fatness (Huerta-Leidenz *et al.*, 1996). The accumulation of SFA in adipose tissue increases with age/ growth/ fatness of animals (Kemp *et al.*, 1981). In lambs, the percentage of PUFA decreases with increasing carcass fatness (Nürnberg *et al.*, 1998). Lambs of the same breed slaughtered at higher slaughter weights have higher palmitic acid (16:0) in subcutaneous and intramuscular fats. For lambs slaughtered at lower weights, lower percentages of mystyric (14:0) and higher proportions of palmitic acid are observed.

Gender is an important factor for fatty acid composition because of its effect on carcass fatness. In males, total muscle lipid content is lower while PUFA level and PUFA: SFA ratio is greater. Does and heifers have higher percentages of trans-11 isomers (C18:1) and lower levels of mystyric acid (C14:0) and stearic acid (C18:0) (Matsuoka *et al.*, 1997; Johnson *et al.*, 1995). However, Malau-Aduli *et al.* (1998) reported the opposite for heifers and steers.

Some invlestigations note that cholesterol content increases as intramuscular fat increases (Smith, Smith & Hunt, 2004). Contradictory results indicate that cholesterol content does not increase as intramuscular fat content increases (Sales, 1994). It seems that sex does not affect the cholesterol concentration of bovine skeletal muscle (Rule *et al.*, 1997).

Literature on the effect of production/feeding system on the fatty acid profile of different fat depots is scarse. Many scientific investigations only investigate the effect of production/feeding system on the fatty acid

profile of (1) intramusclar fat (Nuernberg *et al.*, 2005; Varela *et al.*, 2004); (2) subcutaneous fat (Casey & Webb, 1995; Webb *et al.*, 1994) or (3) subcutaneous and intramuscular fat (Diaz *et al.*, 2002; Wachira *et al.*, 2002). Furthermore, the comparison of free-range with feedlot finishing for Dorper sheep under South African conditions has not yet been reported. In this experiment Dorper lambs of all gender groups of the same age were finished off in the feedlot or under free-range conditions and slaughtered after a predetermined period. The main objective of this study was to investigate the effect of production system (free-range or feedlot) and gender (castrate, ewe and ram) on the fatty acid profile of the various fat depots found in Dorper lambs.

MATERIALS AND METHODS

Sixty Dorper lambs were divided into two production/feeding groups (feedlot {FL-} and free-range {FR-}) at weaning. Data was available for date of birth for each individual lamb thus allowing for the calculation of each lamb's age (Age final). Each production group consisted of 10 lambs from each gender class (ewes, rams and castrates). The feedlot lambs were fed a commercial pelleted ration (Complete sheep finisher, Veekos, batch number 44442; see Chapter 3 for bag minimum and maximum specifications) while the free-range group grazed natural pastures until slaughter. The experimental outlay (age of the lambs, selection of the lambs, description of the production system, diet composition, plant grazed, etc.) is given in detail in Chapter 3. After a predetermined period of five weeks, 15 lambs from each of the two production groups (each group represented by five lambs from each gender class) were randomly selected, weighed and transported approximately 250 km to the abattoir. Lambs slaughtered after five weeks (slaughter date 1) weighed approximately 42.0 ± 4.4 kg. Upon arrival at the abattoir, all lambs were grouped together in overnight lairage. The next morning, lambs were electrically stunned and slaughtered using standard South African methods. The remaining 15 lambs that were slaughtered in week six (slaughter date 2) weighed approximately 44.0 ± 5.1 kg.

During evisceration, abdominal fat lining the viscera was removed from each carcass, weighed and placed in individually coded bags. The bags were placed in an insulated cool box and transported to the Meat Science Laboratory at the University of Stellenbosch. At the laboratory, abdominal fat samples were sealed under vacuum and stored at -18ºC.

After forty-eight hours of refrigeration at 4ºC, a piece of subcutaneous fat covering the *Longissimus dorsi* (LD) muscle on the left side of each carcass was cut off, placed in individually coded bags and placed in an insulated cool box. Thereafter, LD muscle samples were excised between the 8^{th} to 11^{th} ribs from both sides of each carcass, placed in individually coded bags and placed in an insulated cool box. Furthermore, kidney fat insulating both kidneys was removed from each carcass, weighed and placed in individually coded bags. The right hind leg of each carcass was also removed and placed in individually coded bags. Subcutaneous and kidney fat samples, LD muscle samples and right hind legs of each carcass were transported to the Meat Science laboratory at the University of Stellenbosch. At the Meat Science laboratory, subcutaneous and kidney fat samples were sealed under vacuum and stored at -18ºC, until

further required for cholesterol and fatty acid analysis. The LD muscles from the right side of each carcass were used for subcutaneous fat thickness measurements (Chapter 3) and thereafter vacuum-sealed and stored at -18ºC until required for sensory meat quality evaluation (Chapter 5). LD muscles from the left side of the carcass were trimmed of all visible fat, placed in individually coded bags, sealed under vacuum and stored at -18°C. The *Biceps femoris* (BF) muscle was removed from each hind leg, placed in individually coded bags, vacuum sealed and stored at -18°C. Intermuscular fat found below the BF muscles of each carcass was removed, placed in individually coded bags, vacuum sealed and stored at -18°C until further required for fatty acid analysis.

Biceps femoris and LD muscle samples were later removed from freezing conditions and thawed overnight in a cold room (4ºC). Each BF and LD sample was thereafter minced, divided into duplicate portions, placed in separate, individually coded bags, sealed under vacuum and stored at -18°C until further required for proximate chemical composition (Chapter 4) as well as cholesterol and fatty acid analysis.

The cholesterol content of muscle (intramuscular fat (BF and LD)) and lipid (abdominal, subcutaneous, kidney and intermuscular fat) depots was determined using a modified, combined method of Kovacs *et al.* (1979) and Van Jaarsveld *et al.* (2000). For the muscle depots, the lipids in a 2 g meat sample of thawed homogenized meat were extracted with chloroform/methanol (CM 2:1 v/v) according to the modified method of Folch *et al.* (1957). For the fat depots, 1 g of fat was used. An antioxidant (0.01% butylated hydroxytoluene (BHT)) was added to all the extraction solvents. A polytron mixer was used to homogenize each sample with the extraction solvent. Sub-samples of the homogenized samples were transferred to Klimax tubes. Thereafter, stigmasterol was added as an internal standard and the contents of the tubes were dried under nitrogen in a 45ºC water bath. Ethanol and KOH (50% v/v) were used to saponifise the extractions for 1 hour at 70ºC in a water bath. Distilled water and hexane were added after the samples had cooled down. The top phase of each sample was transferred to a blood tube and dried under nitrogen in a 45ºC water bath. CS2 was added and the resultant extraction was analysed by GLC. A 15 m BPX50 glass column of 0.53 mm internal diameter, 0.50 µm film was used. Gas flow rates were: hydrogen (carrier), 30 ml/min; air, 200 ml/min. Temperatures were: injector temperature 220ºC; column temperature 250ºC; and detector temperature 260ºC.

For fatty acid analysis, previously stored samples (abdominal fat, subcutaneous fat, kidney fat, intermuscular fat and intramuscular fat (BF and LD minced muscle samples) were thawed overnight at 4ºC. The fatty acid content of intramuscular fat (LD and BF) muscles was determined by extracting a 2g sample of meat with a chloroform/methanol (CM 2:1; v/v) solution. For fat samples, 1g sample of fat was used. An antioxidant (0.01% butylated hydroxytoluene (BHT)) was added to all the extraction solvents. A polytron mixer was used to homogenize the sample with the extraction solvent. The isolated lipids were transmethylated with a transmethylating reagent (methanol/sulphuric acid; 19:1; v/v) for two hours at 70ºC. After cooling the resulting fatty acid methyl esters (FAME) were extracted with water and hexane and the top of the hexane phase was transferred to a spotting tube and dried under nitrogen. The fame were purified using a thin layer of chromatography plates (TLC, silica gel 60 plates) and analysed with a Thermo Finnigan Focus Gas chromatograph (Thermo Electron S.P.A., Strade Rivoltana, 20090 Rodano, Milan,

Italy). A 60 m BPx70 capillary columm (SGE Int. Pty. Ltd., 7 Argents place, Victoria, 3134, Ringwood, Australia) with an internal diameter of 0.25mm was utilized and hydrogen (30ml/min) was used as a carrier gas. Temperature programming was linear at 4ºC /min with the different setting as follows: an initial temperature of 140ºC, a final temperature of 240ºC, an injector temperature of 220ºC and a detector temperature of 260ºC. The FAME were identified by comparing the retention times to those of a standard FAME mixture (Supelco 37 Component FAME mix C4 – C24. Supelco, 595 North Harrison Road., Bellefonte, PA, 16823-0048, USA; Cat no. 18919). The identified FAME is reported as a % of identified fatty acids.

Statistical analysis

A 2 x 3 x 2 factorial analysis was performed in a randomized complete block design with two main treatments replicated in 60 blocks (animals). The factors were two productions systems (FL and FR), gender (ewe, ram and castrate lambs) and date of slaughter (date 1 and date 2). The data were subjected to factorial analysis using Proc GLM of SAS version 9.1 (SAS, 1999). Before the data was subjected to analysis, the data was tested for normality and homogeneity of variance.

Cholesterol differences between different fat depots (abdominal, subcutaneous, kidney, intermuscular, and intramuscular fat (BF and LD) were established by subjecting the data to Proc GLM of SAS (1999). Preliminary analysis involved the full model, i.e. the effects of production system, gender, slaughter date and age (as a covariate) as well as all the interactions among main effects on all the fat depots. All the interactions were removed from the final analysis, because results indicated that these were not significant ($P > 0.05$). The intermuscular fat depot was also removed from the final analysis because of an interaction between production system and slaughter date. The final model used to establish cholesterol differences between abdominal, subcutaneous, kidney and intramuscular fat (BF and LD) included all the main effects (production system, gender, slaughter date and age final as a covariate). The final model for intermuscular fat included all the main effects as well as the two-way interaction between production system and slaughter date.

