Developing a model for feedlot production of Boer goat slaughter kids

by

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Declaration

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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Summary

In this study, the effects of energy content of the feedlot diet as well as the length of the production period were investigated for Boer goat slaughter kids. The kids were housed in individual pens on the Elsenburg experimental farm, Western Cape, South Africa. Boer goat castrate kids were weaned at approximately 18 weeks of age (weighing 22.2 ± 3.5 kg) and were randomly allocated to one of three trial diets that varied in energy content; namely a low, medium and high energy diet (11.3, 12.0 and 12.7 MJ ME/ kg feed respectively) which were supplied *ad libitum*. The goats were further randomly allocated to one of five slaughter groups that were slaughtered at five week intervals at a commercial abattoir. The first group of goats was slaughtered at the start of the trial in order to serve as a baseline reference. During the study the effects of dietary energy content, and time spent in the feedlot were investigated for the feedlot production and slaughter characteristics of Boer goat kids. Additionally the effect of the energy content of the feedlot diets on the sensory and chemical properties of goat meat were evaluated.

During the production period individual feed intake and live weight gain were monitored on a weekly basis. It was observed that live weight of the goats increased throughout the production period. Quadratic functions were used to describe the change in average daily gain and dry matter intake of the goats during the feeding period. Goats that were fed the low and medium energy diets exhibited higher daily gains ($P = 0.02$) and dry matter intakes ($P < 0.01$) than goats on the high energy diets. Dietary energy content and age of the animal in the feedlot did not influence the feed conversion ratio to produce a unit of live weight. A linear function was used to model the growth of the goats during this production period. The goats were not able to reach the point of inflection on the growth curve. Therefore the sigmoidal growth curve could not be plotted which could have been modelled by a function similar to the Gompertz model.

Dressing percentages of the carcasses varied throughout the production period for all the diets, with goats on the low energy diet having the lowest dressing percentage (45.8%; $P = 0.04$). The energy content of the trial diets had no effect on the yield of the offal components and retail cuts of the carcass. Generally it was observed that the yields of the hindquarter and neck cuts decreased whilst that of the forequarter increased with the age of the goats at slaughter. The degree of carcass fatness increased with time spent in the feedlot, with the majority of fat being deposited in the abdominal cavity, rather than in the subcutaneous fat depot.

Dietary energy content was expected to influence the levels of intramuscular fat, which in turn would affect the eating quality of the meat. However, the levels of energy in the diets fed to goats did not influence the tenderness, juiciness or the aroma and flavour profiles of the goat meat as observed during descriptive sensory analysis of the meat by a trained panel. Chemical analysis of the cooked meat samples also showed that the levels of intramuscular fat did not vary between the samples, resulting in the lack of differences detected between treatments in the sensory evaluation.

Opsomming

In hierdie studie is die effek van die energie-inhoud van die voerkraal dieet, tesame met die lengte van die produksie tydperk, vir Boerbok lammers ondersoek. Die lammers is in individuele kampies gehuisves op die Elsenburg proefplaas, Wes- Kaap, Suid-Afrika. Die gekastreerde Boerbok lammers is gespeen op ’n ouderdom van ongeveer 18 weke (gewig van 22.2 ± 3.5 kg) en is ewekansig toegewys aan een van die drie proefdiëte waarvan die energie-inhoud gewissel het; naamlik 'n lae, medium en hoë-energie dieet (11.3, 12.0 en 12.7 MJ ME / kg voer onderskeidelik) wat *ad libitum* verskaf is. Die bokke is verder lukraak toegewys aan een van vyf slag groepe, wat met vyf weke tussenposes by ’n kommersiële abattoir geslag is. Die eerste groep bokke is aan die begin van die proef geslag om sodoende as basislyn verwysing te dien. Tydens die studie is die effek van die verskil in energie-inhoud van die dieet en die tyd wat in die voerkraal gespandeer is, op die voerkraal produksie en slag eienskappe van die Boerbok lammers ondersoek. Daarbenewens is die effek van die verskil in energie-inhoud van die voerkraal dieet op die sensoriese en chemiese eienskappe van bokvleis geëvalueer.

Tydens die produksie periode is individuele voerinname en liggaamsgewig toename op ’n weeklikse basis gemonitor. Dit is waargeneem dat die liggaamsgewig van die bokke tydens die hele produksie tydperk toegeneem het. Kwadratiese funksies is gebruik om die verandering in die gemiddelde daaglikse toename tydens die voerperiode, sowel as die droëmateriaal inname van die bokke te beskryf. Bokke wat die lae en medium-energie diëte gevoer is, het hoër daaglikse toenames ($P = 0.02$) en droë materiaal inname ($P< 0.01$) as bokke op die hoë-energie dieet getoon. Die voeromset verhouding benodig om ’n eenheid lewendige gewig te produseer is nie beïnvloed deur die energie-inhoud van die dieet, of die ouderdom van die bokke in die voerkraal nie. ’n Lineêre funksie is toegepas om die groei van die bokke gedurende die produksie tydperk te modelleer. Die groei van die bokke kon nie die infleksiepunt van die groeikurwe bereik nie. Dus kon die sigmoïdale groeikurwe nie getrek word nie, wat deur ’n funksie soortgelyk aan die Gompertz model gemodelleer kon word.

Uitslag persentasies van die karkasse het l regdeur die produksie tydperk varieër vir al die diëte; bokke op die lae-energie dieet het die laagste uitslagpersentasie gehad (45.8%; $P = 0.04$). Die energie-inhoud van die proefdiëte het geen effek op die opbrengs van die afval komponente en handelsnitte van die karkasse gehad nie. Oorhoofs is dit waargeneem dat die opbrengs van die agterkwart en neksnitte afgeneem het, terwyl dié van die voorkwart toegeneem het met slag ouderdom. Die vetheidsgraad van die karkas het toegeneem met tyd spandeer in die voerkraal, met die meerderheid van die vet gedeponeer in die buikholte, eerder as in die onderhuidse vetlaag.

Daar is verwag dat die energie-inhoud van die dieet die vlakke van binnespierse vet sal beïnvloed, wat op sy beurt ‘n effek op die eetkwaliteit van die vleis sal hê.. Teenstrydig met verwagtinge het die vlakke van energie in die dieet van die bokke geen invloed gehad op die sagtheid, sappigheid of die aroma en geur profiele van bokvleis nie, soos waargeneem deur middel van beskrywende sintuiglike analise van die vleis deur 'n opgeleide paneele. Chemiese ontleding van die gaar vleismonsters het ook geen verskillein die vlakke van binnespierse vet tussen die verskillende monsters getoon nie, wat gelei het tot daar geen verskille tussen die behandelings in die sensoriese evaluasie waargeneem is nie.

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Abbreviations

ANOVA	Analysis of variance
ADG	Average daily gain
BW	Body weight
$BW^{0.75}$	Metabolic body weight
DA	Discriminant analysis
DFD	Dark firm and dry
DMI	Dry matter intake
DSA	Descriptive sensory analysis
FCR	Feed conversion ratio
LL	*Longissimus lumborum* muscle
LSD	least square differences
LSM	least square mean
LnDMI	Natural logarithm of dry matter intake
ME	Metabolisable energy
MEI	Metabolisable energy intake
NRC	National Research Council
PCA	Principle component analysis
PSE	Pale soft and exudative
SEM	standard error of the mean

Table of Contents

Chapter 1

General Introduction

The Boer goat is a breed that was developed in the Eastern Cape Province of South Africa by early farmers who reared goats in order to clear the bush or shrubs to make way for other agricultural practices (Steyn, 2010). These farmers used indigenous goat breeds and incorporated a breeding scheme to develop a superior meat goat breed by selecting goats for high fertility, high growth rates and good body conformation (Casey & Van Niekerk, 1988). This led to a meat goat breed that has been described as the standard to which other meat goats are compared (Steyn, 2010) and is popular for use in crossbreeding strategies to improve the meat production of smaller unimproved goat breeds all over the world (Owen & Norman, 1977). The Boer goat can be identified by its characteristic red head with Roman nose and its white body with a well-rounded conformation. This style of coat colouring allows farmers to easily find and identify the animals in thick bush.

The Boer goat is reared by communal subsistence farmers for meat and milk production as well as by commercial farmers in extensive production systems or in combination with mixed agriculture systems (Casey & Van Niekerk, 1988). They are generally reared in arid or semi-arid regions with sparse grazing and the veld predominantly consists of bushes or shrubs. The Boer goat is adaptable to most climatic regions and is robust, allowing it to be tolerant to dry, extensive conditions and resistant to endemic diseases (Casey & Webb, 2010). Goat production is suited to such regions, as goats are better able to utilize lower quality roughages than other livestock species and exhibit different foraging behaviours (Casey & Van Niekerk, 1988). Goats exhibit a very selective feeding behaviour, showing preference to the more digestible plant matter from small trees and shrubs (Malan, 2000). Goats possess a highly efficient capacity for recycling the excess ammonia in the rumen, which is converted to urea in the liver and recycled through the saliva. Along with greater volumes of saliva production, this allows goats to overcome the bitter taste and protein binding effect of tannins found in leaves (Animut & Goetsch, 2008), as well as supply additional nitrogen for production of microbial protein in the rumen. Although goat farming is greatly associated with extensive production systems, the Boer goat can adapt to more intensified systems (Fernandes *et al*., 2007).

With an increased demand for red meat, farmers opt to finish lambs and slaughter kids in feedlots rather than off pastures in order to increase their profit margins. Feedlot finishing of slaughter kids on concentrate diets ensures increased growth rates, which allows them to reach the desired slaughter weight at an earlier age. Removing kids from the pasture and introducing them to the feedlot soon after weaning, allows the farmer to decrease the competition for feed resources and makes a greater proportion of the pasture available to breeding does (Ryan *et al*., 2007). By employing such intensive management and feeding strategies, one can shorten production cycles, improve reproductive performance and achieve greater product yields (Webb & Casey, 2010). Boer goats exhibit similar feeding efficiencies as South African Mutton Merinos when supplied a feedlot ration, although they grow at a slower rate (Sheridan *et al*., 2003). A common trend in South Africa is to feed goats diets that have been formulated specifically for sheep, even though the nutritional requirements of the two species differ, along with the differences in growth or maturation rates and body composition. The major component of a concentrate finishing ration is the energy content of the ration. The energy component is obtained by supplying highly digestible starch in the diet in the form of cereal grains such as maize. The energy density of the diet is important as it provides the animal with energy necessary for growth, activity and to sustain body processes. It has also been identified as a main driver that has been seen to influence feed intake in ruminants (Lu & Potchoiba, 1990) as well as the utilization of other nutrients. Therefore, the energy content of the diet affects the level of weight gain of the animal. Excess energy that is absorbed by the body is either excreted or converted into fat, which serves as an energy store that can be utilized when the demand is greater than the amount of energy that is supplied in the diet.

Animal growth is considered to be an increase in body mass, which is accompanied by changes in body conformation as a result of cellular growth and differentiation. The change in body weight can be plotted against time from birth until maturity to produce a sigmoidal growth curve which can be used to describe the growth rate as well as show growth patterns (Bathaei & Leroy, 1996). These curves can be identified by their characteristic “S-shape” which consists of an initial lag phase followed by a period of rapid growth which tends to level out and plateau when the animal reaches mature body weight after it has passed the point of inflection. Different mathematical functions can be applied to such growth curves and be used to predict growth at varying accuracies depending on the conditions. A mathematical model is an equation or set of equations that can be used to represent trends of a biological system as it condenses multiple measurements taken throughout the system into a few parameters that have biological meaning (Thornley & France, 2007). Growth models can be used to predict the growth trends of an animal, as well as compare the effects of different treatments and interactions between subpopulations. Through proper understanding of such models, one can improve the level of production by optimizing the resources available to the animals at specific growth stages and ensure optimal growth, as well as identify individuals that deviate from predicted outcomes (Najari *et al*., 2007). An important parameter of any growth model is the mature body weight which in turn has an effect on the growth rate of the animal.

It is assumed that when an animal reaches its mature body, it achieves its maximum muscle mass and further changes in body weight may be ascribed to increased fat deposition (Owens *et al*., 1993). Different body tissues and organs develop and mature at different rates which accounts for the differences in body shape that an animal experiences as it grows (Owens *et al*., 1993). The three major tissues of the body which are important in meat production are bone, lean muscle and fat. Of these tissues, bone is the first to develop and reaches maturity soon after birth. The absolute weight of bone increases with the age of the animal, however the proportion of bone decreases relative to the proportions of muscle and fat as the animal gets older. The conformation or muscularity of an animal can be described as the amount of lean muscle surrounding the skeleton. Muscle growth and development differs for different parts of the body at various stages depending on the activity which it performs. After birth, the larger muscles of the hind legs develop faster than the rest of the body as the locomotive capacity of the young animal increases (Butterfield, 1988). Further changes in muscle weight distribution are minimal until puberty is reached, when the body shape changes with associated secondary sexual characteristics. Typically after puberty, intact males will have a more muscular neck and forequarter region while females will be more developed around the pelvic region, which is an adaptation for survival and reproduction. Intact male animals are also generally leaner than females, which tend to start accreting fat earlier in life. The initial rate of muscle development increases after birth, but then decreases and increases at the same rate as the rest of the body (Butterfield, 1988). The relative proportion of muscle in the body then remains fairly constant and only starts to decrease as the proportion of body fat increases as the animal nears maturity.

Goats are late maturing when compared to sheep and grow at a slower rate, while the Boer goat is considered to be an early maturing goat breed. Unlike mutton breeds, goats deposit a greater amount of fat internally in the abdominal and kidney fat depots than in the subcutaneous and intramuscular depots (Webb, 2014). This may perhaps be because of the later maturing nature of goats, so fat is only deposited at a later stage, although goat meat is generally considered a lean meat that is an ideal protein source for health conscious groups that try to limit their fat intake. Due to the lack of subcutaneous fat on goat carcasses, goat meat is very susceptible to cold shortening during cooling, which results in the meat being tough (Kannan *et al*., 2014). Chevon commonly refers to the meat from goats that have not reached maturity; it is thus the goat equivalent of lamb, which is the meat from sheep that have less than two permanent incisors. Meat from older goats, which is equivalent to mutton is simply referred to as goat meat. Goat meat or chevon resembles the flavour and aroma profile of mutton or lamb and is therefore seen as an acceptable, often cheaper, substitute, although the meat from older animals often presents an additional off-flavour or aroma that is described to be goat-like (Schönfeldt *et al.,* 1993). The inherent toughness and goat-like flavours found in goat meat are deterrents that make many people who are not fully familiar with goat meat prejudiced against its consumption (Borgogno *et al*., 2015). As a result, goat meat is often consumed by groups with a lower income status. The sale of goat meat in South Africa does not follow conventional commercial slaughter channels through registered abattoirs. It was estimated in 2013 that South Africa produced about 35 000 tonnes of goat meat, with a large majority of the goats produced being marketed directly from the farm at 3-6 months of age, weighing between 20-40 kg live body weight. The largest consumers of goat meat in South Africa includes the ethnic South African population, who traditionally herd goats as part of their livestock, as well as the Hindu and Muslim populations who slaughter large quantities of goats to provide meat for their cultural and religious festivals (Van Niekerk & Casey, 1988).