Enser *et al.* (1998) suggests that it is useful to present the fatty acid composition in mg per gram muscle, especially when calculating the nutritional value of meat. The fatty acid composition can however also be expressed as a percentage of the total identified fatty acids present – this is helpful when comparing fatty acid profiles between samples. In this study, all the fatty acids (as a percentage of identified fatty acids) present in the different fat depots were analysed. However, only the fatty acids that are biologically important/ significant are presented and discussed. Biologically significant fatty acids refer to those fatty acids whose presence can be linked to the metabolism of fatty acids. For example, stearic acid owes its presence to linoleic acid (C18:2) which is reduced to a trans-11 isomer. The extent to which trans-11 C18:1 is hydrogenated to C18:0 depends on conditions in the rumen (Jenkins, 1993). Also, only the interactions that were of biological significance were discussed.

For the preliminary analysis of intramuscular LD, all the main effects (production system, gender, slaughter date and age final as a covariate) and their interactions were included in the model. Results of the preliminary analysis indicated that age final, gender, production system, slaughter date and the two way interaction between age final x slaughter date were only significant for oleic acid (C18:1nt-9c), sum of SFA, sum of MUFA and sum of TUFA. The final analysis therefore included two models. One model included gender, production system and slaughter date as the main effects, age final as a covariate, a two way interaction between age final x slaughter date and (C18:1n- 9t), sum of SFA, sum of MUFA and sum of TUFA as dependent variables. The second final model included production system, gender and slaughter date as the main effects and C16:0, C16:1, C18:1n-9t, PUFA and the P: S ratio as dependent variables.

Preliminary results for intramuscular BF indicated that four final models had to be constructed. The first model included production system, gender and slaughter date as main effects, age final as a covariate, a two way interactions between gender and gender x slaughter date and C16:0, C18: 2n-6t, SFA and TUFA as dependent variables. Model two included the two- way interaction between age final x gender and oleic acid (C18: 1n-9c) as a dependent variable. The third model included gender and slaughter date as the main effects, two way interactions between production system x gender and linolenic acid (18: 3n-3) as a dependent variable. Model three included gender, production system and slaughter date as the main effects, age final as a covariate and C18: 3n-6 as a dependent variable. The fourth model included production system, gender and slaughter date as main effects, age at slaughter as a covariate and C14:0, C18:0, C18:1n-9t, and the remaining PUFA's, sum of PUFA and the P:S ratio as dependent variables.

Preliminary results for abdominal, subcutaneous, kidney and intermuscular fat indicated that only the fatty acids present in all the tables in the text would be included in the final model. The final model therefore included production system, gender and slaughter date as the main effects, age final as a covariate, and the fatty acids as dependent variables.

RESULTS AND DISCUSSION

The analysis of variance (ANOVA) of cholesterol for abdominal, subcutaneous, kidney, intermuscular and intramuscular fat (BF and LD) of Dorper lambs is presented in Table 1. None of the main effects had a significant effect ($P > 0.05$) on the cholesterol content of abdominal, subcutaneous, kidney and intramuscular (BF and LD) fat. Results for intermuscular fat indicated that the effect of production system, slaughter date as well as the two way interaction between production system and slaughter date (Table 2) were all significant for the cholesterol content of intermuscular fat. The interaction effect will therefore be discussed.

Results pertaining to intermuscular fat indicated that FL-lambs slaughtered on date 2 had the highest overall cholesterol content (Table 2). Although, this study did not determine the lipid percentage of intermuscular fat, results pertaining to intramuscular fat (BF and LD) indicate that, in absolute terms, the lipid percentage of FL-lambs was higher than that of FR-lambs (Chapter 4, Table 3). The higher lipid

percentage of FL-lambs can be attributed to the FL-diet, which because of its dense energy content, is associated with greater fat deposition in animals (Díaz *et al.*, 2002; Notter *et al.*, 1991). The higher lipid content in FL-lambs can therefore be linked to higher cholesterol content. Smith *et al.* (2004) also concluded that as the lipids in muscle increases, cholesterol content might also increase. Contradictory results by Sales (1994) indicated that cholesterol content does not increase when intramuscular fat increases. High cholesterol levels in the blood are associated with the incidence of coronary heart diseases (MacRae *et al.*, 2005).

In this study lambs slaughtered on date 2 generally displayed lower carcass fatness levels than lambs slaughtered on date 1 (Chapter 3). This result thus suggests that lower lipid levels lead to an increase in cholesterol content.

Table 1. Analysis of variance (ANOVA) for the cholesterol content of abdominal, subcutaneous, kidney, intermuscular and intramuscular (LD and intramuscular BF) fat depots of Dorper lambs reared either under free-range or feedlot system feeding/ production system.

		Abdominal fat		Subcutaneous fat		Kidney fat		Intermuscular fat		Intramuscular LD		Intramuscular BF	
Source	**df**	**MS**	**P-value**	**MS**	**P-value**	**MS**	**P-value**	**MS**	**P-value**	**MS**	**P-value**	**MS**	**P-value**
Age Final	1	73.32	0.67	373.77	0.39	380.90	0.36	2.17	0.93	86.17	0.54	119.28	0.48
Gender	2	279.95	0.50	386.39	0.47	627.47	0.25	242.45	0.41	194.70	0.43	67.45	0.75
Production System	1	1058.50	0.11	0.77	0.97	412.30	0.34	5817.28	**<.0001**	286.73	0.27	84.04	0.56
Slaughter date	1	640.76	0.21	64.63	0.72	1116.17	0.12	3606.95	**0.0006**	360.25	0.21	324.81	0.25
Prod system x S.date	1							6333.76	**<.0001**				

Table 2. Means (S.E.) depicting the two way interaction between production system and slaughter date on the cholesterol content (mg/100g) of intermuscular fat of Dorper lambs slaughtered on date 1 and 2 respectively.

	Slaughter date 1		Slaughter date 2	
	Feedlot (FL)	**Free-range (FR)**	**Feedlot (FL)**	**Free-range (FR)**
Intermuscular fat	68.04± 3.93	70.48 ± 6.45	77.27 ± 6.69	62.18 ± 3.57

LD *Longissimus dorsi*
BF *Biceps femoris*

As indicated in Table 3, the major fatty acids of the intramuscular BF and LD irrespective of production system, were oleic (C18:1n-9c), stearic (C18:0) and palmitic acid (C16:0) followed by linoleic (C18: 2n-6) acid in lower concentrations. It is known that intramuscular fat of all animal species mainly consists of C18:1n-9c, C18:0 C16:0 and C18: 2n-6 (Lawrie, 1998).

The fatty acid composition of the LD muscles (intramuscular fat) show FL-lambs had higher levels of palmitic acid (C16:0) compared to FR-lambs. Furthermore, palmitate (C16:1) tended to be higher (P = 0.06) in FL-than in FR-lambs. On the other hand, FR-feeding generally showed a tendency for elaidic acid (C18:1n-9t) to increase (P = 0.0610). As for the effect of slaughter date (Table 4), the concentrations of oleic acid (C18:1n-9c), elaidic acid (C18:1n-9t), sum of SFA and sum of MUFA were higher for lambs slaughtered on date 2 while the TUFA concentration was higher (P = 0.0302) for lambs slaughtered on date 1. Both sum of PUFA and the P: S ratio tended to be higher (P = 0.0629 and P = 0.0821 respectively) for lambs slaughtered on date 1 compared to lambs slaughtered on date 2.

It is known that energy dense FL-diets increase the rate of *denovo* fatty acid synthesis, a process that results in high levels of SFA (Santos-Silva *et al.*, 2002; Russo *et al.* 1999). The higher fat content in LD muscles (in absolute terms) of FL-lambs observed in this study (Chapter 4) may therefore be associated with increased levels of C16:0. Palmitic acid is known to increases the lipid content in blood which, in turn increases serum cholesterol (Bonamone & Grundy, 1988). High cholesterol levels are associated with incidences of coronary heart diseases (MacRae *et al.*, 2005). The higher percentages of oleic acid (C18:1n-9c) and elaidic acid (C18:1n-9t) for lambs slaughtered on date 2 may, on part, be linked to prolonged feeding conditions. It is possible that half the number of lambs (that stemmed from the FL-system) slaughtered on date 2 significantly increased the percentage of C18:1n-9c and C18:1n-9t for the entire group. Linoleic acid, which is usually in high concentrations in FL-diets, possibly inhibited the complete hydrogenation of C18:1 to C18:0 (Jenkins, 1993). Díaz *et al.* (2002) reported increased levels of C18:1 fatty acids for lambs slaughtered at heavier live weights. In this study, lambs slaughtered on date 2 were also heavier at slaughter (Chapter 3, Table 3 & 4). Heavier slaughter weights of lambs can therefore be linked to increased levels of C18:1n-9c and C18:1n-9t. According to Sauvant *et al.* (1979), MUFA levels generally decrease in all depots of kids at heavier live weights. Results of this investigation differed with increased levels of MUFA at heavier slaughter weights. Similarly, the higher sum of SFA of the intramuscular LD fat of slaughter date 2 lambs does not agree with previously reported results where SFA levels increase with carcass fatness (Nürnberg *et al.*, 1998).

Results pertaining to the TUFA level of the intramuscular LD fat depot indicate that thicker carcass fatness displayed by lambs slaughtered on date 1 lead to larger TUFA concentrations. This result concurs with results reported by Kemp *et al.* (1981), who observed a positive correlation between carcass fatness and sum of TUFA. Díaz *et al.* (2002) also reported higher TUFA levels in fatter lambs, although these values were observed in the subcutaneous fat of concentrate fed lambs. The sum of both PUFA and the P:S ratio of intramuscular LD tended to be higher in lambs slaughtered on date 1 than lambs slaughtered on date 2. Díaz *et al.* (2002) found that the sum of PUFA and the P:S ratio was lower in lambs slaughtered at lower weights. Increased percentages of both the sum of PUFA and the P:S ratio of intramuscular LD observed

in this investigation could therefore be linked to the lower live weights of lambs slaughtered on date 1 (Chapter 3).