Various studies have been performed in order to investigate whether Boer goat kids, as well as their crossbreeds, can be finished under feedlot conditions. It is, however, not a common practice in South Africa to finish goats in a feedlot, and goats are rather marketed directly from the veld soon after weaning. In order to improve the scale of production and maximize profits, it is advisable for farmers to finish young goats when the price of feeds is favourable. As goats are typically fed diets that have been formulated for finishing sheep in feedlots, it is necessary to determine what the nutritional requirements of goats are in order to formulate specific rations that optimize goat growth. Therefore, the focus of this study is to investigate the effect of feeding Boer goats finishing diets with different energy contents on the growth and meat production characteristics. As the ideal slaughter weight, and feedlot production period of Boer goats are not known, and goat kids are slaughtered anywhere between 20-40 kg live weight, it is important to determine an ideal slaughter weight that presents the best yield and fat cover through a process of serial slaughter after different periods under feedlot conditions. Identifying the age at which the point of inflection is reached on the growth curve of the Boer goats, will give an indication of the maximum age that Boer goats can be finished in a feedlot efficiently, and what the ideal slaughter weight of a Boer goat is to give an optimal carcass yield. These results will then be incorporated into a mathematical model which can then be used in the industry to predict and compare the feeding requirements, growth rates and ideal slaughter weight of Boer goats under feedlot conditions.

References

Animut, G., Goetsch A., Aiken G., Puchala R., Detweiler G., Krehbiel C., Merkel R., Sahlu T., Dawson L., and Johnson Z. 2006. Performance by goats and sheep consuming a concentrate-based diet subsequent to grazing grass/forb pastures at three stocking rates. Small Ruminant Research. 66: 92-101.

Bathaei, S., and Leroy P. 1996. Growth and mature weight of Mehraban Iranian fat-tailed sheep. Small Ruminant Research. 22: 155-162.

Borgogno, M., Corazzin M., Saccà E., Bovolenta S., and Piasentier E. 2015. Influence of familiarity with goat meat on liking and preference for capretto and chevon. Meat Science. 106: 69-77.

Butterfield, R. M. 1988. New concept of sheep growth. Department of Veterinary Anatomy, University of Sydney. Australia. pp 2-33.

Casey, N., and Van Niekerk W. 1988. The Boer goat. I. Origin, adaptability, performance testing, reproduction and milk production. Small Ruminant Research. 1: 291-30.

Casey, N. H., and Webb E. C. 2010. Managing goat production for meat quality. Small Ruminant Research. 89: 218-224.

Fernandes, M., de Resende K. T., Tedeschi L., Fernandes J., Silva H., Carstens G., Berchielli T., Teixeira I., and Akinaga L. 2007. Energy and protein requirements for maintenance and growth of Boer crossbred kids. Journal of Animal Science. 85: 1014-1023.

Kannan, G., Lee J., and Kouakou B. 2014. Chevon quality enhancement: Trends in pre- and post-slaughter techniques. Small Ruminant Research. 121: 80-88.

Lu, C., and Potchoiba M. 1990. Feed intake and weight gain of growing goats fed diets of various energy and protein levels. Journal of Animal Science. 68: 1751-1759.

Malan, S. 2000. The improved Boer goat. Small Ruminant Research. 36(2): 165-170.

Najari, S., Gaddoun A., Hamouda M. B., Djemali M., and Khaldi G. 2007. Growth model adjustment of local goat population under pastoral conditions in Tunisian arid zone. Journal of Agronomy. 6: 61.

Owen, J. E., and Norman G. A. 1977. Studies on the meat production characteristics of Botswana goats and sheep—Part II: General body composition, carcass measurements and joint composition. Meat Science. 1: 283-306.

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

Ryan, S., Unruh J., Corrigan M., Drouillard J., and Seyfert M. 2007. Effects of concentrate level on carcass traits of Boer crossbred goats. Small Ruminant Research. 73: 67-76.

Schönfeldt, H., Naude R., Bok W., Van Heerden S., Smit R., and Boshoff E. 1993. Flavour- and tenderness-related quality characteristics of goat and sheep meat. Meat Science. 34: 363-379.

Sheridan, R., Ferreira A., and Hoffman L. 2003. Production efficiency of South African Mutton Merino lambs and Boer goat kids receiving either a low or a high energy feedlot diet. Small Ruminant Research. 50: 75-82.

Steyn, J. 2010. Farming with Boer goats: A practical guide for Southern African conditions. First ed. Patriot Publishers. Potchefstroom, South Africa.

Thornley, J. H. M., and J. France. 2007. Mathematical models in agriculture: Quantitative methods for the plant, animal and ecological sciences. Second ed. CABI. United Kingdom.

Van Niekerk, W., and Casey N. 1988. The Boer goat. II. Growth, nutrient requirements, carcass and meat quality. Small Ruminant Research. 1: 355-368.

Webb, E. 2014. Goat meat production, composition, and quality. Animal Frontiers. 4: 33-37.

Chapter 2

Literature Review

2.1 Introduction

Traditionally, goats are reared by subsistence farmers to provide meat and milk for the household as well as for trade purposes, unlike on commercial farms where goats are regarded as a source of income and are usually integrated with other agricultural systems (Casey & Van Niekerk, 1988). The Boer goat was developed from indigenous goats found in South Africa, selecting for a meat breed with a good body conformation, high growth rates and high fertility. A meat goat breed such as the Boer goat must be robust for extensive conditions and be resistant or tolerant to endemic diseases while also maintaining high fertility and fecundity rates (Casey & Webb, 2010). The improved Boer goat is regarded as the standard to which all other meat goat breeds are compared (Steyn, 2010) and has been identified as a key to upgrading indigenous communal goats for improved meat production (Owen & Norman, 1977).

In South Africa, goat production is generally localized to arid and semi-arid regions, and has been seen to flourish in the thorn bush country of the Eastern Cape and the Karoo biomes (Campbell, 2003). Although the Boer goat is a very adaptable breed and is able to thrive in all climatic regions of South Africa (Casey & Van Niekerk, 1988). Goats are better at utilising low quality roughages than other livestock species and have different foraging habits (Casey & Van Niekerk, 1988), showing a preference for small trees and shrubs (Malan, 2000). Goats exhibit a selective feeding behaviour, which allows them to select highly digestible plant material (Morand-Fehr, 2005). They are able to overcome the effect of tannins found in leaves by having larger salivary glands and an efficient urea cycling capacity (Animut & Goetsch, 2008). Therefore goat farming is synonymous with extensive livestock production, although the Boer goat can adapt to intensive production (Fernandes *et al*., 2007).

The primary objectives for improving the efficiency of slaughter kid production include selecting for higher reproductive traits and more efficient lean growth to heavier body weights (Olson *et al*., 1976). With intensive management and feeding regimens, production cycles can be shortened and greater product yields can be achieved (Webb & Casey, 2010). Small ruminant production is of growing importance (Sayed, 2011) and many farmers opt to finish their lambs and slaughter kids in a feedlot rather than on pasture in order to increase their profit margins. This allows for slaughter kids to be finished to the desired slaughter weight at an earlier age, while at the same time making more pasture available for goat does as they do not have to compete for resources with their weaned young (Ryan *et al*., 2007). Information on the production characteristics and nutritional requirements of the South African Boer goat under intensive feeding conditions is limited. This is due to the market for goat meat in South Africa being underdeveloped due to the discrimination against goat meat as there is a greater preference for the more dominant beef and mutton. Chevon is largely consumed by the ethnic South African population who traditionally herd goats as part of their livestock, and by the Hindu and Muslim populations who generally do not consume beef or pork, due to cultural beliefs, and find meat from goats to be an acceptable substitute (Van Niekerk & Casey, 1988). The demand for goat meat is seen to peak around the times of cultural and religious festivals. Therefore, farmers rear goats to be market ready to be sold directly from the farm around the time of these cultural festivals. This can be optimised by making use of intensive finishing systems in order to ensure large numbers of market ready kids.

It was estimated that the production of goat meat in South Africa was about 35 000 tonnes in 2013, whilst about 143 000 tonnes of mutton was produced in the same year (FAOSTAT, 2015). The production and consumption of goat meat is clearly lower than that of mutton, though the values for goat production are merely estimates, as most goats are marketed through informal channels and not through commercial registered abattoirs. Although goat production in South Africa cannot compete with the higher mutton production, it still contributes high quality protein production for human consumption as well as to traditional livestock rearing and trade practices (Tshabalala *et al*., 2003). Goat carcasses are leaner than that of lamb and the meat also has a lower fat content (Casey & Van Niekerk, 1988; Glimp 1995). Fat partitioning differs in goats in that the majority of fat is deposited in adipose tissue surrounding the viscera and kidneys in the abdominal cavity, while low levels of fat are accreted in the subcutaneous and intramuscular depots (Sheridan *et al*., 2003c; Casey & Webb, 2010; Webb, 2014). The lack of subcutaneous fat on the goat carcass makes the muscles prone to cold shortening during rapid cooling of the carcass (Kannan *et al*., 2006). This cold shortening of the muscles effectively contributes to the perceived toughness which is associated with goat meat. The flavour of goat meat closely resembles that of mutton or lamb (Madruga *et al*., 2009), although it does have an additional characteristically strong goat-like flavour which becomes more intense with age of the animal (Schönfeldt *et al.,* 1993). Many people are prejudiced against this characteristic flavour, although the low fat content of chevon does make it an attractive protein source to health conscious groups (Lee *et al*., 2008), and is appreciated by those who are familiar with it (Borgogno *et al*., 2015).

The level of production depends heavily on the animal's level of nutrition, with energy being identified as a major factor (Sayed, 2011). Only a portion of the energy supplied in the diet is available to the animal and this net energy is used for maintenance of basal metabolic processes and minimal voluntary activity to sustain life and energy used for the production of body tissues (Tedeschi *et al*., 2010). In addition to this, dietary energy levels influence the utilization of different feed ingredients and thus the productivity or gain of the animal (Sayed, 2011). There is a principle that in ruminants the level of feed intake is regulated by the energy density of the diet (Lu & Potchoiba, 1990). Therefore, the dry matter intake of an animal will decrease with the intake of higher energy density diets. Lu and Potchoiba (1990) found that the dry matter intake of goat castrates is higher than that of female kids; therefore more rapid growth can be expected from castrates and intact males. Lu and Potchoiba (1990) also found that increasing the energy content of the diet, results in an increase in fat deposition in the animal. This is because excess nutrients, in this case energy, are either converted into fat, catabolised or excreted (Owens *et al*., 1993).

Animal growth is generally considered to be an increase in body mass due to cell multiplication and cell enlargement until mature body size is reached and is accompanied by changes in body conformation (Lawrie & Ledward 2006). The change in body weight can be plotted from birth to maturity, to describe the growth rate as well as show patterns or trends in growth (Bathaei & Leroy, 1996). Animal growth generally follows the sigmoidal growth curve of weight gain plotted against time (Owens *et al*., 1993). Generally the mature size of an animal is considered to be the point of maximum rate of muscle mass deposition and where the rate of fat deposition increases (Owens *et al*., 1993). The maximum growth rate of an animal is determined genetically, though factors such as nutrition and hormones can limit or increase growth rates (Owens *et al*., 1993). Voluntary feed intake above the maintenance requirements results in an increase in the rate of weight gain of an animal. As animals mature, this rate of gain tends to reach a plateau at the mature body weight (Owens *et al*., 1993) as the maintenance requirements increase with increased tissue mass. The growth of an animal can be described by mathematical equations, which condense data from changes in body weight over time into a few parameters that can be used to predict growth trends (Thornley & France, 2007). Analysis of such models can then be used to establish efficient feeding strategies, as well as determine an optimal slaughter age for profitable production that presents higher yields (Malhado *et al*., 2009).

2.2 Breed History

The precise origin of the improved Boer goat is vague. The ancestors of the breed could probably be traced to goats that were herded by migrating African tribes, along with an influence from Indian and European breeds by migration and trade practices of the early inhabitants of Southern Africa (Casey & Van Niekerk, 1988). Indigenous goats may have been used by early farmers to clear the bush for Angora and sheep production (Campbell, 2003).

During this time, farmers may have selected these goats for distinct characteristics and breeding improved goats with good body conformation, high fertility and growth rates (Casey & Van Niekerk, 1988).

The origins of the Boer goat as we know it today can be traced back to goat breeders from the Eastern Cape Province in South Africa, who selected traits from existing breeds found in South Africa to achieve the functional characteristics found in the improved Boer goat (Malan, 2000). The South African Boer goat Breeders Association was formed on the 4th of July 1959, and they defined the Boer goat as a goat with a red head with a blaze and a white body with red patches, a well pigmented skin, robust well rounded conformation, strong jaws, roman nose, relatively short legs and well fleshed hind quarters (Casey & Van Niekerk, 1988; Campbell, 2003). The Savannah white and Kalahari red goat breeds are other meat goat breeds that are recognized in South Africa. Both of these breeds were developed from indigenous breeds along the Boer goat breed to form breeds with similar production characteristics, but with solid white or red coats (Campbell, 2003). The Savannah white is popular for use in ritual slaughter practices and can thus be sold at a higher price to fit the demand, while the Kalahari red is described to be more tolerant and robust than Boer goats.

In 1970 the Boer goat breed was incorporated into the National Mutton Sheep and Goat Performance Testing Scheme, which is the only known testing scheme that makes provision for selecting goats for meat. Under the scheme the production performance of goats is estimated by the following techniques (Steyn, 2010; Casey & Van Niekerk, 1988):

Phase A - The mothering characteristics of the dam and growth of the kid until weaning.
Phase B - Post-weaning growth measured at various ages.
Phase C - Feed conversion efficiency and growth of male kids under controlled conditions.
Phase D - Growth of male kids on the farm.
Phase E - Qualitative and quantitative analysis of carcass components of the sire's progeny.