Results for the intramuscular BF fat indicate that g-linolenic acid (C18:3n-6) was higher in FL- lambs ($P < 0.0001$) while linolelaidic acid (C18:2n-6t) was higher in FR-lambs ($P = 0.0031$). The effect of gender (Table 5) shows that rams had the highest C16:0 and sum of TUFA ($P = 0.0019$ and $P = 0.0014$ respectively). On the other hand, castrates displayed the highest concentrations of α-linolenic acid (C18:3n-3) ($P = 0.0260$) and tended ($P = 0.06$) to have higher concentrations of g-linolenic acid C18:3n-6. As for ewes lambs, the highest ($P = 0.0014$) sum of SFA were observed in this fat depot. The effect of slaughter date indicated that the percentage concentrations of mystyric C14:0, C16:0, C18:0, C18:2n-6t and C18:3n-6 and sum of SFA were higher for lambs slaughtered on date 1 compared to lambs slaughtered on date 2. On the other hand, percentage concentrations of C18:3n-3 and sum of TUFA were higher for lambs slaughtered on date 2 compared to lambs slaughtered on date 1. The two way interaction between gender x slaughter date indicated that ram lambs slaughtered on date 1 had the highest percentage of SFA (50.17%) while ewe lambs slaughtered on date 2 had the lowest SFA (37.82%).

It is well-known that pasture feeding increases n-3 fatty acids in muscle while concentrate feeding leads to higher proportions of n-6 fatty acids (Nuernberg *et al.*, 2005; Piasentier, 2003; Santos-Silva *et al.*, 2002; Enser *et al.*, 1998). It is therefore not clear why BF muscles of FL-lambs had more C18:3n-6 and FR-lambs had more linolelaidic acid (C18:2n-6t). The highest levels of C16:0 observed in intramuscular BF of ram lambs is in agreement with Bas *et al.* (1982) who also reported that the levels of branched chain fatty acids (i.e. C16:0) was higher in intact males compared to that of castrated kids, although this was in the subcutaneous fat. Díaz *et al.* (2002) observed that lambs slaughtered at higher slaughter weights had higher C16:0 concentrations. In this study, ram lambs attained the highest (Chapter 3; $P < .0001$) overall slaughter weights (48.00 ± 0.86 kg). High slaughter weights of ram lambs can therefore be linked with increased levels of C16:0. It is known that high levels of C16:0 increase plasma cholesterol levels (Grundy & Denke, 1990). It has been established so far that higher TUFA are associated with greater fatness levels. This argument cannot be used in this study since ram lambs had the lowest overall fatness levels (Chapter 3, Table 3).

The higher C18:3n-3 and C18:3n-6 concentrations of intramuscular BF displayed by castrates is contrary to results reported by Kemp *et al.* (1981) who indicated that these two fatty acids were negatively correlated to carcass fatness.

Alpha -linolenic acid and the sum of TUFA were higher for lambs slaughtered on date 2 for intramuscular BF. Kemp *et al.* (1981) found that C18:3n-3 was negatively correlated with carcass fatness. Díaz *et al.* (2002) reported that the percentage of TUFA increased with greater fatness levels. The same trend was not observed in this study.

Table 3. Means (S.E.) of total fatty acid composition (%) of Dorper intramuscular LD and BF fat depots for lambs finished off under either feedlot (FL) or free-range (FR) feeding.

	Intramuscular LD		Intramuscular BF	
Fatty acids	**Feedlot (FL)**	**Free-range (FR)**	**Feedlot (FL)**	**Free-range (FR)**
SFA				
C14:0	0.847 ± 0.006	0.938 ± 0.143	1.295 ± 0.153	1.020 ± 0.128
C16:0	17.092 ± 0.513	15.760 ± 0.788	19.011 ± 3.875	18.700 ± 0.526
C17:0	14.092 ± 0.513	15.139 ± 0.952	15.894 ± 0.884	15.758 ± 1.119
C18:0	18.437 ± 0.144	19.115 ± 0.785	15.780 ± 0.373	17.403 ± 0.476
MUFA				
C16:1	0.763 ± 0.037	0.661 ± 0.050	0.991 ± 0.050	0.980 ± 0.049
C18:1n9t	1.403 ± 0.133	1.768 ± 0.111	1.346 ± 0.108	1.762 ± 0.111
C18:1n-9c	27.926 ± 1.413	24.449 ± 1.767	26.763 ± 1.604	25.273 ± 1.825
PUFA				
C18:2n-6t	0.375 ± 0.014	0.455 ± 0.081	0.354 ± 0.0013	0.404 ± 0.010
C18:2n-6c	5.575 ± 0.345	5.424 ± 0.491	6.535 ± 0.348	6.123 ± 0.261
C18:3n-6	0.086 ± 0.032	0.164 ± 0.103	0.087 ± 0.005	0.056 ± 0.005
C18:3n-3	0.170 ± 0.033	0.376 ± 0.123	0.739 ± 0.107	0.526 ± 0.112
C20:3n-6	0.274 ± 0.020	0.480 ± 0.129	0.305 ± 0.013	0.296 ± 0.019
C20:3n-3	0.233 ± 0.015	0.385 ± 0.135	0.253 ± 0.017	0.236 ± 0.013
SFA	40.453 ± 0.680	40.586 ± 0.956	40.473 ± 1.074	41.850 ± 0.959
MUFA	49.340 ± 0.907	47.355 ± 1.489	45.703 ± 1.278	46.362 ± 1.450
PUFA	10.207 ± 0.578	12.059 ± 1.573	13.824 ± 1.321	11.787 ± 1.155
TUFA	59.547 ± 0.679	59.414 ± 0.956	59.527 ± 1.074	58.150 ± 0.959
P:S	0.254 ± 0.015	0.318 ± 0.058	0.362 ± 0.238	0.287 ± 0.032

LD *Longissimus dorsi*
BF *Biceps femoris*
SFA Saturated fatty acids
MUFA Monounsaturated fatty acids
PUFA Polyunsaturated fatty acids
TUFA Total unsaturated fatty acids
P: S Polyunsaturated to Saturated fatty acid ratio

Table 4. Means (S.E.) of total fatty acid composition (%) of Dorper intramuscular LD and BF fat depots for lambs slaughtered either on slaughter date 1 or 2.

	Intramuscular LD		Intramuscular BF	
Fatty acids	**Slaughter date 1**	**Slaughter date 2**	**Slaughter date 1**	**Slaughter date 2**
SFA				
C14:0	0.892 ± 0.556	0.893 ± 0.138	1.280 ± 0.140	1. 035 ± 0.143
C16:0	16.161 ± 0.740	17.207 ± 0.614	19.849 ± 0.718	17.861 ± 0.441
C17:0	16.022 ± 0.962	13.208 ± 0.709	16.382 ± 0.876	15.269 ± 1.116
C18:0	18.653 ± 0.807	18.900 ± 0.484	17.044 ± 0.506	16.138 ± 0.375
MUFA				
C16:1	0.716 ± 0.050	0.709 ± 0.039	1.031 ± 0.049	0.940 ± 0.049
C18:1n9t	1.398 ± 0.137	1.773 ± 0.106	1.718 ± 0.580	1.391 ± 0.117
C18:1n-9c	25.212 ± 1.820	27.164 ± 1.397	23.781 ± 2.123	28.256 ± 1.042
PUFA				
C18:2n-6t	0.460 ± 0.081	0.370 ± 0.013	0.392 ± 0.014	0.366 ± 0.010
C18:2n-6c	5.940 ± 0.450	5.159 ± 0.384	6.281 ± 0.340	6.377 ± 0.276
C18:3n-6	0.192 ± 0.107	0.058 ± 0.006	0.077 ± 0.005	0.066 ± 0.006
C18:3n-3	0.314 ± 0.113	0.232 ± 0.064	0.617 ± 0.120	0.649 ± 0.102
C20:3n-6	0.459 ± 0.129	0.295 ± 0.022	0.317 ± 0.009	0.284 ± 0.016
C20:3n-3	0.401 ± 0.135	0.216 ± 0.010	0.244 ± 0.015	0.245 ± 0.015
SFA	39.795 ± 0.873	41.244 ± 0.760	42.386 ± 5.900	39.937 ± 0.918
MUFA	47.358 ± 1.430	49.337 ± 0.999	44.494 ± 1.695	47.572 ± 0.857
PUFA	12.847 ± 1.546	9.418 ± 0.525	13.120 ± 1.517	12.490 ± 0.921
TUFA	60.205 ± 0.873	58.756 ± 0.760	57.613 ± 1.077	60.063 ± 0.918
P:S	0.342 ± 0.572	0.230 ± 0.013	0.321 ± 0.043	0.328 ± 0.034

LD *Longissimus dorsi*
BF *Biceps femoris*
SFA Saturated fatty acids
MUFA Monounsaturated fatty acids
PUFA Polyunsaturated fatty acids
TUFA Total unsaturated fatty acids
P: S Polyunsaturated to Saturated fatty acid ratio

Table 5. Means (S.E.) of total fatty acid composition (%) of Dorper intramuscular LD and BF fat depots for castrates, ewes and ram lambs.

	Intramuscular LD			Intramuscular BF		
Fatty acids	**Castrates**	**Ewes**	**Rams**	**Castrates**	**Ewes**	**Rams**
SFA						
C14:0	0.822 ± 0.130	0.062 ± 0.193	0.794 ± 0.104	1.295 ± 0.153	1.177 ± 0.150	1.258 ± 0.176
C16:0	16.883 ± 0.779	17.338 ± 0.973	15.831 ± 0.736	19.011 ± 3.875	18.778 ± 0.667	19.216 ± 0.970
C17:0	14.007 ± 0.874	14.926 ± 1.307	14.913 ± 1.038	15.894 ± 0.884	14.005 ± 1.019	17.471 ± 1.309
C18:0	19.088 ± 0.553	18.445 ± 1.145	18.796 ± 0.634	15.780 ± 0.373	16.090 ± 0.509	17.030 ± 0.663
MUFA						
C16:1	0.715 ± 0.063	0.748 ± 0.049	0.674 ± 0.052	0.881 ± 0.059	1.110 ± 0.045	0.965 ± 0.066
C18:1n9t	1.024 ± 0.125	1.533 ± 0.184	1.599 ± 0.156	1.346 ± 0.108	1.604 ± 0.143	1.601 ± 0.172
C18:1n-9c	24.001 ± 1.569	24.755 ± 2.714	26.004 ± 1.486	26.763 ± 1.604	27.822 ± 2.090	22.994 ± 2.515
PUFA						
C18:2n-6t	0.368 ± 0.019	0.521 ± 0.120	0.356 ± 0.008	0.354 ± 0.0013	0.411 ± 0.014	0.373 ± 0.017
C18:2n-6c	4.829 ± 0.541	5.760 ± 0.539	6.059 ± 0.444	6.535 ± 0.348	5.698 ± 0.344	7.390 ± 0.369
C18:3n-6	0.103 ± 0.047	0.203 ± 0.155	0.069 ± 0.007	0.087 ± 0.005	0.058 ± 0.007	0.078 ± 0.006
C18:3n-3	0.146 ± 0.030	0.439 ± 0.182	0.234 ± 0.051	0.739 ± 0.107	0.388 ± 0.118	0.743 ± 0.150
C20:3n-6	0.294 ± 0.025	0.489 ± 0.190	0.347 ± 0.051	0.305 ± 0.013	0.302 ± 0.013	0.339 ± 0.020
C20:3n-3	0.232 ± 0.018	0.438 ± 0.201	0.256 ± 0.032	0.253 ± 0.017	0.232 ± 0.012	0.289 ± 0.018
SFA	40.890 ± 0.827	40.777 ± 1.457	39. 892 ± 0.557	40.473 ± 1.074	40.261 ± 1.139	43.069 ± 1.592
MUFA	49.301 ± 1.114	46.991 ± 2.217	48.751 ± 1.095	45.703 ± 1.278	47.444 ± 1.731	43.577 ± 1.764
PUFA	9.809 ± 0.902	12.232 ± 2.139	11.357 ± 1.009	13.824 ± 1.321	12.295 ± 1.752	13.353 ± 0.680
TUFA	59.110 ± 0.827	59.223 ± 1.457	60.108 ± 0.557	59.527 ± 1.074	59.739 ± 1.140	56.931 ± 1.592
P:S	0.244 ± 0.024	0.328 ± 0.082	0.287 ± 0.029	0.362 ± 0.238	0.318 ± 0.052	0.318 ± 0.021

LD: *Longissimus dorsi* BF: *Biceps femoris* SFA: Saturated fatty acids MUFA: Monounsaturated fatty acids PUFA: Polyunsaturated fatty acids
TUFA: Total unsaturated fatty acids P/S: Polyunsaturated to Saturated fatty acid ratio

Other depot lipids

As noted in Tables 6, 7 and 8, results of this investigation indicate that the main fatty acids of depot fat, regardless of location in the body, are C18:0, C16:0 and C18:1n-9c, followed by C14:0 and C18:2n-6c in lower concentrations. According to Banskalieva *et al.* (2000), the main fatty acids of adipose in goats regardless of location in the body are C18:1, C18:0 and C16:0 followed by C14:0, palmitelaidic (C16:1), heptadecenoic (C17:0) and linoleic acid (C18:2) in lower concentrations.

Results for abdominal fat indicate that C14:0 and C18:0 were higher for lambs slaughtered on date 2 (Table 7). On the other hand, homo-g-linolenic (C20:3n-6) and the sum of PUFA were higher for lambs slaughtered on date 1. Homo-g-linolenic acid (C20:3n-6) is an n-6 PUFA. Since tissue concentrations of n-6 PUFA's are usually increased by energy dense diets (Rhee *et al.*, 1992) which lead to increased fatness levels, it may be argued that greater fatness levels of lambs slaughtered on date 1 may have lead to higher levels of homo-g-linolenic acid (C20:3n-6). Gender effect indicated that ewe lambs had the highest ($P = 0.0115$) concentration of lignoceric acid (C24:0) for abdominal fat compared to castrates and ram lambs.

As for subcutaneous fat, results indicate that the FL-diet significantly increased ($P = 0.0067$) percentage concentrations of C18:2n-6c compared to the FR-diet (Table 6). On the other hand, the percentage of C18:3n-3 was higher ($P = 0.0104$) in FR-lambs than in FL-lambs. It is known that FL-diets are high in C18:2, the precursor of n-6 fatty acids (Díaz *et al.*, 2002). This may have lead to high concentrations of C18:2n-6c in the subcutaneous fat of FL-lambs (Mitchell *et al.*, 1999; Rhee, 1992). Similarly, free-range diets lead to higher concentrations of n-3 PUFA because these diets normally contains high levels of linolenic acid, the precursor of the n-3 fatty acids (Mitchell *et al.*, 1999; Rhee, 1992). It can also be argued that despite biohydrogenation in the rumen, linolenic acid contained in grass is deposited in higher concentrations in depots of animals on free-range diets (Nuernberg *et al.*, 2005).

For kidney fat, FR-feeding caused significant increases in the percentage of C18:0, C18:2n-6t, C18:3n-3 and homo-g-linolenic acid (C20:3n-6). Conversely, FL-feeding increased the percentage concentrations of linoleic acid (C18:2n-6c). When the gender effect was considered (Table 8), results revealed that ewe lambs had the highest homo-g-linolenic (C20:3n-6) percentage (0.056 ± 0.006) compared to rams (0.051 ± 0.003) and castrate lambs (0.050 ± 0.005). Greater proportions of C18:0 in the kidney fat of FR-lambs may be attributed to the FR-diet, which may have stimulated ruminal activity and thus the biohydrogenation of the fatty acids, ultimately increasing the level of saturates (Choi *et al.*, 1997). Other scientific investigations have established that the fatty acids in forage fed lambs are more saturated than unsaturated (Okeudo *et al.*, 1994). The fact that FR-feeding lead to higher levels of C18:3n-3 was expected since it is generally known that FR-diets lead to higher concentrations of n-3 PUFA. It is unclear why this study observed high levels of linolelaidic acid (C18:2n-6t) and homo-g-linolenic acid (C20:3n-6) for FR-lambs. The result that FL-feeding increased percentage concentrations of C18:2n-6c concurs with previously reported results (Mitchell *et al.*, 1999; Rhee, 1992). It is known that FL-diets, because of its dense energy content are associated with greater fat deposition (Díaz *et al.*, 2002; Notter *et al.*, 1991). Greater fatness levels that stem from the consumption of high energy diets lead to high tissue concentrations of n-6 fatty acids

(Crouse & Field, 1978). Moreover, ewe lambs present greater fatness levels than castrates and ram lambs (Vergara *et al.*, 1999). This study also observed that ewe lambs generally presented greater fatness levels than castrates and ram lambs (See Chapter 3, Table 3). It can therefore be argued that greater fatness levels of ewe lambs increased percentage concentrations of homo-g-linolenic (C20:3n-6).

Results pertaining to intermuscular fat indicate that higher percentages of linolenic acid (C18:3n-3) ($P = 0.0113$) and the sum of SFA ($P = 0.0341$) were observed for FR-lambs compared to FL-lambs. Furthermore, the sum of TUFA for intermuscular fat was higher ($P = 0.0341$) in FL-lambs compared to FR-lambs. The argument that FR-feeding leads to higher levels of C18:3n-3 (Díaz *et al.*, 2002) and increased levels of saturated fatty acids (Okeudo *et al.*, 1994), is also true for intermuscular fat. Higher levels of TUFA observed in FL-lambs concurs with previously reported results which indicate FL-feeding increases the level of unsaturation (Okeudo *et al.*, 1994).

Table 6. Means (S.E.) of total fatty acid composition (%) of Dorper lamb abdominal, subcutaneous, kidney and intermuscular fat depots for lambs finished off under either feedlot (FL) or free-range (FR) feeding.