This has ensured that the Boer goat is recognized as a high quality meat goat breed capable of good growth, making it ideal to use as a terminal sire in crossbreeding systems for improving the growth rate of indigenous and dairy goat kids (Fernandes *et al.,* 2007).

2.3 Production Traits

2.3.1 Growth

A shift in domestic meat animal production has been to produce an animal with a high growth rate, large mature body weight with an optimal degree of fatness at an acceptable slaughter weight, to meet the demands of the consumer (Berg & Walters, 1983). The growth of an organism occurs in the form of an increase in size and shape, which is initially based upon hyperplasia, an increase in number of cells, and hypertrophy, an increase in cell size, followed by cellular differentiation (Owens et al., 1993; Kamalzadeh et al., 1998). In animal production, growth is characterised by the change in body weight per unit time (Bathei & Leroy, 1996), which is accompanied by a change in body conformation. Development of body tissues generally start at the head of the animal and spreads caudally along the trunk with a secondary wave that starts at the extremities and passes dorsally and meets the first wave at the junction of the loin and the last rib (Berg & Walters, 1983). This causes the shape of the body to change over time as the various tissues develop (Owens *et al.*, 1993). The development of muscle tissues results in an increase in muscle thickness relative to the dimensions of the skeleton, which defines the muscularity or conformation of the body (Purchas et al., 1991).

Net growth is the difference between the synthesis and degradation of body tissue (Owens *et al*., 1993). The main tissues of concern in animal growth are lean muscle mass and fat that is deposited as the animal gets older (Owens *et al*., 1993). The absolute weights of visceral organs increase with the age of the animal, while relative weights may differ (Owens *et al*., 1993). It is seen that organs and various tissues develop at different rates, which change as the animal grows towards maturity (Casey & Webb, 2010). During gestation the embryo grows in the uterus and forms a foetus. As the foetus grows, cells differentiate to form and develop the central nervous system and organ systems, as well as the basic skeletal and muscle structures (Bell et al., 2005). Muscles develop from myoblasts, which fuse to form multinucleated myotubes and then elongate to form mature muscle fibres that grow in length (Warris, 2010). After birth, the large muscles of the hind leg develop along with the improved locomotive capacity of the animal (Berg & Walters, 1983). Later as the young animal starts to ingest greater quantities of roughage and feed, the musculature of the abdominal wall increases in order to support the gut and its contents (Berg & Walters, 1983). Further change in the muscle weight distribution is minimal until maturity is passed (Berg & Walters, 1983) when secondary sexual characteristics develop. Body weight does not remain fixed at maturity, and fluctuations can be observed according to the animal’s nutritional as well as production status (Owens *et al*., 1993).

Maximum muscle mass will only be achieved at maturity (Owens *et al*., 1993). After the onset of maturity, fat deposition in adipose tissue will account for major changes in body weight. The rate at which maturity is reached follows the sigmoidal growth curve, where the maximum rate is reached at the point of inflection and then decreases as the animal nears its mature body weight due to physiological limits and increased maintenance costs (Webb & Casey, 2010). According to Malan (2000), the mature weight of a Boer goat buck ranges between 100-120 kg and 70-80 kg for a doe. The mature body size is determined genetically, although it can be altered by nutritional as well as by hormonal factors (Owens *et al.*, 1993). The mature body size of an animal is recognized to be the main factor that influences the growth rate of lean muscle (Glimp, 1995).

Pre-weaning weight gain occurs at a faster rate than post-weaning weight gain (Gebrelul *et al*., 1994), as the maintenance costs of the smaller animal are lower and therefore a greater proportion of the nutrients can be used for growth. It has been seen in crossbreeding systems, that kids sired by Boer goats had higher birth weights, while pre-weaning growth rates were related to milk production capacity of the dam breed (Goonewardene *et al*., 1998). Post weaning growth rates of Boer goat crosses have been observed to be higher (more than 150 g/day) than other pure goat breeds (Cameron *et al*., 2001). Pre-weaning growth is seen to be influenced by the genotype of the young animal, the environmental conditions it is exposed to, as well as the maternal characteristics of the dam (Burfening & Kress, 1993). Rapid growth early on in life, before weaning, is an important tool that can be used to reduce the cost of rearing an animal (Zhang *et al*., 2009). Nutrient restrictions, specifically protein, can result in a reduction of mature body size as well as increased fat accretion in the body (Owens *et al*., 1993).

Different species and breeds mature at different rates (Berg & Walters, 1983). Goats reach mature body size at a later chronological age than most sheep breeds, and thus grow at a slower rate (Casey & Webb, 2010). Smaller goat breeds exhibit slower growth, whilst large breeds grow at a rate of more than 200 g/day (Van Niekerk & Casey, 1988; Warmington & Kirton, 1990). Solaiman *et al*. (2012), reported growth rates of 120-150 g/day under feedlot conditions, while Sheridan *et al*. (2003a) found that the ADG of Boer goats varied between 150 and 220 g/day when fed diets that vary in energy content. Lower gains (90-100 g/day) were reported by Ryan *et al*. (2007) when Boer crossbred goats were supplied varying levels of concentrate. It can be seen that goats grow at higher rates when they are supplied high energy concentrate diets which exceed maintenance requirements and promote growth. Estimates on the maintenance requirements of growing Boer goats need to be established so that concentrate rations can be formulated that will allow goats to reach their full growth potential after weaning.

2.3.2 Gender effect

Male animals have higher growth rates than female or castrate animals, and also exhibit higher mature body weights (Bathaei & Leroy, 1996; Mourad & Anous, 1998). As the mature body weight of females is lower than males, females reach mature weight earlier than males. Goat bucks are heavier than does (Warmington & Kirton, 1990) with the mature weight of Boer bucks assumed to be 100-120 kg and that of Boer does between 70-80 kg (Malan, 2000). The difference in tissue maturation rates accounts for the body shape differences exhibited by the different sexes (Berg & Walters, 1983; Owens *et al*., 1993). Before weaning, males and females exhibit similar growth rates but from the onset of puberty, the musculature of the animal adapts for its survival and reproduction characteristics (Berg & Walters, 1983). Male animals will exhibit a greater level of muscularity than females and castrates, and will have more developed necks and shoulders, whereas females will have more developed hindquarters (Goetsch *et al*., 2011). Females tend to accrete higher levels of fat, while castrates fall midway in between intact males and females in terms of growth rate and carcass composition (Hogg *et al*., 1992). Animals that have excessive muscling are often seen to be less tolerant to environmental stress and this phenomenon is often also associated with reproductive problems in females (Berg & Walters, 1983).

2.3.3 Birth status

The birth type or status refers to the number of young that a dam produces at kidding. The number of young born in a litter can vary from a single offspring to multiples as is the case with twins and triplets. The age of the dam plays an important role in the growth of the young animals during the pre-weaning period. The parity of the dam has an effect on the litter size (Zhang *et al.,* 2009), as younger females generally give birth to a single offspring that have lower birth weights, while the litter size increases with parity number (Jiménez-Badillo *et al*., 2009). The dam’s level of milk production also increases with age (Bathaei & Leroy, 1996; Mourad & Anous, 1998), therefore as it gets older, it is able to produce enough milk for more than one offspring. These characteristics can be related to the increase in the dam’s body weight as it gets older, and therefore it has greater reserves in order to sustain multiple young (Luo *et al*., 2000). Generally ewes and does are mated for the first time before they reach their mature body weight and are still growing during their first gestation, thus they do not always contain sufficient body reserves to produce multiple young. As the dam’s age and body reserves increase, so does the birth and weaning weights of the offspring due to a greater availability of resources to the foetus pre-partum and higher milk production during lactation (Jiménez-Badillo *et al*., 2009).

Single born kids or lambs will have higher birth weights than that of twins or triplets, as they do not have to compete for space and nutrients in the uterus (Jiménez-Badillo *et al*., 2009; Mourad & Anous, 1998). The suckling period is important as pre-weaning growth is relatively faster than growth after the animal has been weaned. Ruminants have the ability to undergo compensatory growth, which is when there is an increase in weight gain during re-alimentation, following a period of limiting nutrition (Owens *et al*., 1993). This is often seen when young animals start to ingest greater quantities of roughage or creep feed, and is less dependent on milk from the dam where it has to compete with its siblings.

2.3.4 Production system

Goats are reared by commercial and subsistence farmers for meat, milk and leather production. Breeds such as Saanen and British Alpine goats are specifically selected for dairy goat production due to their higher milk production capabilities, while a range of breeds contribute to goat meat production, from the smaller indigenous breeds to the improved Boer goat or Kalahari red, with the skins being used for cashmere and leather after slaughter. The productivity of a goat farming system depends on the genotype used, the environmental factors that it is exposed to, as well as animal husbandry practices implemented (Owen & Norman, 1977). Meat goat production can be divided into capretto production, where suckling or freshly weaned kids are slaughtered resulting in a carcass weighing between 6-12 kg, which is preferred by many European cultures (Dubeuf *et al*., 2004; Mohrand-Fehr *et al*., 2004; Borgogno *et al.,* 2015), and chevon production where a larger carcass is required and goats are slaughtered between four and eight months of age. In South Africa, goats are typically marketed directly from the farm and the goat meat industry is focussed around ethic and cultural demands, which experiences peaks around holidays and religious festivals. The key production parameters that influence meat goat production include the reproductive rate, kid mortality rate, post weaning growth rate and carcass merit (Alexandre & Mandonnet, 2005).

The reproduction performance has been regarded as an indication of how compatible or adapted an animal is to an environment (Casey & Van Niekerk, 1988). Adaption can be defined as the ability of an animal to adjust its behaviour, nutritional preferences, physiology and metabolism in order to maintain its welfare and ensure its survival (Alexandre & Mandonnet, 2005). The improved Boer goat is able to adapt to most climatic regions and shows resistance to internal parasites and diseases such as blue tongue, prussic acid poisoning and enterotoxaemia (Malan, 2000). However, disease and parasite control should still be applied at strategic times before breeding and weaning to ensure welfare and high levels of production (Alexandre & Mandonnet, 2005). Boer goats are not restricted to seasonal breeding (Malan, 2000) and kidding can take place throughout the year, depending on the system used. In extensive production systems, a single buck can be used to breed with 35 does in a mass mating system or in a continuous mating system, a single buck can be used per 50 does (Malan, 2000). With good nutrition and management, does can be mated twice a year or three times in two years in order to increase kid production (Casey & Van Niekerk, 1988). The gestation period of the Boer goat is about 150 days and conception rates of about 90% can be expected (Malan, 2000). The Boer goat is renowned for its high fertility rate, with a kidding rate of approximately 180% (Malan, 2000) and a higher incidence of twins and triplets than of single births can be expected (Aucamp & Venter, 1981). The milk production of Boer goat does can vary between 1.5-2.5 kg/day depending on whether the doe has single or multiple young that it has to sustain until weaning (Casey & Van Niekerk, 1988). Boer goats have a high fecundity and present a weaning rate of 149% when kids are weaned from their dams at three to four months of age with an average weight of 29 kg (Malan, 2000).

For efficient production, goat herds should be managed so that kidding occurs when feed or pasture resources are most plentiful. The timing of kidding should also match when the nutritional reserves remain available until after the kids have been weaned at three months (Alexandre & Mandonnet, 2005). This allows sufficient nutrition for the lactating does so that they are able to regain body condition soon after weaning, while at the same time providing nutrition to growing goat kids before they are marketed soon after weaning. Supplementation and managing the stocking rates may be necessary at different times of the year depending on the quality and abundance of pasture resources (Alexandre & Mandonnet, 2005). Goats prefer to browse and consume a wider range of plant species, and thus may be reared along with cattle and sheep as their grazing habits do not overlap (du Plessis *et al*., 2004; Morand-Fehr, 2005; Animut & Goetsch, 2008). Care should be taken during continuous grazing, as the selective feeding behaviour of goats may lead to pasture degradation (Animut & Goetsch, 2008). Pastures may be divided in order to separate animals in different groups as well as implement rotational grazing strategies, though one must consider that goats are intelligent and will often break through the fencing. Therefore camps and handling facilities should be designed with tight fencing such that the goats are not able to jump over or climb through.

2.3.5 Feeding and Nutrition

Goats have a greater ability to survive and produce under harsh conditions compared to other livestock species, which may be as a result of their feeding behaviour. Goats exhibit high selective behaviour and ingest the parts of the plant that have a higher digestibility and protein content (Morand-Fehr, 2005). Compared to cattle and sheep, goats consume and select their diets from a wider variety of plant species (Animut & Goetsch, 2008). Unlike sheep and cattle, goats prefer to browse from shrubs and trees. Their narrow deep mouth with mobile lips and tongues makes them suited for browsing and selective harvesting (Animut & Goetsch, 2008). Though goats are not obligate browsers (Morand-Fehr, 2005), Van Niekerk and Casey (1988) stated that Boer goats tend to consume diets that consist of about 82% browse material and 18% grass. These proportions may differ according to the sward availability and quality, but goats will still show a greater preference towards forbs rather than grass (Animut & Goetsch, 2008). The composition of vegetation selected by goats gives a better reflection of the plant species available on the pasture that can be consumed, compared to simply grasses alone (Goetsch *et al*., 2011). As goats do not have to compete with other livestock species for grazing, they may be herded together to improve the production capacity of the pasture while also controlling bush encroachment (Van Niekerk & Casey, 1988). The stocking rate of the pasture should be monitored and adjusted according to changes in the vegetation mass and species composition, as well as the level of animal production (Goetsch *et al*., 2011). This can be aided through strategic supplementation at specific stages, which will improve growth and production rates (Bathaei & Leroy, 1996).