	Abdominal fat		Subcutaneous fat		Kidney fat		Intermuscular fat	
Fatty acids	**Feedlot (FL)**	**Free- range (FR)**	**Feedlot (FL)**	**Free- range (FR)**	**Feedlot (FL)**	**Free- range (FR)**	**Feedlot (FL)**	**Free- range (FR)**
SFA								
C14:0	6.622± 0.471	6.853.± 0.517	8.366 ± 0.426	9.034 ± 0.518	6.474 ± 0.283	5.615 ± 0.472	7.662± 0.287	8.506 ± 0.406
C16:0	26.923 ± 1.471	26.352 ± 1.469	26.692 ± 0.533	27.111 ± 0.682	26.326 ± 0.482	25.752 ± 0.550	26.601 ± 0.920	28.462 ± 0.590
C17:0	0.816 ± 0.348	3.570 ± 1.659	4.994 ± 0.519	6.476 ± 0.561	6.539 ± 0.273	6.174 ± 0.350	6.453 ± 0.286	7.062 ± 0.436
C18:0	26.889 ± 1.874	28.140 ± 2.021	19.875 ± 0.764	19.340 ± 0.754	29.162 ± 0.675	31.710 ± 0.979	19.656 ± 0.990	21.497 ± 0.641
MUFA								
C16:1	1.407 ± 0.117	1.446 ± 0.103	2.751 ± 0.203	2.998 ± 0.179	1.096 ± 1.025	1.008 ± 0.434	1.853 ± 0.191	1.827 ± 0.074
C18:1n9t	1.467 ± 0.862	1.117 ± 0.863	0.262 ± 0.037	0.264 ± 0.032	0.775 ± 0.184	0.884 ± 0.293	1.439 ± 0.135	0.367 ± 0.030
C18:1n-9c	16.773 ± 2.157	15.220 ± 12.219	28.927 ± 1.706	27.598 ± 1.900	27.294 ± 1.208	25.513 ± 1.366	30.548 ± 1.091	28.730 ± 1.425
PUFA								
C18:2n-6t	0.960 ± 0.248	0.665 ± 0.050	0.573 ± 0.021	0.603 ± 0.030	0.535 ± 0.011	0.636 ± 0.017	0.646 ± 0.086	0.623 ± 0.015
C18:2n-6c	3.913 ± 0.274	3.156 ± 0.239	3.055.± 0.170	2.981 ± 0.153	2.865 ± 0.283	2.152 ± 0.160	2.770 ± 0.159	2.594 ± 0.072
C18:3n-6	0.158 ± 0.061	0.088 ± 0.023	0.096 ± 0.009	0.085 ± 0.008	0.029 ± 0.003	0.033 ± 0.003	0.081 ± 0.034	0.050 ± 0.004
C18:3n-3	1.088 ± 0.062	1.251 ± 0.075	1.235 ± 0.049	1.450 ± 0.066	0.894 ± 0.048	1.159 ± 0.040	1.121 ± 0.046	1.287 ± 0.044
C20:3n-6	0.256 ± 0.058	0.219 ± 0.031	0.102 ± 0.013	0.138 ± 0.033	0.047 ± 0.003	0.057 ± 0.005	0.103 ± 0.419	0.070 ± 0.008
C20:3n-3	0.343 ± 0.151	0.277 ± 0.082	0.152 ± 0.021	0.143 ± 0.018	0.088 ± 0.039	0.740 ± 0.021	0.160 ± 0.035	0.094 ± 0.014
SFA	63.445 ± 3.343	67.077 ± 2.577	58.027 ± 1.351	59.133 ± 1.553	64.422 ± 1.112	65.762 ± 1.242	56.719 ± 1.730	61.631 ± 1.203
MUFA	26.545 ± 3.143	22.248 ± 2.480	34.676 ± 1.523	33.857 ± 1.801	30.335 ± 1.090	28.791 ± 1.181	37.013 ± 1.703	32.628 ± 1.366
PUFA	10.009 ± 0.0607	10.675 ± 1.094	7.297 ± 0.293	7.010 ± 0.339	5.243 ± 0.352	5.447 ± 0.263	6.268 ± 0.370	5.740 ± 0.234
TUFA	36.555 ± 3.343	32.923 ± 5.777	41.973 ± 1.351	40.867 ± 1.553	35.578 ± 1.112	34.238 ± 1.243	43.281 ± 1.730	38.369 ± 1.203
P:S	0.241 ± 0.068	0.175 ± 0.026	0.126 ± 0.004	0.118 ± 0.004	0.082 ± 0.006	0.084 ± 0.004	0.126 ± 0.018	0.093 ± 0.003

LD: *Longissimus dorsi* BF: *Biceps femoris* SFA: Saturated fatty acids MUFA: Monounsaturated fatty acids PUFA: Polyunsaturated fatty acids
TUFA: Total unsaturated fatty acids P/S: Polyunsaturated to Saturated fatty acid ratio

Table 7. Means (S.E.) of total fatty acid composition (%) of Dorper abdominal, subcutaneous, kidney and intermuscular fat depots for lambs slaughtered either on date 1 or 2.

	Abdominal fat		Subcutaneous fat		Kidney fat		Intermuscular fat	
Fatty acids	**Slaughter date 1**	**Slaughter date 2**	**Slaughter date 1**	**Slaughter date 2**	**Slaughter date 1**	**Slaughter date 2**	**Slaughter date 1**	**Slaughter date 2**
SFA								
C14:0	6.016 ± 0.505	7.431 ± 0.447	8.719 ± 0.493	8.681 ± 0.463	5.956 ± 0.333	6.134 ± 0.452	8.133 ± 0.397	7.997 ± 0.321
C16:0	26.358 ± 1.727	26.921 ± 1.172	26.228 ± 0.395	27.576 ± 0.520	25.489 ± 0.374	26.589 ± 0.617	27.429 ± 1.055	27.634 ± 0.374
C17:0	2.525 ± 1.625	1.827 ± 0.589	5.639 ± 0.537	5.831 ± 0.520	5.984 ± 0.363	6.729 ± 0.240	7.126 ± 0.407	6.389 ± 0.321
C18:0	24.176 ± 2.413	30.121 ± 1.163	18.412 ± 0.724	20.803 ± 0.731	30.224 ± 0.698	30.648 ± 1.018	19.919 ± 0.957	21.234 ± 0.710
MUFA								
C16:1	1.443 ± 0.132	1.411 ± 0.086	2.977 ± 0.202	2.772 ± 0.180	1.066 ± 0.033	1.038 ± 0.039	1.978 ± 0.186	1.702 ± 0.078
C18:1n9t	2.350 ± 1.210	0.275 ± 0.028	0.230 ± 0.033	0.279 ± 0.036	0.684 ± 0.225	0.974 ± 0.260	1.456 ± 0.994	0.349 ± 0.029
C18:1n-9c	13.339 ± 2.294	18.592 ± 0.029	29.455 ± 1.591	27.070 ± 1.981	27.287 ± 1.044	25.520 ± 1.495	28.608 ± 1.580	30.669 ± 0.842
PUFA								
C18:2n-6t	0.963 ± 0.259	0.672 ± 0.034	0.594 ± 0.031	0.602 ± 0.020	0.575 ± 0.015	0.596 ± 0.019	0.692 ± 0.085	0.577 ± 0.014
C18:2n-6c	3.421 ± 0.249	3.658 ± 0.282	3.236 ± 0.174	3.400 ± 0.171	2.578 ± 0.226	2.438 ± 0.251	0.083 ± 0.123	2.680 ± 0.126
C18:3n-6	0.189 ± 0.065	0.060 ± 0.003	0.094 ± 0.010	0.087 ± 0.008	0.30 ± 0.003	0.031 ± 0.003	0.087 ± 0.034	0.043 ± 0.005
C18:3n-3	1.209 ± 0.086	1.129 ± 0.050	1.378 ± 0.065	1.306 ± 0.056	1.000 ± 0.047	1.053 ± 0.058	1.240 ± 0.060	1.168 ± 0.029
C20:3n-6	0.336 ± 0.083	0.142 ± 0.009	0.149 ± 0.034	0.091 ± 0.010	0.049 ± 0.003	0.056 ± 0.004	0.109 ± 0.042	0.065 ± 0.005
C20:3n-3	0.475 ± 0.170	0.152 ± 0.024	0.149 ± 0.021	0.146 ± 0.018	0.117 ± 0.043	0.045 ± 0.005	0.136 ± 0.024	0.119 ± 0.029
SFA	62.386 ± 3.879	67.980 ± 1.738	57.214 ± 1.278	59.947 ± 1.580	64.229 ± 0.916	65.955 ± 1.386	58.468 ± 2.067	59.882 ± 0.741
MUFA	25.682 ± 3.612	23.226 ± 1.911	35.665 ± 1.505	32.867 ± 1.782	30.426 ± 0.856	28.699 ± 1.356	35.292 ± 2.098	34.349 ± 0.826
PUFA	11.932 ± 1.100	8.794 ± 0.425	7.121 ± 0.303	7.186 ± 0.332	5.345 ± 0.287	5.346 ± 0.333	6.240 ± 0.374	5.769 ± 0.231
TUFA	37.614 ± 3.879	32.020 ± 1.735	42.786 ± 1.278	40.053 ± 1.580	35.771 ± 0.916	34.045 ± 1.386	41.531 ± 2.067	40.118 ± 0.741
P:S	0.290 ± 0.072	0.130 ± 0.006	0.124 ± 0.004	0.120 ± 0.005	0.084 ± 0.005	0.082 ± 0.005	0.122 ± 0.018	0.097 ± 0.003

LD: *Longissimus dorsi* BF: *Biceps femoris* SFA: Saturated fatty acids MUFA: Monounsaturated fatty acids PUFA: Polyunsaturated fatty acids
TUFA: Total unsaturated fatty acids P/S: Polyunsaturated to Saturated fatty acid ratio

Table 8. Means (± s.e.) of total fatty acid composition (%) of Dorper abdominal and subcutaneous fat depots for castrates, ewes and ram lambs.

	Abdominal fat			Subcutaneous fat		
Fatty acids	**Castrates**	**Ewes**	**Rams**	**Castrates**	**Ewes**	**Rams**
SFA						
C14:0	6.539 ± 0.780	6.885 ± 0.563	6.784 ± 0.411	8.666 ± 0.462	9.010 ± 0.635	8.425 ± 0.649
C16:0	25.792 ± 2.349	27.843 ± 0.940	26.275 ± 1.827	27.204 ± 0.716	27.082 ± 0.735	26.420 ± 0.791
C17:0	3.915 ± 2.324	0.620 ± 0.408	1.965 ± 0.815	4.789 ± 0.615	5.877 ± 0.485	6.539 ± 0.764
C18:0	26.146 ± 2.523	28.885 ± 1.208	26.533 ± 3.135	20.802 ± 1.106	19.350 ± 0.671	18.670 ± 0.922
MUFA						
C16:1	1.662 ± 0.058	2.042 ± 0.276	1.817 ± 0.114	2.770 ± 0.028	2.815 ± 0.260	3.039 ± 0.239
C18:1n9t	0.838 ± 0.395	0.238 ± 0.032	2.889 ± 1.809	0.262 ± 0.047	0.263 ± 0.040	0.237 ± 0.041
C18:1n-9c	12.122 ± 2.706	19.217 ± 2.494	16.726 ± 2.757	27.793 ± 2.480	28.374 ± 1.936	28.621 ± 2.254
PUFA						
C18:2n-6t	1.196 ± 0.363	0.615 ± 0.047	0.625 ± 0.067	0.611 ± 0.039	0.579 ± 0.027	0.604 ± 0.029
C18:2n-6c	3.209 ± 0.358	3.333 ± 0.259	4.111 ± 0.329	3.203 ± 0.246	3.326 ± 0.232	3.375 ± 0.151
C18:3n-6	0.234 ± 0.093	0.065 ± 0.006	0.069 ± 0.004	0.084 ± 0.009	0.076 ± 0.006	0.111 ± 0.015
C18:3n-3	1.184 ± 0.100	1.096 ± 0.075	1.228 ± 0.080	1.343 ± 0.084	1.275 ± 0.067	1.408 ± 0.072
C20:3n-6	0.364 ± 0.115	0.163 ± 0.015	0.182 ± 0.043	0.078 ± 0.006	0.106 ± 0.017	0.176 ± 0.049
C20:3n-3	0.537 ± 0.224	0.149 ± 0.032	0.244 ± 0.112	0.146 ± 0.027	0.119 ± 0.017	0.177 ± 0.027
SFA	65.190 ± 4.803	67.235 ± 2.318	63.144 ± 3.697	59.455 ± 1.974	59.188 ± 1.428	57.097 ± 1.907
MUFA	23.838 ± 9.321	24.429 ± 2.317	25.064 ± 3.711	33.594 ± 2.280	33.927 ± 1.681	35.278 ± 2.157
PUFA	10.973 ± 0.799	8.318 ± 0.365	11.792 ± 1.601	6.951 ± 0.420	6.884 ± 0.353	7.625 ± 0.379
TUFA	34.810 ± 4.803	32.747 ± 2.118	36.856 ± 3.697	40.545 ± 1.974	40.811 ± 1.428	42.903 ± 1.907
P:S	0.293 ± 0.101	0.125 ± 0.005	0.209 ± 0.038	0.117 ± 0.005	0.116 ± 0.004	0.134 ± 0.005

LD: *Longissimus dorsi* BF: *Biceps femoris* SFA: Saturated fatty acids MUFA: Monounsaturated fatty acids PUFA: Polyunsaturated fatty acids
TUFA: Total unsaturated fatty acids P/S: Polyunsaturated to Saturated fatty acid ratio

Table 8 (continues). Means (S.E.) of total fatty acid composition (%) of Dorper kidney and subcutaneous fat depots for castrates, ewes and ram lambs.

	Kidney fat			Intermuscular fat		
Fatty acids	**Castrates**	**Ewes**	**Rams**	**Castrates**	**Ewes**	**Rams**
SFA						
C14:0	6.230 ± 0.312	6.553 ± 0.519	5.352 ± 0.560	7.800 ± 0.453	8.247 ± 0.456	8.147 ± 0.423
C16:0	26.302 ± 0.515	25.361 ± 0.654	26.453 ± 0.714	27.139 ± 0.291	26.806 ± 1.413	28.648 ± 0.831
C17:0	5.586 ± 0.370	6.415 ± 0.340	7.068 ± 0.382	6.396 ± 0.465	6.883 ± 0.460	6.994 ± 0.447
C18:0	30.556 ± 0.797	29.781 ± 1.206	30.972 ± 1.169	21.132 ± 0.595	19.069 ± 1.235	21.529 ± 1.121
MUFA						
C16:1	1.026 ± 0.038	1.054 ± 0.449	1.077 ± 0.049	1.323 ± 0.143	1.384 ± 0.111	1.581 ± 0.147
C18:1n9t	1.043 ± 0.363	0.582 ± 0.203	0.863 ± 0.242	0.442 ± 0.041	1.954 ± 1.491	0.312 ± 0.025
C18:1n-9c	25.757 ± 1.603	26.853 ± 1.596	26.600 ± 1.607	30.970 ± 0.442	29.248 ± 1.835	28.698 ± 1.949
PUFA						
C18:2n-6t	0.575 ± 0.019	0.605 ± 0.019	0.576 ± 0.023	0.594 ± 0.013	0.713 ± 0.492	0.597 ± 0.025
C18:2n-6c	2.264 ± 0.294	2.611 ± 0.227	2.649 ± 0.345	2.842 ± 0.122	2.532 ± 0.150	2.673 ± 0.175
C18:3n-6	0.029 ± 0.004	0.038 ± 0.004	0.026 ± 0.003	0.056 ± 0.006	0.097 ± 0.051	0.042 ± 0.004
C18:3n-3	0.980 ± 0.071	1.063 ± 0.042	1.038 ± 0.069	1.214 ± 0.039	1.187 ± 0.072	1.211 ± 0.061
C20:3n-6	0.050 ± 0.005	0.056 ± 0.006	0.051 ± 0.003	0.078 ± 0.013	0.059 ± 0.006	0.123 ± 0.063
C20:3n-3	0.112 ± 0.058	0.069 ± 0.025	0.062 ± 0.020	0.164 ± 0.044	0.135 ± 0.031	0.081 ± 0.014
SFA	65.589 ± 1.325	64.403 ± 1.503	65.284 ± 1.543	59.176 ± 0.572	57.043 ± 2.685	61.302 ± 1.763
MUFA	29.100 ± 1.365	29.905 ± 1.405	29.685 ± 1.466	34.880 ± 0.477	37.245 ± 2.696	32.337 ± 1.882
PUFA	5.312 ± 0.463	5.693 ± 0.309	5.031 ± 0.349	5.944± 0.191	5.712 ± 0.226	6.357 ± 0.593
TUFA	34.411 ± 1.325	35.598 ± 1.503	34.716 ± 1.543	40.824 ± 0.572	42.957 ± 2.2685	38.694 ± 1.763
P:S	0.082 ± 0.007	0.090 ± 0.005	0.078 ± 0.006	0.102 ± 0.004	0.122 ± 0.026	0.105 ± 0.011

LD *Longissimus dorsi*
BF *Biceps femoris*
SFA Saturated fatty acids
MUFA Monounsaturated fatty acids
PUFA Polyunsaturated fatty acids
TUFA Total unsaturated fatty acids
P: S Polyunsaturated to Saturated fatty acid ratio

CONCLUSIONS

The aim of this study was to determine the effect of feeding/ production system and gender on the fatty acid profile of abdominal, subcutaneous, kidney, intermuscular and intramuscular (LD and BF) fat of Dorper lamb. Results pertaining to cholesterol content indicated that intermuscular fat of FL- lambs slaughtered on date 2 had the highest cholesterol. High cholestrerol levels have been linked to cardiovascular diseases in humans consuming such diets.

Results of intramuscular LD fat indicated that FL-feeding raises C16:0 as well as palmitate. High levels of palmitic acid are associated with an increase in plasma cholesterol. Lambs slaughtered on date 2, which displayed lower carcass fatness had more SFA and sum of MUFA while lambs slaughtered on date 1 whith greater carcass fatness levels, had more TUFA. Both the sum of PUFA and the P:S ratio tended to be higher for lambs slaughtered on date 1.

Results for intramuscular BF fat as pertaining to C18:3n-6 and C18:2n-6t were confusing and unexpected. Similar studies involving this muscle should be undertaken to get comparative results. Castrate had the highest C18:3n-3 while ewe lambs had the highest SFA percentages. In the intramuscular BF fat, C14:0, C16:0, C18:0, C18:2n-6t and C18:3n-6 as well as the sum of SFA were higher for lambs slaughtered on date 1. On the other hand, percentage C18: 3n-3 and sum of TUFA were higher on date 2.

C14:0 and C18:0 in the abdominal fat were higher for lambs slaughtered on date 2 while C20:3n-6 and sum of PUFA was higher for lambs slaughtered on date 1.

For subcutaneous fat, the FL-diet increased the percentage C18:2n-6c while the percentage C18:3n-3 was increased by the FR-diet. FR-feeding also raised the percentages of C18:0, C18:2n-6t, C18:3n-3 and C20:3n-6 in the kidney fat. Conversely, FL-feeding increased the percentage of C18:2n-6c in this fat depot. When the gender effect was considered, results revealed that ewe lambs had the highest level of C20:3n-6.

As for intermuscular fat, higher percentages of C18:3n-3 and sum of SFA were observed for FR-lambs compared to FL-lambs. Furthermore, the sum of TUFA for intermuscular fat was higher in FL-lambs compared to FR-lambs.

REFERENCES

Aurousseau, B., 1981. Elaboration des lipids corporals at valeur des carcass des ruminants (Developments of body lipids and valour of ruminant carcasses). Bull. Tech. CRZV Theix, INRA, 45, 43-50.

Banskalieva, V, Sahlu, T. & Goetsch, A.L. 2000. Fatty acid composition of goat muscles and fat depots: a review. Small Ruminant Research, 37, 255-268.

Bas, P., Hervieu, J., Morand-Fehr, P. & Sauvant, D. 1982. Factors influencing the composition of fat in slaughater kids: effects on quality of carcass fat. Nutrition et systemes d'alimentation de chervre, 1, 90-100.

Boname, A., Grundy, S.M. 1998. Effect of dietary stearic acid on plasma cholesterol and lipoprotein levels. New England Journal of Medicine, 318, 1244-1247.

Casey, N.H. & Webb, E.C. 1995. Influence of dietary energy levels and form of diet on composition of fatty acids in subcutaneous adipose tissue of wethers. Small Ruminant Research, 18, 125-132.

Choi, N.J., Kim, E.J., Maeng, W.J., Neville, M.A., Enser, M., Wood, D.J. & Scollan, N.D. 1997. Rumen biohydrogenation of fatty acids of different sources of fat: as cited by: Diaz, M.T., Velasco, S., Caneque, V., Lauzurica, S., de Huidobro, F. R., Perez, C., Gonzalez, J. & Manzanares, C. 2002. The use of concentrate or pasture for fattening lambs and its effect on carcass and meat quality. Small Ruminant Research, 43, 257-268.

Crouse, J.D. & Field, R.A. 1978. Effect of dietary energy intake on carcass composition and palatability of different weight carcasses from ewe and ram lambs. Journal of Animal Science, 47, 1207-1218.

Díaz, M.T., Velasco, S., Caneque, V., Lauzurica, S., de Huidobro, F. R., Perez, C., Gonzalez, J. & Manzanares, C. 2002. The use of concentrate or pasture for fattening lambs and its effect on carcass and meat quality. Small Ruminant Research, 43, 257-268.

Enser, M., Hallet, K.G., Hewwett, B., Fursey, G.A.J., Wood, J.D., Harrington, G. 1998. Fatty acid acid and composition of UK beef lamb muscle in relation to production system and implications for human nutrition. Meat Science, 49, 329-341.