The digestive system of goats, like other ruminants, entails a stomach which is divided into four compartments, namely the rumen, reticulum, omasum and abomasum. When goats ingest feed and water, it passes into the rumen, which contains various microorganisms that partially ferment the organic material. This gives the animal the ability to ingest low quality fodder and utilize nutrients derived from microbial fermentation. Carbohydrates, which include simple sugars as well as cellulose, are fermented in the rumen to form volatile fatty acids that are absorbed into the body through the rumen wall, as well as methane and carbon dioxide gasses which are released during eructation (Macdonald *et al*., 2011). The principal volatile fatty acids are acetate, butyrate and propionate and serve as the major energy sources in the animal. The consumption of diets high in fibre content results in an increase in the proportion of acetate produced, while consuming concentrate diets increase the proportion of propionate, as well as an increase in lactate in the rumen, with the increase in starch fermentation (Macdonald *et al*., 2011). The ability of an animal to grow and produce is dependent on the amount of available energy contained in its diet (Van Niekerk *et al*., 1988). The basal metabolic rate refers to the amount of energy required to maintain life processes of a fasting animal, as well as the energy that is lost as heat (Fernandes *et al*., 2007; Tedeschi *et al*., 2010). When the energy intake of an animal exceeds these maintenance requirements, excess energy will be used for production or stored as fat (Owens *et al*., 1993). Dietary fats in the rumen are hydrolysed into an alcohol and fatty acid chains. Unsaturated fatty acids are hydrogenated and double bonds are broken to form saturated fatty acids (Macdonald *et al*., 2011). Short chain fatty acids may be absorbed into the blood through the rumen wall, whilst larger chains pass through to the abomasum and small intestine for further digestion and absorption. Lipids can be protected from hydrogenation in the rumen through saponification and can then only be digested and absorbed in the small intestine and stored in adipose tissues. These body reserves can then be mobilized when the requirements of the goat are higher than what can be supplied in the diet, as is the case when feed is limited and during gestation or lactation (Morand-Fehr, 2005). Grain based concentrate diets are high in energy, although feeding such rations to goats without prior adaption in order to alter the rumen microbial profile, will lead to rumen acidification (Lee *et al*., 2009). This acidification of the rumen environment will decrease fermentation and nutrient absorption as well as deteriorate the health of the animal. Goats show a higher sensitivity towards concentrate diets (Morand-Fehr, 2005) and perform better on diets that have a higher roughage content (Sheridan et al., 2003a).

Compared to other ruminants, lower quality roughage diets are retained longer in the gastrointestinal tracts of goats (Morand-Fehr, 2005) to increase the digestive efficiency. Animut & Goetsch (2011) reported that goats had proportionally smaller reticulo-rumens, which would cause a rapid passage rate of feed to the small intestine, while Morand-Fehr (2005) stated that goats have larger rumens. This contradicting evidence may suggest that other factors may be involved in fibre digestion of the goat. Protein nutrition is unique in ruminants, as the majority of amino acids that the animal absorbs, are derived from rumen microorganisms. They are also able to recycle nitrogen through their saliva and improve the digestion of forages in the rumen. Microbes in the rumen degrade protein in the diet into amino acids, organic acids and ammonia, while non-protein nitrogen sources such as urea are also converted into ammonia (Macdonald *et al*., 2011). Microorganisms in the rumen are able to synthesize amino acids using hydrocarbon chains from organic acids and ammonia; this is then used to produce microbial proteins. Microorganisms containing microbial protein pass along with feed as the digesta passes from the rumen to the other compartments and the small intestine, where it can be digested by host enzymes and absorbed. Ammonia accumulates in the rumen as proteins are degraded, while excess ammonia is absorbed through the rumen wall into the blood and transported to the liver where it is converted into urea, which can be recycled through the rumen wall or animal’s saliva, or it may be excreted in the urine (Macdonald *et al*., 2011). Goats have a greater capacity for recycling nitrogen (Morand-Fehr *et al.,* 2004; Morand Fehr 2005; Animut & Goetsch, 2008), which may be a mechanism that helps them to survive in regions that may not be suited for other animals. Goats browse leaves from bushes that contain tannins, which bind to proteins and lower the digestibility. Salivary glands in goats are larger than in sheep, and so goats produce greater volumes of saliva containing mucus, which lowers the capacity of the tannins to bind to proteins and lower their digestibility (Animut & Goetsch, 2008). The greater saliva volume also acts to dilute the bitter taste associated with tannins, which would influence the palatability and intake, as well as supply additional urea to the rumen.

Generally, the growth performance of goats is not improved by high dietary concentrate levels (Goetsch *et al*., 2011), although it does influence the dry matter intake. The physical form as well as particle size influences the time spent eating and ruminating and thus the level of intake (Gipson *et al*., 2007). The level of intake also varies with the body size of the goat, therefore as the goat grows it consumes more feed (Lu & Potchoiba, 1990; Warmington & Kirton, 1990). During ingestion the rumen fills, stimulating mechanical and stretch receptors which notify the brain to decrease intake, whilst chemoreceptors detect the levels of fermentation products in the blood and rumen walls and use feedback signals to adjust intake accordingly (Baumont *et al*., 2000). The energy content, as well as the protein content, has been seen to influence the dry matter intake as well as feeding efficiency (Sheridan *et al*., 2003a; Kannan *et al*., 2006; Wang *et al*., 2014). The dry matter intake varies in a curvilinear fashion, which decreases with an increase in dietary energy, while an increase in the crude protein content of a feed results in a linear increase in intake (Lu & Potchoiba, 2006). While the dry matter intake decreases with higher dietary energy levels, Sheridan *et al*. (2003a) found that lower energy diets, with greater roughage contents, had a greater digestibility due to longer retention times. Feeding and growth trials can be used to determine the amount of energy that is required by goats for growth, and to what extent goats are able to adjust their level of intake in response to the energy content. Data from such trials could then be used to develop regressions with age and body weight of the animal in order to predict feed intake and the ideal dietary energy content.

2.4 Feedlot Production

2.4.1 Background

Feedlotting can be summarised as the practice of purchasing young, weaner animals and improving their market value through intensive feeding and management to achieve increased, high quality meat production. It is used to ensure a consistent supply of quality meat that meets market specifications for weight and degree of fatness (Duddy *et al*., 2007). The feeding of high concentrate diets to young animals typically results in a higher quality carcass (Ryan *et al*., 2007).The practice of finishing animals in a feedlot reduces the production time of an animal, thus allowing carcasses from younger animals to be available for the market earlier (da Cunha Leme *et al*., 2013). Weaning animals and finishing them on concentrate diets is also advantageous to the dam herd, as it decreases the stocking pressures on the pasture and allows for greater quantities of grazing available to the dams (Ryan *et al*., 2007). The efficiency of production focuses mostly on intensive finishing systems, as well as the effects that animal handling and welfare have on the product quality (Webb & Casey, 2010).

Before opting to finish animals, one must consider the profitability of a feedlot. This is principally governed by the price of a kilogram meat produced and the price of feed consumed by the animal. The profit margin per individual animal is generally low, therefore the economics of scale are required to make it a competitive enterprise, with profits being shared from a large stock of animals. Profitability depends on accurate record keeping and knowledge of price tendencies, proper preparation of goats before entering the feedlot by inoculating, deworming and adapting them. Production factors that influence the profitability of the operation include the initial weight of the animal when it enters the feedlot and the number of days spent in the feedlot in order to reach the target weight, which is related to the feed conversion efficiency and growth rate.

2.4.2 Feedlot Nutrition

The key role of nutrition in feedlot finishing is to supply sufficient quantities of nutrients to the animal to ensure maximal growth while maintaining welfare and health standards. The addition of supplementary or concentrated complete feeds can result in improved growth rates and animals can attain the desired body weight at a younger age (Bathaei & Leroy, 1996). To achieve high weight gains, grain based concentrates are fed rather than forage alone (Lee *et al*., 2008), although when the costs of feeds are high and forage is plentiful, it can be used to finish animals, though the growth rate will be much lower than when using concentrate rations. Generally the growth of goats is not greatly improved by feeding high concentrate levels (Goetsch *et al*., 2011). Sheridan *et al*. (2003a) also found that goats are more efficient at utilising roughage in the ration compared to sheep. The effects of feeding common feedstuffs such as cereal grains and oilseed meals are similar to those seen in sheep and cattle (Goetsch *et al*., 2011). However, goats are better at utilising roughage and may be more prone to develop ruminal acidosis.

When a ruminant is introduced to a feedlot diet, the rapid fermentation of the high grain and starch content in the ration affects the microorganism profile of the gastrointestinal tract and results in a build-up of lactic acid in the rumen (Lee *et al*., 2009). This accumulation of lactic acid reduces the pH of the rumen, causing ruminal acidosis which causes discomfort to the animal and results in a decrease in dry matter intake, depression and diarrhoea. This can be prevented by gradually adapting the rumen microorganism population to develop a stable population that is able to metabolise lactic acid (Bowen *et al*., 2006). This can be done by implementing a step up program where the animal is accustomed from a forage based diet to the finisher diet by increasing the proportion of concentrate supplied in the ration daily until only concentrate is supplied and the animal does not show any signs of acidosis. This takes place over a period of 10-14 days when the animals are introduced to the feedlot. Generally in formulating a feedlot ration, sufficient buffers (such as feed lime or bicarbonate of soda) should be included in order to prevent the development of acidosis (Brand, T. S., Pers. Comm.). Some nutritionists also include small quantities of ionophores and antibiotics, such as virginiamycin, in the feed formulation to suppress lactic acid bacteria and so facilitate adaption (Bowen *et al*., 2006). The physical form of the ration is important as it influences the ruminating behaviour; larger particles require a greater amount of chewing activity, thereby stimulating saliva secretion which acts as a buffer in the rumen. Smaller particles are also fermented more readily in the rumen and lead to acidosis. Roughage should make up at least 30% of the diet in order to ensure efficient rumen function (Duddy *et al*., 2007). Early exposure of young animals to grain feeds prepares them and makes it easier for them to accept feedlot diets after they have been weaned (Bowen *et al*., 2006). Therefore by supplementing kids and lambs with creep feed while they are still suckling not only improves pre-weaning growth (Goetsch *et al*., 2011; Yiakoulaki *et al*., 2014), but also makes it easier to adapt the animals to a concentrate diet. These aspects of adapting an animal to a feedlot diet should be carefully considered as to how it may be applied to different feeding regimes.

There are different feeding systems that can be used in a feedlot operation. These include the use of total mixed rations, pelleted concentrate diets or a combination of grain provided with forage separately (Bowen *et al*., 2006). For improved feedlot performance it is advisable to pellet the feeds. By pelleting the feeds, one eliminates the selective feeding behaviour that is greatly exhibited in goats (Goetsch *et al*., 2011) and reduces the amount of wastage. By eliminating feed selection, the time spent feeding is reduced, while allowing a greater level of dry matter intake (Pi *et al*., 2005; Gipson *et al*., 2007). Although, pelleting does increase the costs of producing the feed (Gipson *et al*., 2007). In a feedlot, feed intake is considered to be the driving force behind production. Rakes *et al*. (1961) found that daily feed intake and weight gain in lambs could be increased by feeding small quantities multiple times a day compared to providing a single meal. This can also be applied to using social facilitation of other individuals' feeding or the movement of a feedlot operator around the feed bunk to stimulate the animal to feed (da Cunha Leme *et al*., 2013), thus increased stimulation will lead to greater feed intake. Water intake is also correlated to feed intake, however the Boer goat has been adapted to conserve water and so feed intake is less dependent on the amount of water consumed (Ferreira *et al*., 2002).

Meeting the energy, protein, vitamin and mineral requirements are essential in ensuring optimal goat growth. The nutrient requirements of growing meat goats are outlined in Table 2.1. Values for the nutrient requirements are usually lower than the true requirements, especially in the case of Boer goats which have a larger body size compared to other goats and therefore have greater maintenance demands.

Table 2.1 Daily nutrient requirements for growing goats with a live weight between 30 and 50 kg, as derived from NRC (2007).

Body weight (kg)	**Dry matter intake (kg)***	**Metabolisable energy intake (MJ/ kg feed)**	**Crude protein intake (g)**	**Calcium intake (g)**	**Phosphorous intake (g)**
Maintenance requirements (Including stable feeding conditions and minimal activity)					
30	0.65	5.44	51	2	1.4
50	0.95	8.00	75	3	2.1
Additional requirements for growth- 100 g/day for all goat sizes					
	0.36	3.01	28	1	0.7
Additional requirements for growth- 150 g/day for all goat sizes					
	0.54	4.52	42	2	1.4

* Calculated for a feed with an energy content of 8.37 MJ ME/ kg feed.

The level of production of an animal depends heavily on the animal's level of nutrition, with energy being a major contributing factor (Sayed, 2011). The maintenance requirement is the minimal amount of energy required to maintain life processes of an animal in the fasting state (Tedeschi *et al*., 2010). Energy in the diet that is supplied above these levels will be used for growth and production. Excess energy in the diet will either be converted into fat, catabolised during exercise or excreted (Owens *et al*., 1993). Dietary energy is important as it also influences the efficiency of how other feed components are utilised and thus the productivity of the animal (Sayed, 2011). The dry matter intake in goats is also influenced by dietary energy content in a curvilinear fashion (Lu & Potchoiba, 1990), and decreases with an increase in energy content (Kannan *et al*., 2006). Proteins are principle constituents in the body and are continuously synthesized and replaced (NRC, 2007), and animals require a continuous supply of amino acids, which are the building blocks of proteins, in their diets. The crude protein content of the diet affects the rate of growth as well as the feed conversion efficiency (Lu & Potchoiba, 1990; Wang *et al*., 2014). Ruminants are less dependent on the quality and composition of proteins in the diets, as rumen microbes synthesize their own proteins which can be digested by the animal (Macdonald *et al*., 2011). However, certain proteins that have been processed, reduce the degradability of the proteins in the rumen, which allows more to be digested in the small intestine. These protein sources include oilseed meals that have undergone heat processing which alters the shape of the protein. Urea can be used as a non-protein nitrogen source for rumen microorganisms, although to prevent the risk of urea poisoning, it should not constitute more than 15-25% of the total crude protein content (Stanton & Levalley, 2006). When formulating the finisher diet, protein and energy sources should be compared in order to make the ration as cost effective as possible while still considering maximum inclusion levels (Stanton & Levalley, 2006).

Calcium and phosphorous are the major minerals that should be considered in goat nutrition as they are involved in tissue and bone development. The effects of other minerals are not well understood, although understanding about mineral interactions and toxicities is needed (NRC, 2007). The ratio of calcium to phosphorous is critical and should not exceed the ratio of 2 or 2.5:1 to avoid problems with mineral absorption and the risk of developing urinary calculi (Stanton & Levalley, 2006). Ammonium chloride or sulphate may be included in the diet to prevent the formation of urinary calculi. Most cereal grains are low in sodium and calcium, and salt and ground feed lime may be added to the diet at an inclusion level of 1-1.5% (Duddy *et al*., 2007). Vitamins A, D and E are important in growing goats, and should be supplemented in the feed (NRC, 2007). Trace minerals should be provided according to the requirements outlined by the NRC (2007).

2.4.3 Feedlot management

Feedlot finishing of animals involves removing animals from open pastures and introducing them to smaller pens and enclosures in order to reduce the amount of movement and time spent searching for food. The stocking density and the size of the camp are important factors that influence the behaviour in a feedlot. Ruminants are gregarious animals and require social interaction, therefore isolating individuals from the group would result in the animal becoming stressed (da Cunha Leme *et al*., 2013). When the stocking density is increased, the competition for feed, space and water increases, resulting in aggression as the dominance ranks are established, while lower stocking densities in large camps are also not desired, as it increases the energy expenditure of the animals as they move around more (da Cunha Leme *et al*., 2013). When designing a feedlot, one should ensure that there is sufficient feeding and drinking space, as well as space for animals to rest and ruminate and allowance should be made for animals to present normal social behaviour. Variation in weight exists between individuals and therefore grouping is essential in order to prevent smaller individuals from being dominated and denied feed (Bowen *et al*., 2006). It also allows for the feeding regime to be adapted for groups with uniform weights. It is important that care should be taken when handling or loading animals, as these processes are stressful and increase the risks of injury and mortality (Minka *et al*., 2009). An understanding of the animal's natural behaviour as well as indicators of discomfort, such as freezing, struggling, backing away, attempting to escape and vocalisation can lead to improved management strategies that will benefit animal health and production (Minka *et al*., 2009).

The daily duties of the feedlot operator involve the inspection of animals for the incidence of diseases, as animals in a feedlot are more prone to develop metabolic disorders, which results in morbidity and mortality and so affect production and profit margins (Smith, 1998). Lactic acidosis is a metabolic disorder associated with rapid starch fermentation in the rumen when high concentrate levels are fed. The occurrence of lactic acidosis can be characterised by feed rejection as well as depression and may result in lameness (Jensen & Swift, 1982). It may be prevented by gradually adapting the rumen microorganisms of animals from high roughage, low concentrate diets to a high concentrate, low roughage diet (Bowen *et al*., 2006). Other disorders that are associated with feeding high concentrate based diets include the occurrence of rectal prolapse and the formation of urinary calculi caused by a mineral imbalance in the diet, resulting in the blockage of the urinary tract (Jensen & Swift, 1982). Other diseases that are commonly found in feedlot systems include eye disorders, foot rot, pneumonia, enterotoxemia and coccidiosis (Jensen & Swift, 1982). Coccidiosis is characterised by the occurrence of hemorrhagic diarrhoea, depression and weight loss (Jensen & Swift, 1982) and is common with high stocking densities and wet weather (Taylor, 2012). Some feedlot diets may contain coccidiostats in order to rid the animal of the bacteria that cause the disease. Pneumonia or pasteurellosis commonly affects individuals within three weeks after shipping and transport and results in sudden death (Jensen & Swift, 1982). The weight gains for healthy animals are greater than that of sick animals and therefore it is beneficial to implement vaccination programs (Walker *et al*., 2007).

When selecting animals for the feedlot one should consider that live weight is an important factor that will influence production, and that animals for the feedlot should be free of disease (Duddy *et al*., 2007). On arrival at the feedlot, animals should be injected with a broad spectrum vaccine that is active against pasteurella and clostridia bacteria (Jensen & Swift, 1982). Animals should also be drenched against internal parasites and it is advisable to inject animals with a multivitamin (Bowen *et al*., 2006). Animals should be grouped in pens according to gender, live weight and size to ensure uniform feeding and growth while limiting bullying and aggressive behaviour (Duddy *et al*., 2007). Feedlot animals should receive a constant supply of feed to ensure optimal growth and good feeding efficiency. Animals do present improved feeding behaviour if they have been accustomed to receiving grain based rations (Walker *et al*., 2007). Therefore, good adaptation in the feedlot is of the utmost importance. Slow growers or individuals that do not adapt well to feedlot conditions may be identified through regular weighing and can be fed separately (Bowen *et al*., 2006).

2.5 Growth Models

Animal growth can be characterised as the change in body weight per unit time (Bathaei & Leroy, 1996). Plotting the growth of an animal from birth to maturity against time will produce a sigmoidal or S-shaped curve (Owens *et al*., 1993). This curve is characterised by a brief lag phase followed by a period of rapid growth until maturity is reached, where the curve tends to reach a plateau and level out. Such growth curves can be used in conjunction with mathematical models fitted to the curve to estimate and predict trends, compare the effects of various treatments and interactions between subpopulations and treatments on the growth rate and identify animals whose performance deviate from predicted trends (Bathaei & Leroy, 1996; Malhado *et al.,* 2009).

A mathematical model is an equation or set of equations that can be used to represent the trends of a biological system (Thornley & France, 2007). An advantage of using a model to describe animal growth is that it condenses the data collected from weighing at several different points in the animal's lifetime into a few parameters that have biological meaning (Bathaei & Leroy, 1996). Analysis of such growth models can be helpful in establishing efficient feeding strategies, as well as determine an optimal slaughter age (Malhado *et al.,* 2009). A growth function can be derived in order to present the growth rate as the first derivative. The average daily gain or growth rate, may be used as an independent variable with the change in body weight, along with regression analysis to indicate energy retention with a high accuracy (Luo *et al.,* 2004). Through proper understanding of a growth model, it can be used to reduce production expenses by optimising available resources at specific periods in the animal's lifetime (Najari *et al.,* 2007). Many growth models rely on the assumption that internal and environmental factors remain constant when in fact, natural processes during the animal's lifetime, such as weaning, the onset of puberty and sexual maturity are affected by environmental factors (Kamalzadeh *et al*., 1998).

Many different models can be used to represent animal growth, with linear relationships being easier to interpret than curvilinear functions which are difficult to fit (Roux, 1976).

Functions that are commonly used to model small stock growth include three parameter functions such as the Brody, Von Bertalanffy, Gompertz and Logistic models as well as the four parameter Richards model. The basic forms of these equations can be seen in Table 2.2. There is debate about which model best represents animal growth, when different functions have different applications and accuracies under certain conditions. Da Silva *et al.* (2012) observed that the Brody, Gompertz and Logistic models could be applied to the growth curves of Santa Ines sheep, with high accuracy. Laird *et al*. (1965) stated that the Gompertz model is ideally suited for describing the growth curve of finisher animals, since meat from livestock species generally comes from animals that do not attain mature body weight.

Table 2.2: List of growth functions with corresponding equations used to model (Thornley and France, 2007)

Model	Equation
Brody	$Y = a\left(1 - be^{-kt}\right) + \varepsilon$
Richards	$Y = a(1 - be^{-kt})^{-m} + \varepsilon$
Von Bertalanffy	$Y = a(1 - be^{-kt})^{3} + \varepsilon$
Gompertz	$Y = ae^{-e^{-b(t-k)}} + \varepsilon$
Logistic	$Y = a(1 + e^{-kt})^{-m} + \varepsilon$

The variables found in a model function correspond to actual observable quantities or measurements (Thornley & France, 2007). The dependant variable *Y* represents the body weight at time *t* and *a* is the asymptotic or mature weight of the animal (Table 2.2). After the period of rapid growth, the body weight of an animal tends to stabilise around an estimated asymptotic weight (Najari *et al*., 2007). The apparent mature weight for Boer goats is assumed to be 100-120 kg for bucks and 70-80 kg for does (Malan, 2000). Furthermore *b* represents the integration constant which is associated with the birth weight and describes the proportion of live weight that an animal must gain to achieve mature weight (Bathaei & Leroy, 1996). At birth, when *t=0,* the constant is one and as the animal gets older the value decreases as the proportion of weight that the animal must gain decreases. Other constants in growth functions include *k* which represents the maturation rate and *m* the point of inflection.

After a model has been proposed to a specific system, it is tested in order to identify and rectify possible shortcomings in its predictive performance and therefore can allow for accurate predictions and confirm reliability of a model to achieve its stated objectives (Finlayson *et al*., 1995). The Aikake Information Criterion (AIC) is commonly used as a measure of the relative quality of a statistical model for a given set of data, dealing with the goodness of fit and complexity of the model (Thornley & France, 2007). When dealing with a growth model, some of the parameters should be interpreted with care in order to understand the weight evolution in response to varying environmental conditions (Najari *et al*., 2007). Bathaei & Leroy (1996) found that values for the *a*, *b* and *k* parameters in growth models developed for sheep showed variation with gender, single or multiple births and nutritional status. The parameters cannot be considered separately as all the parameters share an important relationship with each other to produce the model (Bathaei & Leroy, 1996). A negative phenotypic correlation between the asymptotic weight and maturation rates indicates that early maturing animals are less likely to attain as large mature weights as animals that mature at a slower rate later in life (Bathaei & Leroy, 1996). This can be seen in the case where female animals reach their mature body weight earlier than males, bearing in mind that the mature weight of a male is greater than that of a female. Positive correlations between the integration constant and maturation rates may suggest that light animals at weaning with a high *b* value, are likely to have higher growth rates at a young age than individuals that have high weaning weights. This can be observed when animals undergo compensatory growth following a period of restricted nutrition before weaning (Kamalzadeh *et al*., 1998). A final interaction to consider is the negative interaction between asymptotic weight and the integration constant, which indicates that animals with lower pre-weaning weights will also tend to have lower mature weights than heavier individuals.

Generally, animals used for meat production are slaughtered before they reach the inflection point on the growth curve, while their growth is still in the linear phase (Bathaei & Leroy, 1996). Feeding animals during this phase will be more efficient, as the maintenance requirements of the animal are relatively low and excess nutrients supplied in the diet are utilised for growth (Lawrence *et al*., 2012). As the animal reaches maturity, the larger body size along with higher levels of body fat increase its maintenance requirements, resulting in decreased growth and less efficient feeding. Therefore, in order to maintain the efficiency of production while ensuring optimal meat yields, animals are typically slaughtered just before they reach the point of inflection in their growth.

2.6 Goat Meat

Meat quality may be defined as the eating quality of meat which comprises of palatability, wholesomeness as well as being free of pathogens and toxins (Casey & Webb, 2010). Goat production can vary according to the meat preferences of the target population. Capretto, which is the meat from suckling or freshly weaned kids with a carcass weight ranging from 6-

12 kg, has a fine texture and its fresh pink colour is popular in certain regions of Europe (Dubeuf *et al*., 2004; Borgogno *et al*., 2015). Chevon is the meat derived from goats that have passed the pre-ruminant stage, with carcasses weighing more than 13 kg. Like lamb, chevon is the meat derived from young goats that have not gone through puberty and attained maturity. As with lamb classification systems, chevon is therefore classed as the meat from goats that have less than two permanent incisors. Meat from older goats which is parallel to mutton in sheep is simply referred to as goat meat. Chevon is considered to be very lean with a characteristic flavour, which is similar to that of lamb or mutton (Madruga *et al*., 2011). Meat from older goats often presents a goat-like flavour which is discriminated against by many cultures due to its intensity (Mohrand-Fehr *et al*., 2004). In South Africa, goat meat is mostly consumed by the ethnic African and Indian communities, with seasonal peaks in the sale of goat meat around religious holidays (Dubeuf *et al*., 2004). It is estimated that South Africa produced about 35 000 tonnes of goat meat in 2013, while 143 000 tonnes of mutton was produced in the same year (FAOSTAT, 2015). This shows that in South Africa, chevon is not as popular as mutton or lamb production. This value is also an estimate, as the majority of goats produced are not slaughtered at registered abattoirs and do not follow conventional meat trade systems (Tshabalala *et al*., 2003). The sale of goat meat mostly occurs through informal channels and is rarely commercially available from urban butchers, although when it is available, goat meat is priced lower than beef or mutton (Sheridan *et al*., 2003b). Goat meat is considered unpopular, especially in urban areas, and therefore many have difficulty in preparing and cooking goat meat, in order to overcome the strong characteristic flavour and toughness that is associated with it (Dubeuf *et al*., 2004).

Goats generally have a lower carcass yield (Glimp, 1995), however Boer goats and their crossbreds which have superior body conformation, exhibit greater slaughter and carcass weights and can dress out at 50.6% (Cameron *et al*., 2001). When slaughtered at the same age, goat carcasses are leaner than that of lamb, and therefore the meat also has a lower fat content (Hogg *et al*., 1992; Glimp, 1995). Unlike lamb, goats have relatively lower levels of subcutaneous and intramuscular fat (Hogg *et al*., 1992; Sheridan *et al*., 2003c), as they tend to deposit higher levels of fat in the abdominal cavity as well as around the kidneys (Casey & Webb, 2010). Chevon has a relatively low intramuscular fat content. These low levels of intramuscular fat contribute to the perceived toughness of meat from animals that are older than six months of age (Mohrand-Fehr *et al*., 2004). Chevon is also generally low in saturated fatty acids, which have been linked to the occurrence of cardiovascular diseases when consumed in great quantities (Beserra *et al*., 2004). However, when goats are fed highly concentrated grain diets, the fatty acid profile changes over time to present higher levels of saturated and monounsaturated fatty acids (Goetsch *et al*., 2011). Opportunities exist for chevon to be included as a suitable protein source in low calorie, low fat diets while upholding the cultural tendencies of consumers to support natural food production (Dubeuf *et al*., 2004).

According to FAOSTAT (2015), the percentage of undernourished people is declining, although the global population continues to grow. It is predicted that by the year 2050 the African population will have grown from the current 1.17 billion people to about 2.39 billion (FAOSTAT, 2015). Therefore an increase in the production of goat meat will be necessary in order to meet the demands of the growing ethnic African population (Kannan *et al*., 2006), as it is a suitable substitute that is more affordable than mutton or beef (Dubeuf *et al*., 2004).

2.6.1 Physical characteristics of meat

2.6.1.1 Colour

Colour is a physical and sensory perception that is used by a consumer in judging meat quality when purchasing meat, as the consumers are accustomed to certain ideals of what the appearance of fresh meat should be. Meat can be described as having a pink or red colour, which can range from pale, almost white, to dark red (Hunt *et al*., 1991). Discolouration of meat that affects the consumer's perception of freshness involves brown, grey, green and yellow colours, which are a result of pigment oxidation (Hunt *et al*., 1991). The variation in meat colour can be attributed to three different sources: 1) The pigment content which is dependent on the species, breed, age and nutritional status of the animal, as well as the type of muscle (Honikel*,* 1998). 2) The pre-slaughter period as well as the slaughter process, which influence the rate of pH decline in the carcass and thus the water holding capacity and meat colour, which may range from pale to dark as seen in pale, soft, exudative (PSE) and dark, firm and dry (DFD) meat (Webb and Casey 2010). 3) Finally during storage, the myoglobin pigments undergo the processes of oxygenation and oxidation as the meat surface comes into contact with the air, this is also referred to as blooming (Honikel*,* 1998). During the process of blooming, myoglobin molecules on the meat surface, which give the cut of a meat a dark red-purple appearance, are oxygenated to oxymyoglobin which changes the colour of the meat to bright red or pink (Boccard *et al*., 1981; Honikel, 1998). Myoglobin and oxymyoglobin can become oxidised as a result of contamination or enzyme activity, which results in meat having a brown colour (Honikel, 1981). The appearance of meat may be enhanced and the colour can be stabilised by adding substances such as nitrites or carbon monoxide to processed meat products (Hunt *et al*., 1991).