Folch, J., Lees, M. & Stanley, G.H.S. 1957. A simple method for the isolation and purification of total lipids from animal tissue. Journal of Biological Chemistry, 226, 497-509.

Grundy, S.M. & Denke, M.A. 1990. Dietary influences on serum lipids. Journal of Lipid Research, 31, 1149-1172.

Higgs, J.D. 2000. The changing nature of red meat: 20 years of improving nutritional meat quality. Trends in Food Science and Technology, 11, 85-95.

Hu, F.B. & Willett, W.C. 2003. Optimal diet prevention of coronary heart diseases. J. Am. Med. Assoc. 288 (20): 2569-2578.

Huerta-Leidenz, N.O., Cross, H.R., Savell, J.W., Lunt, D.K., Baker, J.F. & Smith, S.B. 1996. Fatty acid composition of subcutaneous tissue from male calves at different stages of growth. Journal of Animal Science, 74, 1256-1264.

Jenkins, T.C. 1993. Lipid Metabolism in the Rumen. Symposium: Advances in ruminant lipid metabolism. Journal of Dairy Science, 76, 3851-3863.

Johnson, D.D., Eastridge, J.S., Neubauer, D.R. & McGowan, C.H. 1995. Effect of sex class on the nutrient content of meat from young goats. Journal of Animal Science, 73, 296-301.

Kemp, Y.D., Mahyuddin, M., Ely, J.D.Woody, W.G. 1981. Effect of feeding systems, slaughter weight and sex on organoleptic properties and fatty acid composition of lamb. Journal of Animal Science, 51, 321-330.

Kovacs, M.I.P., Anderson, W.E. & Ackman, R.G. 1979. A simple method for the determination of cholesterol and some plant sterols in fishery based food products. Journal of Food Science, 44, 1299-1305.

Lough, D.S., Solomon, M.B., Rumsey, T.S., Elsasser, T.H., Slyter, L.L., Kahl, S. & Lynch, G.P. 1992. Effects of dietary canola seed and soy lecithin in high forage diets on cholesterol content and fatty acid composition of carcass tissues of growing ram lambs. Journal of Animal Science, 70, 1153-1158.

MacRae, J., O'Reilly, L. & Morgan, P. 2005. Desirable chacteristic of animal product from a human health perpective. Livestock Porduction Science, 94, 95-103.

Malau-Aduli, A.E.O., Siebert, B.D., Bottema, D.K., & Pitchford, W.S. 1998. Breed composition of muscle phospholipids in Jersey and Limousin cattle. Journal of Animal Science, 76, 766-773.

Matsuoka, A., Furokawa, N. & Takahashi, T. 1997. Carcass traits and chemical composition of meat in male and female goats. Journal of Agricultural Science, 42(2), 127-135.

Mitchell, G.E., Reed, A.W. & Rogers, S.A. 1999. Influence of feeding regimen on the sensory qualities and fatty acid contents of on beef steaks. Journal of food Science, 56, 1102-1103.

Notter, D.R. Kelly, R.F. & McClaugherty, F.S. 1991. Effects of ewe breed and management system on efficiency of lamb growth production: II. Lamb growth, survival and carcass characteristics. Journal of Animal Science, 69, 22-33.

Nuernberg, K., Dannenberger, D., Nuernberg, G., Ender, K., Voigt, J., Scollan, N.D., Wood, JD, Nute, G.R. & Richardson R.I. 2005. Effect of grass characteristics and fatty acid composition of longissimus muscle in different cattle breeds. Livestock Production Science 94: 137-147.

Nürnberg, K., Wegner, J. & Ender K. Factors influencing fat composition in muscle and adipose tissue of farm animals. Livestock Production Science, 56, 145-156.

Okeudo, N.J., Mos, B.W., Chestnutt, M.B. 1994. Effect of feeding a milk diet or concentrate plus hay on carcass and meat quality of lamb. In: Proceedings of the 40th International Congress in Meat Science and Technology S-IVA, p. 38.

Piasentier, E. 2003. The effect of grazing on the quality of meat. Internationale Fachtagung für Schafhaltung. p1-5 http://www.gumpenstein.at/publikationen/fachtagungschaf/piasenti.pdf accessed 8 January 2008.

Rhee, K.S. 1992. Fatty acids in meat and meat products. In: Chow, C.K. (Ed), Fatty acids in Foods and their Health implications. Markel Dekker, New York, pp. 65-93.

Richardson, N. J. 1994. UK consumer perceptions of meat. Proceedings of the Nutrition Society, 53, 281-287.

Rule, D.C., Macneil, M.D. & Short, R.E. 1997. Influence of sire growth potential, time on feed and growing finishing strategy on cholesterol and fatty acids of ground carcass and *Longissimus* muscle of beef steers. Journal of Animal Science, 75(6), 1525-1533.

Russo, C., Prezuiso, G., Casarosa, L., Campondi, G., & Ciani, D. 1999. Effect of dietary energy source on the chemical- physical characteristics of meat and depot fat of lamb carcasses. Small Ruminant Nutrition, 33, 77– 85.

Sales, J. 1994. Die identifiseering en verbetering van kwaliteitseienskappe van volstruisvleis. PhD in Animal Science Thesis, University of Stellenbosch, South Africa.

Sanders, T.A.B. 2003. High-versus low fat diets in human diseases. Curr. Opin. Clin.Nutr. Metab.Care 6, 151-155.

Santos-Silva, J., Mendes, L.A. & Bessa, R.J.B. 2002. The effect of genotype, feeding system and slaughter weight on the quality of light lambs 1. Growth, carcass composition and meat quality. Livestock Production Science, 76, 17-25.

SAS Institute, Inc. 1999. SAS/STAT User's Guide, Version 9, 1st printing, Volume 2, SAS Institute Inc, SAS Campus Drive, Cary, North Carolina 27513, USA

Sauvant, D., Bas, P. & Morand-Fehr, P. 1979. Heavy kids production. II. Influence of milk ingestion and weaning on performance of adipose tissue composition of kids. Ann. Zootech, 28, 73-92.

Scollan, N.D., Choi, N.J., Kurt, E., Fisher, A.V., Enser, M., Wood, J.D. 2001. Manipulating the fatty acid composition of muscle and adipose tissue in beef cattle. British Journal of Nutrition. 85, 115-124.

Smith, S.B., Smith, D.R. & Lunt, D.K., 2004. Chemical and physical characteristics of meat/ Adipose tissue. In: Encyclopedia of Meat Science (edited by Jensen, W.K., Devine, C. & Dikeman, M.). Vol.1.Pp 233-234. Oxford, UK:ElsevierLtd.

Van Jaarsveld, P.J., Smuts, C.M., Tichelaar, H.Y., Kruger, M. & Spinnler Benadé, J.A. 2000. Effect of palm oil on plasma lipoprotein concentrations and plasma low-density lipoprotein composition in non-human primates. International Journal of Food Science and Nutrition, 51, 521-530.

Varela, A., Oliette, B., Moreno, T., Portela, C., Monserrrat, L., Carballo, J.A. & Sánchez, L. 2004. The effect of pasture finishing on the meat characteristics and intramuscular fatty acid profile of steers of the Rubia Gallega breed. Meat Science, 67, 515-522.

Verberke, W.A.J., & Viaene, J. 2000. Ethical challenges for livestock Production: Meeting consumer concerns about meat safety and animal welfare. Journal of Agricultural and Environmental Ethics, 12, 141-151.

Vergara, H., Molina, A. & Gallego, L. 1999. Influence of sex and slaughter weight on carcass and meat quality in light and medium weight lambs produced in intensive systems. Meat Science, 52, 221-226.

Vitamin Information Centre. 2005. Facing polyunsaturated fatty acids: where do we stand? Medical Update N0.45. Islando, South Africa.

Wachira, A.M., Sinclair, L.A., Wilkinson, R.G., Enser, M., Wood, J.D. & Fisher, A.V. 2002. Effects of dietary fat source and breed on the carcass composition, n-3 polyunsaturated fatty acid and conjugated fatty acid content of sheep meat and adipose tissue. British Journal of Nutrition, 88, 607-709.

Webb, E.C., Casey, N.H. & Van Niekerk, W.A. 1994. Fatty acids in the subcutaneous adipose tissue of intensively fed SA Mutton Merino and Dorper Wethers. Meat Science, 38, 123-131.

Chapter 7

General Conclusions

The effect of production system (feedlot {FL-} vs. free-range {FR}), gender (ram, ewe or castrate) and slaughter date (date 1 and date 2) was investigated in a 2 X 3 X 2 factorial experiment. Sixty Dorper lambs that were randomly allocated to these treatments provided material for the study.

This investigation has shown that FL-ram lambs generally grow faster than ewe lambs. The growth advantage of FL-ram lambs is attributed to their ability to utilize feed more efficiently, this effect being more pronounced on FL-diets (Notter *et al.*, 1991; Arnold & Meyer, 1988; Crouse *et al.*, 1981; Bradford & Spurlock, 1964). Results of this study further suggest that FR-feeding may be sufficient for ewe lamb growth whilst ram lamb growth is compromised. It is not certain whether these results may be coincidental or not.

The effect of production system on the slaughter traits of Dorper sheep indicated that FL-lambs are generally fatter at slaughter and have a higher dressing percentage than FR-lambs, in agreement with previous results (Díaz *et al.*, 2002; Cañeque *et al.*, 1990). Lower carcass weights and dressing percentages of FR-lambs in this study can be attributed to the reduced carcass fatness in these lambs (McClure *et al.*, 1994). Moreover, it may be possible that part of the difference in dressing percentage between FL- and FR-lambs stems from a smaller alimentary tract in the former, fed concentrates. FR-lambs consuming herbage have larger alimentary tracts and thus weigh more (Owens *et al.*, 1993). Leaner carcasses from a growing-out environment perceived by consumers to benefit animal welfare, thus weighs profoundly in favour of the FR-management system. Furthermore, results pertaining to production system also indicated that FL-lambs had greater subcutaneous, abdominal and kidney fat deposition than FR-lambs, again in accordance with previous studies (Díaz *et al.*, 2002). It is however not clear why; (1) both FL- and FR-lambs slaughtered on date 1 had greater subcutaneous fat than lambs slaughtered on date 2, (2) both FL- and FR-lambs slaughtered on date 1 had greater abdominal fat than lambs slaughtered on date 2 and (3) FR-lambs slaughtered on date 1 had more kidney fat than FR-lambs slaughtered on date 2. The effect of gender on the slaughter traits of Dorper sheep in this investigation indicated that male lambs (rams and castrates) produced heavier carcasses than ewe lambs. Similar results where previously reported by Dransfield *et al.* (1990).

It is well documented that greater carcass fatness results in slower cooling rates followed by a more rapid post mortem glycolysis which ultimately lowers muscle pH (French *et al.*, 2001; Lawrie, 1998). FL-lambs in this investigation also had a significantly lower pH45 than FR-lambs ($P < 0.01$), possibly resulting from their thicker subcutaneous fat cover. As far as meat colour is concerned, it is known that meat from FR-animals is darker than meat from FL-animals (Piansentier, 2003; Diaz *et al.*, 2002; Priolo *et al.*, 2002; Baardseth *et al.*, 1988; Bidner *et al.*, 1981) because of the higher haemic pigment concentration in muscles as a result of

exercise (Piansentier, 2003; Diaz *et al.*, 2002; Priolo *et al.*, 2002). The reduced redness and colour intensity of lambs finished under FR-conditions in this study is therefore not clear. Results of this investigation indicate that meat from FR-lambs can compete favourably with meat from FL-lambs since no tenderness differences (as indicated by the Warner-Bratzler shear force values) were observed. This is an important finding, particularly since consumers consider tenderness as the most important meat palatability trait. Although not significant, meat from the the *biceps femoris* muscle (BF) muscle of FL-lambs tended to have a greater intramuscular lipid concentration. Since meat from FR-animals generally have relatively less fat, the FR-production system can be regarded as a better choice from a human health perspective.

According to sensory evaluation results, the advantage of FL-diets seem to be its ability to produce juicier and more tender meat –phenomena attributed to the higher lipid content of FL-diets. Meat tenderness was compromised in ram lambs in the FR-production system for lambs slaughtered on slaughter date 1 when the production system X gender X slaughter date interaction was considered. Lamb flavour was more intense in ram lambs in the FR-production system when the feeding system X gender interaction was considered. Furthermore, the gender effect suggested that meat tenderness was compromised in ram lambs compared to the other gender groups.

Many scientific studies investigating the effect of production/feeding system on the fatty acid profile of sheep only look at the following depots (1) intramusclar fat (Nuernberg *et al.*, 2005; Varela *et al.*, 2004; (2) subcutaneous fat (Casey & Webb, 1995; Webb *et al.*, 1994) or (3) subcutaneous and intramuscular fat (Diaz *et al.*, 2002; Wachira *et al.*, 2002). The present study however investigated the effect of production system, gender and slaughter date on the fatty acid profiles of subcutaneous fat, abdominal fat, kidney fat, intramuscular fat and intermuscular fat. There is a lack of comparable studies involving the effect of feeding/production system, gender and slaughter date on the fatty acid profiles of different depots of Dorper lambs. This makes it difficult to relate the present results to literature findings.

The fatty acid profile of the intramuscular LD fat suggest that it is better to consume meat from lambs slaughtered at lower weights because of the higher levels of PUFA displayed by these lambs. The consumption of intramuscular BF fat from ram lambs could also endanger human health because of the high palmitic acid levels (Bonamone & Grundy, 1988). The high levels of SFA in the intramuscular BF fat of ewe lambs could be another health risk since high levels of SFA are linked to high cholesterol levels which in turn is linked to the incidence of coronary heart disease and cancer in humans (MacRae *et al.*, 2005).

For subcutaneous, kidney and intermuscular fat, FR-feeding increased the percentage of linolenic acid while FL-feeding increased the percentage of linoleic acid. The regular intake of omega-3 (from FR-lambs) reduces the risk of cancer, especially cancer of the gastrointestinal tract and breast tissue (Vitamin Information Centre, 2005).

It seems that consumers may not necessarily distinguish between meat from FR- or FL-lambs. The possibility that they may discriminate against the increased fatness of the FL-lambs however exists. No apparent benefits regarding production system and its link to the proximate chemical composition as well as

the fatty acid composition of the meat was observed. Certain production systems could be in favour of the faster growth and shorter production cycle of FL-lambs. However, this needs to be weighed against the cost of concentrate feeding and the preference consumers are likely to develop for lamb produced in natural environments.

REFERENCES

Arnold, A. M. & Meyer, H. H. 1988. Effects of gender, time of castration, genotype and feeding regime on lamb growth and carcass fatness. Journal of Animal Science, 66, 2468-2475.

Baardseth, P., Skrede, G., Naes, T., Thomassen, M.S., Iversen, A. & Kaaber, L. 1988. A comparison of the CIE L*A*B values obtained from two different instruments on several food commodities. Journal of Food Science, 53, 1737-1742.

Bidner, T.D., Schupp, A.R., Montgomery, R.E. & Carpenter, J.C. 1981. Acceptability of beef finished on all forage, forage-plus-grain or high energy diets. Journal of Animal Science, 53, 1181-1187.

Boname, A., Grundy, S.M. 1998. Effect of dietary stearic acid on plasma cholesterol and lipoprotein levels. New England Journal of Medicine, 318, 1244-1247.

Bradford, G.E. & Spurlock, G.M. 1964. Effect of castrating lambs on growth and body composition. Journal of Animal Production, 6, 291-299.

Cañeque, V., Huidobro, F., Hernandez, J.A. & Dolz, J.F. 1990. Comparison between four fattening systems for lambs and their effects on carcass quality. As cited by: Diaz, M.T., Velasco, S., Caneque, V., Lauzurica, S., de Huidobro, F. R., Perez, C., Gonzalez, J. & Manzanares, C. 2002. The use of concentrate or pasture for fattening lambs and its effect on carcass and meat quality. Small Ruminant Research, 43, 257-268.

Casey, N.H. & Webb, E.C. 1995. Influence of dietary energy levels and form of diet on composition of fatty acids in subcutaneous adipose tissue of wethers. Small Ruminant Research, 18, 125-132.

Crouse, J. D., Busboom, J. R., Field, R. A. & Ferrell, C. L. 1981. The effects of breed, diet, sex, location and slaughter weight on lamb growth, carcass composition and meat flavour. Journal of Animal Science, 53, 376-381.

Díaz, M.T., Velasco, S., Caneque, V., Lauzurica, S., de Huidobro, F. R., Perez, C., Gonzalez, J. & Manzanares, C. 2002. The use of concentrate or pasture for fattening lambs and its effect on carcass and meat quality. Small Ruminant Research, 43, 257-268.

Dransfield, E., Nute, G.R., Hogg, B.W., & Walters, B.R. 1990. Carcass and eating quality of ram, castrated ram and ewe lambs. Animal Production, 50, 291- 299.

French, P., O'Riordan, E.G., Monahan, F.J., Caffrey, P.J., Mooney, M.T., Troy, D.J. & Moloney, A.P. 2001. The eating quality of steers fed grass and/or concentrates. Meat Science, 57 379-386.

Lawrie, R.A. 1998. Meat Science, 6th edition. Pergamon Press. New York.

McClure, K.A., Van Keuren, R.W. & Althouse, P.G. 1994. Performance and carcass characteristics of weaned lambs either grazed on orchard grass, ryegrass or alfafa or fed all concentrate diets in drylots. Journal of Animal Science, 72, 3230-3237.

MacRae, J., O'Reilly, L. & Morgan, P. 2005. Desirable chacteristic of animal product from a human health perpective. Livestock Porduction Science, 94, 95-103.

Notter, D.R., Kelly, R.F. & McClaugherty, F.S. 1991. Effects of ewe breed and management system on efficiency of lamb growth production: II. Lamb growth, survival and carcass characteristics. Journal of Animal Science, 69, 22-33.

Nuernberg, K., Dannenberger, D., Nuernberg, G., Ender, K., Voigt, J., Scollan, N.D., Wood, JD, Nute, G.R. & Richardson R.I. 2005. Effect of grass characteristics and fatty acid composition of longissimus muscle in different cattle breeds. Livestock Production Science 94: 137-147.

Owens, F.N., Dubeski, P. & Hanson, C.F. 1993. Factors that alter the growth and development of ruminants. Journal of Animal Science, 71, 3138-3150.

Piasentier, E. 2003. The effect of grazing on the quality of meat. Internationale Fachtagung für Schafhaltung. p1-5 http://www.gumpenstein.at/publikationen/fachtagungschaf/piasenti.pdf accessed 8 January 2008.

Priolo, A., Micol, D. and Agabriel, J., Prache, S. & Dransfield, E. 2002. Effect of grass or concentrate feeding systems on lamb carcass and meat quality. Meat Science, 62, 179-185.

Seideman, S. C., Cross, H. R, Oltjen, R. R. & Scanbacher, B. D. 1982. Utilization of intact male for red meat production. Journal of Animal Science, 55, 826- 840.

Varela, A., Oliette, B., Moreno, T., Portela, C., Monserrrat, L., Carballo, J.A. & Sánchez, L. 2004. The effect of pasture finishing on the meat characteristics and intramuscular fatty acid profile of steers of the Rubia Gallega breed. Meat Science, 67, 515-522.

Vitamin Information Centre. 2005. Facing polyunsaturated fatty acids: where do we stand? Medical Update No.45. Islando, South Africa.

Wachira, A.M., Sinclair, L.A., Wilkinson, R.G., Enser, M., Wood, J.D. & Fisher, A.V. 2002. Effects of dietary fat source and breed on the carcass composition, n-3 polyunsaturated fatty acid and conjugated fatty acid content of sheep meat and adipose tissue. British Journal of Nutrition, 88, 607-709.

Webb, E.C., Casey, N.H. & Van Niekerk, W.A. 1994. Fatty acids in the subcutaneous adipose tissue of intensively fed SA Mutton Merino and Dorper Wethers. Meat Science, 38, 123-131.