Blooming is an important step in determining meat colour as it is stable and presents the colour of fresh meat that influences the decision of the consumer when purchasing meat. Ensuring that the pH has stabilised when measuring is important, as the decline in pH causes proteins to denature, affecting the colour stability. The change in protein structure increases the light scattering properties and thus meat appears pale and opaque compared to pre-rigor muscle (Warris, 2010). There are various methods used to measure meat colour, which include subjective visual appraisal where a sample is compared to a range of pictorial standards as well as more objective instrumental methods (Hunt *et al*., 1991). For either method it is important that the light source as well as sample thickness and orientation remain constant. Instrumental methods that can be applied to measuring meat colour include reflectance photometers, tristimulus reflectance meters, colour difference meters and reflectance spectrophotometers (Boccard *et al*., 1981). Reflectance measurements are useful in that they closely relate to what the human eye and brain can detect (Hunt *et al*., 1991). Reflectance measurements are affected by the muscle structure, the amount of surface moisture, intramuscular fat content and concentration of pigments (Hunt *et al*., 1991). The readings from the above instruments can be applied to colour difference meters with uniform scales in terms of visual lightness such as the Hunter or more common CIE Lab systems (Boccard *et al*., 1981).

The CIE Lab colour space system describes colour according to three coordinates namely lightness L*, redness a*, and yellowness b*. Lightness can be plotted by the function $L^*= 10\ Y^{1/2}$ with lower L* values indicating a darker sample with 0 indicating pure black. The redness coordinated can be plotted by the function $a^* = 17.5\ (1.02X\text{-}Y)/(Y^{1/2})$ to give the degree of redness of the sample if the value is positive; if the sample should present a negative a* value it would mean that green pigments are being detected. The b* coordinate can be plotted by $b^*=7.0\ (Y\text{-}0.847Z)/\ (Y^{1/2})$, with a positive value indicating the degree of yellowness, while a negative value indicates the degree of blueness (Boccard *et al*., 1981). Other characteristics that may be described by the CIE Lab colour space include the chroma, which is the degree of colour saturation given by $(a^{*2}+b^{*2})^{1/2}$, and the hue which describes the colour group and is the difference in wavelength impulses and can be calculated by the function ATAN2 (b*/a*) (Hunt *et al*., 1991).

Consumers cannot readily distinguish between fresh lamb and chevon (Lee *et al*., 2008), although Chevon has higher L* values than lamb and therefore appears lighter, it also has lower b* values and so is less yellow (Sheridan *et al* 2003c; Casey & Webb, 2010). The colour of chevon can be affected by the diet that it receives during the fattening phase. Ryan *et al*. (2007) found that meat from goats fed grain diets was redder and more yellow than pasture fed goats, while also having greater hue and chroma values. Chevon has higher lightness and redness than lamb because of lower intramuscular fat (Babiker *et al*., 1990).

2.6.1.2 Post-mortem acidification

Adenosine triphosphate or ATP is an important molecule in muscle metabolism as it acts as an energy store. It is generated by glycolysis of glycogen or glucose and by oxidative phosphorylation when oxygen is present. The role of ATP in the muscle is to provide energy in order to enable muscle contraction and to actively pump calcium ions back into the sarcoplasmic reticulum. After an animal has been killed, the supply of blood which carries oxygen and glucose to the muscles, ceases. As metabolic activities in the muscle do not cease and as the muscle continues to contract, subsequent metabolism is anaerobic and ATP is generated by the lactate pathway which produces lactic acid (Warris, 2010). As lactic acid cannot be removed in the blood so that it can be broken down, it accumulates in the muscles and lowers the muscle pH. If glycogen stores in the muscle are not limiting, the production of lactic acid will cease when the pH reaches a point where enzyme systems are denatured (Warris, 2010). Post mortem glycolysis, ultimate pH and the rate at which it is reached, are all critical factors that will influence meat quality. The ultimate pH of slaughter kids is about 5.8, which is greater than that of lambs and is also seen to be greater in males than in female animals (Casey & Webb, 2010). The process of acidification takes approximately 12-24 hours in small ruminants (Warris, 2010). Nutrition influences the pH decline as it determines the amount of glycogen stored in the muscles. Safari *et al*. (2009) found that when goats were supplemented with a grain diet, this resulted in an increase in the rate of pH decline which stabilised at a pH of 5.6. This was also confirmed by Wang *et al*. (2014) who found that the ultimate pH could be lowered by increasing the dietary energy content. Low glycogen reserves due to insufficient nutrition would then result in a higher ultimate pH (Safari *et al*., 2009). Any form of stress experienced before slaughter may also affect muscle glucose levels and therefore the rate of pH decline. Stressors may also force the animal to undergo periods of anaerobic respiration which would cause an accumulation of lactic acid and thus lower muscle pH. Livestock that have been stressed prior to slaughter may exhibit undesirable effects such as PSE and DFD meat (Webb & Casey, 2010). Extreme stress shortly before slaughter causes pH to decline rapidly to a low pH causing muscle proteins to denature and lose their water binding capacity leading to PSE meat; whereas with DFD meat, glycogen stores are limited and therefore the muscle pH does not drop as low ensuring that the proteins bind tightly to water molecules (Lawrie & Ledward 2006). Goats tend to have a high glycolytic potential and therefore seem to have a higher sensitivity to ante mortem stress (Webb & Casey, 2010).

2.6.1.3 Water holding capacity

The majority of the water in muscles is found within the myofibrils and in the spaces between the thick myosin filaments and thin actin filaments (Lawrie & Ledward 2006). Water in the muscle can either be free within the interfilament spaces or bound to proteins. As the pH of the muscle drops during post-mortem acidification, myofibrillar proteins reach their isoelectric point, which is the point where the molecule has a net charge of zero and so lose their binding capacity to water (Sheridan *et al*., 2003c; Safari *et al*., 2009). During post-mortem muscle contraction, the lattice of thick and thin filaments shrinks, forcing water within these spaces out to the exterior (Lawrie & Ledward 2006). When the pH reaches the isoelectric point, the repulsive forces between myofilaments is reduced which allow the filaments to pack more tightly and diminishing the volume of water that can be held within the fibril (Safari *et al*., 2009). The expelled fluid accumulates in the extracellular spaces between muscle fibrils and then drains from the surface when meat is cut (Honikel, 1998). This fluid is then referred to as the exudate or drip. The amount of moisture that meat loses is important as it influences the juiciness or succulence of fresh meat, as well as the technological value for processed meat products (Warris, 2010)

Factors such as the rate of pH decline, temperature and chilling process are important as they affect the water holding capacity of muscle (Honikel, 1998). Goat meat is regarded as having a higher water holding capacity than mutton, as a result of the higher ultimate pH which promotes water binding (Safari *et al*., 2009). During heating, the denaturation of proteins occurs at temperatures varying between 37-75 °C, which causes structural changes such as the destruction of cell membranes and further shrinkage of muscle fibres and connective tissue (Honikel, 1998). Safari *et al.* (2009) found that the amount of moisture lost when goat meat was cooked at 80°C for an hour was in the range of 26.5-29.2%. The higher pH of goat meat, which increases the water binding capacity means that less moisture would be lost during cooking or would evaporate from the surface of a cut sample (Casey & Webb, 2010), provided that the integrity of the muscle was maintained so that no other external forces other than gravity would force fluid out (Honikel, 1998). The water binding capacity is also influenced by the age of the animal (Schönfeldt e*t al*., 1993) and by the diet it was fed before slaughter (Ryan *et al*., 2007).

2.6.1.4 Tenderness

Tenderness can be described as the impression formed by the consumer when biting into a piece of meat and the ease at which the teeth can penetrate the meat and break it into fragments, as well as the amount of residue that remains after chewing (Lawrie & Ledward

2006). The perception of tenderness is subjective and may vary between individuals, therefore mechanical methods of measuring the compression, tensile strength or shearing force were developed to estimate the tenderness of a sample. The Warner-Bratzler method determines the shearing force using a force deformation curve where the peak force and total amount of energy required are recorded (Honikel, 1998). This can be used as an indicator of tenderness, although it does not take into account other factors that influence the perceived tenderness, but can be used to make correlations relating to tenderness. Tenderness can be affected by the texture of the muscle, or the size of the fibre bundle, as well as the size of the muscle fibre and the amount of connecting tissue surrounding it (Lawrie & Ledward 2006).

Chevon is considered to be a tough meat that has a greater shear force than that of mutton or lamb (Casey & Webb, 2010). This may be attributed to the manner in which fat is partitioned in the goat carcass. Goats are known to deposit more fat internally, and less in the subcutaneous and intramuscular fat depots (Webb & Casey, 2010). The lack of subcutaneous fat surrounding the carcass allows it to lose heat to the surroundings more rapidly during post-mortem chilling (Kannan *et al*., 2006). The rapid temperature decline before the onset of rigor mortis reduces the efficiency of calcium uptake into the sarcoplasmic reticulum, which causes further contraction and the sarcomere length decreases, resulting in the cold shortening of meat (Kannan *et al*., 2006; Goetsch *et al*., 2011). The muscle fibres are then shorter as a result of the super-contraction of the sarcomeres, which results in a decrease of tenderness (Kannan *et al*., 2006). Diet does not specifically influence the tenderness of goat meat (Kannan *et al*., 2006). However, when high concentrate diets increase subcutaneous fat deposition on the carcass, decreased cold shortening can be expected (Wang *et al*., 2014). The meat from female goats tends to be more tender than that of males, due to the inherent nature of female animals to accrete higher levels of fat (Hogg *et al*., 1992).Tenderness of meat can also be influenced by the age of the animal; as an animal gets older, its connective tissue, specifically collagen, becomes more stable as it forms crosslinks between the collagen chains (Lawrie & Ledward 2006). The increase in collagen stability as the animal gets older results in decreased tenderness of the meat (Sheridan *et al* 2003c). This effect can be amplified by a greater consumption of proteins, as more amino acids are available for the accretion of lean muscle and connective tissue (Wang *et al*., 2014).

The tenderness of goat meat may be improved by extended cooking times or aging the meat at chill temperatures for a few days. During conditioning, proteolytic enzymes present in the meat break down myofibrillar proteins and disrupt the structure of the muscles in rigor (Lawrie & Ledward 2006). However, in goats, the activity of such enzymes is limited due the inherent rapid pH decline which causes enzymes such as µ-calpains to denature (Kannan *et al*., 2006). Hogg *et al*. (1992) found that goat meat conditioned for 48 hours was considerably more tender than meat tendered for 24 hours. The majority of post-mortem tenderisation of goat meat occurs during the first four days of conditioning, thereafter there is minimal change in the degree of tenderness with increased aging times (Kannan *et al*., 2014). The tenderness may also be improved by implementing electrical stimulation methods during the slaughter process (Hogg *et al*., 1992).

2.6.2 Chemical Composition of meat

Generally the proximate chemical composition of chevon is similar to lamb (Sheridan *et al*., 2003b), although it may have a lower fat content due to goats having less intramuscular fat (Casey & Van Niekerk, 1988). Meat mainly consists of protein, water, soluble carbohydrates, minerals and lipids. Lawrie and Ledward (2006) broadly described the composition of meat to be made up of approximately 75% water, 19% protein and 2.5% fat. Proteins have a wide range of functions in the body, including structural and contractile roles, and also form enzymes, hormones and antibodies (Warris, 2010). The protein fraction of meat consists of myofibrillar proteins, sarcoplasmic proteins and enzymes found in the muscle, as well as connective tissues and haemoglobin and myoglobin pigments. Collagen is the main protein that makes up connective tissue, which forms more stable crosslinks as the animal gets older and so contributes to the toughness of meat in older animals (Schönfeldt *et al.,* 1993). The basic unit of a protein is an amino acid which is principally made up of carbon, hydrogen, oxygen and nitrogen and some amino acids may contain sulphur. Most amino acids can be manufactured by the body, although there are few that can only be attained by consuming a protein source that contains these amino acids which are termed essential amino acids. Animal meat is a high quality protein source and contains all the essential amino acids. Chevon has higher protein and essential amino acid levels than lamb (Sheridan *et al*., 2003b). Cameron *et al*. (2001) found that Boer goat cross breeds contained 20.3-20.6% protein similar to that found by Hogg *et al*. (1992), whilst Sheridan *et al*. (2003b) found that the protein content of Boer goat meat varied between 17.0-17.7% and Tshabalala *et al*. (2003) found that Boer goat meat had a higher protein content of 22.8%.

Fats found in the muscles act as energy stores and form part of the cell membranes in the form of phospholipids and intramuscular fat (Lawrie & Ledward 2006). The most common form of fats in the body are triglycerides, which are made up of three fatty acid chains bound to a molecule of glycerol. The nature of the fatty acids determine the melting point, oxidation potential and to a lesser extent, nutritional value of the fats (Warris, 2010). The main fatty acids found in meat animals are oleic, palmitic and stearic acid (Lawrie & Ledward 2006), although this may vary between species as well as the animal’s nutrition before slaughter.

Concentrate feeding decreases the amount of moisture in the meat and results in an increase in the total lipid content (Animut *et al*., 2006; Lee *et al*., 2008) presumably due to the increase in intramuscular fat content. The moisture and fat content of chevon also vary with the age of the animal (Sheridan *et al*., 2003b; Bessera *et al*., 2004), as muscle growth slows and fat deposition increases with the age of the animal (Owens *et al*., 1993). The fat content of Boer goat meat was found to vary from 10.5% in range fed goats (Tshabalala *et al*., 2003) to between 17 and 23% in concentrate fed goats (Cameron *et al*., 2001; Sheridan *et al*., 2003b; Animut *et al*., 2006). Moisture along with fat in meat contribute to the perceived juiciness during chewing. Moisture content of meat generally decreases with age and with the consumption of concentrate diets (Sheridan *et al*., 2003b; Animut *et al*., 2006). Values for the chemical composition of Boer goat meat are depicted in Table 2.3.

Table 2.3 The chemical composition of fresh Boer goat meat, found in the literature.

Moisture (%)	**Protein (%)**	**Fat (%)**	**Ash (%)**	**Treatment**	**Reference**
56.1	20.3	18.6	3.87	Boer cross Spanish goats	Cameron *et al*., 2001
69.4	22.8	10.5	0.95		Tshabalala *et al*., 2003
65.1	17.7	13.5	3.39	Low energy diet, slaughtered after 28 days	Sheridan *et al*., 2003b
62.1	17.2	17.6	3.30	High energy diet, slaughtered after 28 days	Sheridan *et al*., 2003b
59.5	17.0	21.2	2.94	Low energy diet, slaughtered after 56 days	Sheridan *et al*., 2003b
59.0	17.3	20.2	3.26	High energy diet, slaughtered after 56 days	Sheridan *et al*., 2003b

2.6.3 Sensory characteristics of meat

The concept of meat palatability is complex and incorporates flavour, juiciness and texture attributes that are perceived during mastication (Casey & Webb, 2010). The flavour intensity, as well as the tenderness and juiciness of meat, can be influenced by the preparation method, as meat cooked in an oven is often more tender, while meat that has been fried has a stronger flavour and aroma (Xazela *et al*., 2011). Chevon is attractive to health conscious groups due to its lower fat content compared to other red meats (Lee *et al*., 2008). Chevon is often described as being similar to mutton or lamb (Madruga *et al*., 2009). However many cultures discriminate against the strong taste that is associated with goat meat (particularly that derived from older males) or dairy products (Morand-Fehr *et al*., 2004) and it is also considered to be less tender and juicy than lamb. Consumers that are familiar and have grown up eating goat meat, are more acceptable of the pronounced taste of chevon (Borgogno *et al*., 2015). Consumers may find chevon to be as acceptable as mutton, provided the meat is from young goats (Simela *et al*., 2008). These attributes will have to be appreciated by the consumer for its specific health and nutritional aspects (Schönfeldt *et al*., 1993). In order to make the public more acceptable to goat meat, the palatability of chevon products should be improved and made more familiar to the public (Kannan *et al*., 2006).

2.6.3.1 Aroma and Flavour

Flavour is described by Schönfeldt *et al*. (1993) as a complex sensation that exists from the combination of olfactory and gustatory attributes of meat that are perceived during tasting. The characteristic flavour of chevon closely resembles that of mutton or lamb (Madruga *et al*., 2009). Although goat meat can be distinguished from mutton (Schönfeldt *et al*., 1993; Sheridan *et al*., 2003c), it is often described as having an additional characteristic “goat-like” flavour. The goat-like aroma and flavour is characterised to be similar to the after taste of goat dairy products or the odour of goat hair (Sheridan et al., 2003c), along with livery notes (Borgogno *et al*., 2015). The aroma intensity of chevon is also less pronounced than the intensity of mutton (Schönfeldt *et al*., 1993).

The differences in flavour between chevon and mutton may be ascribed to the differences in fat content (Tshabalala *et al*., 2003). It has also been seen that the flavour intensity increases with age and is more pronounced in older animals which have higher fat levels (Schönfeldt *et al*., 1993). Ryan *et al*. (2007) also found that goats that were fed higher concentrate levels, which increases the degree of fat deposition, had higher goat-like flavour intensity. It can be said that the level of intramuscular fatness, as well as the composition of fatty acids, can affect the flavour and aroma profile of meat.

The aroma and flavour of meat develop from the interactions between volatile compounds and fatty acids, as well as non-volatile precursors, along with mallaird reactions between amino acids and sugars, lipid oxidation and thermal degradation reactions during heating (Madruga *et al*., 2010). The savoury, meaty flavour is associated with the methyl tridecanal compound, while phenolic compounds have a greater association with goat-like or mutton flavours (Madruga *et al*., 2009). Meat often presents a sweet taste and aroma which is derived from sugars in the meat and can specifically be associated with lactones and high levels of linoleic acid (Borgogno *et al*., 2015). The compounds that give rise to species specific flavours can be found in the lipid chemical fraction, which depends on the fatty acid profile of the meat (Madruga *et al*., 2010). Ruminants tend to have more saturated fatty acids, due to the hydrogenation of fatty acids in the rumen (Warmington & Kirton, 1990), and are less affected by the fatty acids consumed in the diet (Ryan *et al*., 2007). Branched chain fatty acids are responsible for the flavour and aroma of mutton (Schönfeldt *et al*., 1993); while hexanoic acid, which is found in goat meat and milk, is identified as having a sour, pungent, goat-like aroma (Madruga *et al*., 2010). Volatile compounds that may also contribute to the complexity of the goat-like flavour or aroma include 2-methyl-propanal, 3-methyl-propanal, 2-methyl-butanal and 2-methyl-2-butenal, because of their low threshold levels as well as their distinct odour characteristics, which include malty, pungent and sweet (Madruga *et al*., 2009).

2.6.3.2 Texture and Juiciness

Texture and juiciness are important sensory attributes that are associated with the consumer's perception of tenderness when chewing meat. Meat texture refers to the size of the muscle fibre bundle and the muscle fibres (Lawrie & Ledward 2006), or simply the coarseness of the meat grain. Smaller, thinner, muscle fibres are easy to shear during chewing and therefore increase the perceived tenderness of the meat. The amount of connecting tissue present in the muscle also influences meat texture, as well as the amount of residue left in the mouth after chewing (Lawrie & Ledward 2006). In older animals there are higher levels of collagen in the connective tissue, which also becomes more stable due to increased cross linking of the collagen fibres, resulting in meat that is tougher (Schönfeldt *et al*., 1993). Goat meat is regarded to be less tender than lamb and a greater amount of residue remains in the mouth after chewing. Intramuscular fat in meat acts as a lubricant which dilutes the meat particles, as it stimulates saliva production and decreases the dryness and stringiness of meat (Webb & O'Neill, 2008).

Intramuscular fat and moisture contribute to the perceived juiciness of meat, while water is the main factor affecting juiciness (Lee *et al*., 2008), and fat contributes to juiciness as well as flavour (Sheridan *et al*., 2003c). This combination stimulates the flow of saliva and thus improves the apparent juiciness (Sheridan *et al*., 2003c; Webb & O'Neill, 2008). Moisture binding capacity of meat is dependent on post-mortem acidification where meat with a low pH will have a low moisture content, while meat with a higher pH will bind water more tightly, and thus the meat will appear dry (Warris, 2010). Juiciness that is experienced with the initial bite into the piece of meat, is as a result of the moisture being released, while the prolonged experience of juiciness is as a result of intramuscular fat (Sheridan *et al*., 2003c). Meat from goats that have been supplemented with concentrate diets, have increased fat levels and present greater initial and sustained juiciness during chewing (Xazela *et al*., 2011).

2.7 Carcass composition

The carcass can be described as the portion of saleable meat that remains after an animal has been slaughtered and dressed. The dressing percentage is an indication of carcass yield after the skin and offal has been removed. The dressing percentage may vary according to gut fill, which is greater in ruminants than in monogastric animals, owing to the lower dressing percentages seen with ruminants (Warris, 2010). The period of pre-slaughter fasting plays a large role in the dressing percentage in ruminants, as gut fill decreases with time (Warmington & Kirton, 1990). There are some parts of the animal that are generally not used for human consumption, including the head, skin and trotters. In some cultures, however, the total meat yield from an animal may actually be greater than that given by the traditional carcass weight, as organs, portions of offal and skin may also be consumed (Goetsch *et al*., 2011). A higher consumption of offal products is mostly seen in developing countries and in certain ethnic markets (Glimp, 1995), while the more expensive and sought after meat cuts are derived from the traditional carcass.

A superior carcass is characterised by having a high proportion of lean muscle, a low proportion of bone and an optimal level of fatness (Berg & Walters, 1983). Carcass conformation describes the shape of a carcass and is a reflection of the meat to bone ratio (Warris, 2010). An increase in the musculature surrounding the animal's skeleton, results in a rounder, more superior conformation, giving a greater meat yield. Species, breed and gender are all factors which influence the body conformation of an animal. Animals that have been primarily bred for meat production, have greater musculature and a more rounded body conformation than animals bred for other purposes. After puberty, secondary sexual characteristics develop which gives rise to male animals having a more defined neck and thorax while female animals tend to have more developed rump regions. The Boer goat is superior to most other goat breeds in that it has a greater conformation, thus yielding heavier carcasses (Owens *et al*., 1977). The Boer goat, which has been bred specifically for improved meat production, will have higher levels of muscularity, especially in the hindquarters, when compared to other goat breeds (Cameron *et al*., 2001). Changes in the body form are accompanied by changes in growth rate and composition, which are of economic importance and therefore reflects industry adjustments to more efficient production (Berg & Walters, 1983), as is the case with the improved Boer goat. Muscle distribution differs with breed and gender of the goat. Male goats tend to have a more developed neck and shoulder regions compared to females (Goetsch *et al*., 2011). However, animals attain puberty after they have passed the point of inflection on the growth curve, which is when these differences will be more distinct. The leg, loin and rack represent the more valuable cuts of the carcass, with the leg and shoulder joints, which have greater lean yields, each making up approximately 30% of carcass weight in small stock (Hogg et al., 1992). The Boer goat exhibits good muscling of the hind leg, however, it does not compare as favourably as with sheep which have more developed hind leg muscles, whereas goats tend to have a more developed neck, forelimb and thorax (Sheridan *et al*., 2003b; Tshabalala *et al*., 2003). Intact males are generally more muscular than castrates, as castration increases the level of fat deposition (Goetsch *et al*., 2011).

As an animal ages, the proportion of fat in the carcass increases while the relative proportions of meat and bone decreases, although the absolute weights of these tissues increases (Warris, 2010). Fat growth is initially slow in comparison with the development of muscle tissue, but increases geometrically as the animal gets older (Berg & Walters, 1983). Fat occurs in adipose tissue which is distributed in different depots throughout the body. Fat depots grow at different rates and the manner in which fat is partitioned and distributed is important, as it affects the commercial value of the carcass (Berg & Walters, 1983). The pattern of fat development in major depots is dependent on the breed, sex, stage of maturity and plane of nutrition that the animal is on (Berg & Walters, 1983). Animals which have been selected for improved meat production, are generally early maturing and fatten earlier. These early maturing animals tend to have higher levels of subcutaneous fat while intramuscular and abdominal fat depots grow at slower rates (Berg & Walters, 1983). Goat kids generally deposit less fat subcutaneously than sheep, with the majority of the fat being deposited internally as abdominal and kidney knob and channel fat (Webb, 2014). This is as a result of sheep being intensively selected for improved meat production while goats have been bred for adaptability and maternal performance (Berg & Walters, 1983). Fat partitioning is influenced by genetic as well as environmental factors. Animals that have been adapted to survive in arid regions, have less subcutaneous fat in order to cope with the heat, while accreting more fat in other depots such as the abdominal cavity or tail to serve as reserves during periods of drought (Epstein, 1960). Females also deposit greater levels of kidney knob and channel fat, which are early developing depots in goats (Casey & Webb, 2010). Castrates fall midway between intact males and females in terms of carcass composition, but still deposit greater levels of fat than males (Hogg *et al*., 1992). As goats deposit less fat in subcutaneous and intramuscular fat depots and rather partition fat to depots found in the abdominal cavity, slaughter kids are seen to contain a greater proportion of muscle and less fat and bone compared to lamb (Casey & Webb, 2010). An increase in the subcutaneous fat depth, leads to an increase in the percentage of carcass fat and therefore to a decrease in lean meat yield (Purchas *et al.,* 1991). Overall, the meat yield of Boer goats compares favourably with sheep, due to the higher fat content of sheep carcasses (Tshabalala *et al*., 2003).

The initial body composition of an animal before fattening affects the rate of development and the composition of tissue that is subsequently accreted (Goetsch *et al*., 2011). After weaning, young animals and individuals with poor body condition tend to be very lean, therefore tissue that will be accreted early in the feeding period will be predominantly lean muscle (Goetsch *et al*., 2011). As the feeding period continues, the weight of the muscles will increase and the animal will start accreting excess energy as fat in the various depots, whilst bone remains independent of supplementation (Safari *et al*., 2009). Confined feeding practices with high concentrate diets influence the rate of fat deposition and increase the internal fat levels, as well as increase marbling, despite the low level of intramuscular fat in chevon compared to beef or mutton (Goetsch *et al.,* 2011).

Boer goats yield a lean carcass with good conformation (Casey & Webb, 2010). However, goats are generally slaughtered at low body weights with carcasses weighing less than 20 kg. A higher meat yield is expected with the increase in carcass size as the goats grow. As the growth of an animal decreases after it has passed the point of inflection on the growth curve (Owens *et al*., 1993), its carcass yield will also reach a plateau during this phase. This stage of growth for Boer goats needs to be determined in order to achieve an optimal meat yield with maximum muscling in the high value retail cuts.

2.8 Conclusion

The Boer goat is considered one of the best meat goat breeds due to its good body conformation, high fertility and good adaptability. The Boer goat is used in extensive commercial production systems and also used to improve the body conformation of smaller indigenous goat breeds in communal crossbreeding systems. Boer goats are typically found in arid and semi-arid regions where the vegetation is predominantly made up of bushes and small trees. The feeding behaviour of goats differs from cattle and sheep as they prefer to browse from bushes rather than graze. They also exhibit a selective behaviour which allows them to select the more digestible parts of the plant. As they do not compete for the same resources, goats can be herded along with cattle and sheep and be used as a tool to control bush encroachment.

Chevon is often compared to mutton or lamb, as the meat from goats is associated with a flavour and aroma that is similar to mutton, although chevon does present an additional goat-like flavour which is considered undesirable by people who are not familiar with it. The fat deposition in the goat carcass differs from that seen in lamb carcasses, as goats tend to accrete more fat internally, around the abdomen and kidneys, as opposed to sheep where higher levels of fat is deposited in the subcutaneous and intramuscular fat depots. This leanness of the goat carcass makes the muscles more susceptible to cold shortening during chilling, which contributes to the inherent toughness of chevon. Due to its low fat content, chevon is a good protein source to health conscious groups although it is relatively less popular than lamb. Goat meat is generally consumed by ethnic communal populations, as well as Hindu and Muslim populations, who find goat meat to be an acceptable substitute for beef or mutton. Seasonal peaks in the demand for goat meat are experienced around religious or cultural holidays and festivals.

In South Africa, goats are typically marketed directly from the farm soon after they have been weaned and only a small percentage is slaughtered through commercial channels. In order to meet the demand for goat meat around cultural holidays, it is advisable to intensify the level of production. This can be done through finishing the goats in feedlots on a high energy and protein concentrate based diet. Finishing goats in a feedlot will increase their growth rates and thus allow them to be marketed at the desired weight at an earlier age. As the young goats are removed from their dams on the pasture and placed in the feedlot, it allows the dams more access to the feed available on the pasture to maintain a high level of production. Currently the information on finishing Boer goats is limited, therefore by developing a growth model that can be fitted to the growth curve of goats will improve the knowledge of the growth trends of goats. Identifying the inflection point on the growth curve of Boer goats, and the age or body weight at that point, will give an indication of up to what age can Boer goats be finished in a feedlot efficiently. This model can then be used to determine an optimal slaughter age, to yield a high quality carcass with maximum muscling, as well as determine the effects of different treatments which can be used to improve the rate of growth and carcass yield.

2.9 References

Alexandre, G., and Mandonnet N. 2005. Goat meat production in harsh environments. Small Ruminant Research. 60: 53-66.

Animut, G., Goetsch A., Aiken G., Puchala R., Detweiler G., Krehbiel C., Merkel R., Sahlu T., Dawson L., and Johnson Z. 2006. Performance by goats and sheep consuming a concentrate-based diet subsequent to grazing grass/forb pastures at three stocking rates. Small Ruminant Research. 66: 92-101.

Animut, G. and Goetsch, A. L. 2008. Co-grazing of sheep and goats: Benefits and constraints. Small Ruminant Research. 77: 127-145.

Aucamp, A. J. and Venter, J. J. 1981. Boer goat performances in the dry grass-bush community of the Eastern Cape. Boer Goat News 3: 25-28.

Babiker, S. A., El Khider, I. A., & Shafie, S. A. 1990. Chemical composition and quality attributes of goat meat and lamb. Meat Science. 28: 273-277.

Bathaei, S., and Leroy P. 1996. Growth and mature weight of Mehraban Iranian fat-tailed sheep. Small Ruminant Research. 22: 155-162.

Baumont, R., Prache S., Meuret M., and Morand-Fehr P. 2000. How forage characteristics influence behaviour and intake in small ruminants: A review. Livestock Production Science. 64: 15-28.

Bell, A., Greenwood P., and Ehrhardt R. 2005. 1 Regulation of metabolism and growth during prenatal life. Biology of Metabolism in Growing Animals. 3: 1.

Berg, R., and Walters L. 1983. Meat animal: Changes and challenges. Journal of Animal Science. 57:133-146

Beserra, F., Madruga M., Leite A., Da Silva E., and Maia E. 2004. Effect of age at slaughter on chemical composition of meat from Moxotó goats and their crosses. Small Ruminant Research. 55: 177-181.

Boccard, R., Buchter L., Casteels E., Cosentino E., Dransfield E., Hood D., Joseph R., MacDougall D., Rhodes D., and Schön I. 1981. Procedures for measuring meat quality characteristics in beef production experiments. Report of a working group in the Commission of the European Communities' (CEC) beef production research programme. Livestock Production Science. 8: 385-397.

Borgogno, M., Corazzin M., Saccà E., Bovolenta S., and Piasentier E. 2015. Influence of familiarity with goat meat on liking and preference for capretto and chevon. Meat Science. 106: 69-77.

Bowen, M., Ryan M., Jordan D., Beretta V., Kirby R., Stockman C., McIntyre B., and Rowe J. 2006. Improving sheep feedlot management. International Journal of Sheep and Wool Science. 54: 27-34.

Brand, T. S. Directorate: Animal Sciences, Department of Agriculture, Western Cape Government, Elsenburg, Private bag X1, Elsenburg 7607, South Africa. Personal communication.

Burfening, P., and Kress D. 1993. Direct and maternal effects on birth and weaning weight in sheep. Small Ruminant Research. 10: 153-163.

Cameron, M., Luo J., Sahlu T., Hart S., Coleman S., and Goetsch A. 2001. Growth and slaughter traits of Boer x Spanish, Boer x Angora, and Spanish goats consuming a concentrate-based diet. Journal of Animal Science. 79: 1423-1430.

Campbell, Q. 2003. The origin and description of southern Africa's indigenous goats. South African Journal of Animal Science. 4: 18-22.

Casey, N., and Van Niekerk W. 1988. The Boer goat. I. Origin, adaptability, performance testing, reproduction and milk production. Small Ruminant Research. 1: 291-302.

Casey, N. H., and Webb E. C. 2010. Managing goat production for meat quality. Small Ruminant Research. 89: 218-224.

da Cunha Leme T. M., Titto E. A. L., Titto C. G., Pereira A. M. F., and Neto M. C. 2013. Influence of stocking density on weight gain and behaviour of feedlot lambs. Small Ruminant Research. 115: 1-6.

da Silva, L. S. A., Fraga, A. B., da Silva, F. D. L., Beelen, P. M. G., de Oliveira Silva, R. M., Tonhati, H. & da Costa Barros, C. 2012. Growth curve in Santa Inês sheep. Small Ruminant Research, 105: 182-185.

Du Plessis, I., Van der Waal C., and Webb E. 2004. A comparison of plant form and browsing height selection of four small stock breeds-preliminary results. South African Journal of Animal Science: 8th International Conference on goats, 34: 31-34

Dubeuf, J., Morand-Fehr P., and Rubino R. 2004. Situation, changes and future of goat industry around the world. Small Ruminant Research. 51: 165-173.

Duddy, G., Bell A., Shands C., and Hegarty R. 2007. Feedlotting lambs. Prime-Facts. (523)

Epstein, H. 1960. History and origin of the Ronderib and Namaqua Afrikaner sheep. Zeitschrift Für Tierzüchtung Und Züchtungsbiologie. 74: 267-292.

FAOSTAT. 2015. Food and Agriculture Organization of the United Nations, Statistics Division. http://faostat3.fao.org/browse/Q/*/E (Accessed September 2015).

Fernandes, M., Resende K. T. d., Tedeschi L., Fernandes J., Silva H., Carstens G., Berchielli T., Teixeira I., and Akinaga L. 2007. Energy and protein requirements for maintenance and growth of Boer crossbred kids. Journal of Animal Science. 85: 1014-1023.

Ferreira, A., Hoffman L., Schoeman S., and Sheridan R. 2002. Water intake of Boer goats and Mutton Merinos receiving either a low or high energy feedlot diet. Small Ruminant Research. 43: 245-248.

Finlayson, J., Cacho O. J., and Bywater A. 1995. A simulation model of grazing sheep: I. Animal growth and intake. Agricultural Systems. 48: 1-25.

Gebrelul, S., Sartin L. S., and Iheanacho M. 1994. Genetic and non-genetic effects on the growth and mortality of Alpine, Nubian and crossbred kids. Small Ruminant Research. 13: 169-176.

Gipson, T., Goetsch A., Detweiler G., and Sahlu T. 2007. Effects of feeding method, diet nutritive value and physical form and genotype on feed intake, feeding behaviour and growth performance by meat goats. Small Ruminant Research. 71: 170-178.

Glimp, H. A. 1995. Meat goat production and marketing. Journal of Animal Science. 73: 291-295.

Goetsch, A., Merkel R., and Gipson T. 2011. Factors affecting goat meat production and quality. Small Ruminant Research. 101: 173-181.

Goonewardene, L. A., Day, P. A., Patrick, N., Scheer, H. D., Patrick, D., and Suleiman, A. 1998. A preliminary evaluation of growth and carcass traits in Alpine and Boer goat crosses. Canadian Journal of Animal Science 78: 229-232.

Hogg, B., Mercer G., Mortimer B., Kirton A., and Duganzich D. 1992. Carcass and meat quality attributes of commercial goats in New Zealand. Small Ruminant Research. 8: 243-256.

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

Hunt, M., Acton J., Benedict R., Calkins C., Cornforth D., Jeremiah L., Olson D., Salm C., Savell J., and Shivas S. 1991. Guidelines for meat color evaluation. American Meat Science Association, Savoy, IL.

Jensen, R. and Swift, B. L. 1982. Diseases of sheep. Second edition. Lea & Febiger. Philadelphia.

Jiménez-Badillo, M. R., Rodrigues, S., Sanudo, C., and Teixeira, A. 2009. Non-genetic factors affecting live weight and daily gain weight in Serrana Transmontano kids. Small Ruminant Research. 84: 125-128.

Kamalzadeh, A., Koops W., and Van Bruchem J. 1998. Feed quality restriction and compensatory growth in growing sheep: Modelling changes in body dimensions. Livestock Production Science. 53: 57-67.

Kannan, G., Gadiyaram K., Galipalli S., Carmichael A., Kouakou B., Pringle T., McMillin K., and Gelaye S. 2006. Meat quality in goats as influenced by dietary protein and energy levels, and post-mortem aging. Small Ruminant Research. 61: 45-52.

Kannan, G., Lee J., and Kouakou B. 2014. Chevon quality enhancement: Trends in pre- and post-slaughter techniques. Small Ruminant Research. 121: 80-88.

Laird, A. K. 1965. Dynamics of tumour growth: comparison of growth rates and extrapolation of growth curve to one cell. British Journal of Cancer. 19: 278-291.

Lawrence, T. L. J., Fowler, V. R. and Novakofksi J. E. 2012. Growth of farm animals. Second edition. CABI. 216-228.

Lawrie, R. A. and Ledward, D. A. 2006. Lawrie's meat science. Seventh edition. Woodhead publishing limited. Cambridge, England.

Lee, J., Kannan G., Eega K., Kouakou B., and Getz W. 2008. Nutritional and quality characteristics of meat from goats and lambs finished under identical dietary regime. Small Ruminant Research. 74: 255-259.

Lee, J., Kouakou B., and Kannan G. 2009. Influences of dietary regimens on microbial content in gastrointestinal tracts of meat goats. Livestock Science. 125: 249-253.

Lu, C., and Potchoiba M. 1990. Feed intake and weight gain of growing goats fed diets of various energy and protein levels. Journal of Animal Science. 68: 1751-1759.

Luo, J., Goetsch A., Sahlu T., Nsahlai I., Johnson Z., Moore J., Galyean M., Owens F., and Ferrell C. 2004. Prediction of metabolizable energy requirements for maintenance and gain of preweaning, growing and mature goats. Small Ruminant Research. 53: 231-252.

Luo, J., Sahlu T., Cameron M., and Goetsch A. 2000. Growth of Spanish, Boer × Angora and Boer × Spanish goat kids fed milk replacer. Small Ruminant Research. 36: 189-194.

Macdonald, P., Edward R. A., Greenhalgh J. F. D., Morgan C. A., Sinclair L. A., and Wilkinson R. G. 2011. Animal nutrition. Seventh ed. Pearson Education Limited. England.

Madruga, M. S., Elmore J. S., Dodson A. T., and Mottram D. S. 2009. Volatile flavour profile of goat meat extracted by three widely used techniques. Food Chemistry. 115: 1081-1087.

Madruga, M., and Bressan M. 2011. Goat meats: Description, rational use, certification, processing and technological developments. Small Ruminant Research. 98: 39-45.

Madruga, M., Elmore J., Oruna-Concha M., Balagiannis D., and Mottram D. 2010. Determination of some water-soluble aroma precursors in goat meat and their enrolment on flavour profile of goat meat. Food Chemistry. 123: 513-520.

Malan, S. 2000. The improved Boer goat. Small Ruminant Research. 36: 165-170.

Malhado, C., Carneiro P., Affonso P., Souza A., and Sarmento J. 2009. Growth curves in Dorper sheep crossed with the local Brazilian breeds, Morada nova, Rabo largo, and Santa inês. Small Ruminant Research. 84: 16-21.

Minka, N. S., Ayo, J. O., Sackey, A. K. B., and Adelaiye, A. B. 2009. Assessment and scoring of stresses imposed on goats during handling, loading, road transportation and unloading, and the effect of pretreatment with ascorbic acid. Livestock Science. 125: 275-282.

Morand-Fehr, P. 2005. Recent developments in goat nutrition and application: A review. Small Ruminant Research. 60: 25-43.

Morand-Fehr, P., Boutonnet J., Devendra C., Dubeuf J., Haenlein G., Holst P., Mowlem L., and Capote J. 2004. Strategy for goat farming in the 21st century. Small Ruminant Research. 51: 175-183.

Mourad, M., and Anous M. 1998. Estimates of genetic and phenotypic parameters of some growth traits in common African and Alpine crossbred goats. Small Ruminant Research. 27: 197-202.

Najari, S., Gaddoun A., Hamouda M. B., Djemali M., and Khaldi G. 2007. Growth model adjustment of local goat population under pastoral conditions in Tunisian arid zone. Journal of Agronomy. 6: 61-67.

National Research Council (US). Committee on Nutrient Requirements of Small Ruminants. 2007. Nutrient requirements of small ruminants: sheep, goats, cervids, and new world camelids.

Olson, L. W., Dickerson G., and Glimp H. 1976. Selection criteria for intensive market lamb production: Growth traits. Journal of Animal Science. 43: 78-89.

Owen, J. E., and Norman G. A. 1977. Studies on the meat production characteristics of Botswana goats and sheep—Part II: General body composition, carcass measurements and joint composition. Meat Science. 1: 283-306.

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

Pi, Z. K., Wu, Y. M., & Liu, J. X. 2005. Effect of pretreatment and pelletization on nutritive value of rice straw-based total mixed ration, and growth performance and meat quality of growing Boer goats fed on TMR. Small Ruminant Research *56*: 81-88.

Purchas, R., Davies A., and Abdullah A. 1991. An objective measure of muscularity: Changes with animal growth and differences between genetic lines of Southdown sheep. Meat Science. 30: 81-94.

Rakes, A. H., Lister E. E., and Reid J. T. 1961. Some effects of feeding frequency on the utilization of isocaloric diets by young and adult sheep. Journal of Nutrition. 75: 86-92.

Roux, C.Z., 1976. A model for the description and regulation of growth and production. Agroanimalia, 8: 83-94.

Ryan, S., Unruh J., Corrigan M., Drouillard J., and Seyfert M. 2007. Effects of concentrate level on carcass traits of Boer crossbred goats. Small Ruminant Research. 73: 67-76.

Safari, J., Mushi D., Mtenga L., Kifaro G., and Eik L. 2009. Effects of concentrate supplementation on carcass and meat quality attributes of feedlot finished small East African goats. Livestock Science. 125: 266-274.

Sayed, A. N. 2011. Effect of different energy levels of diets on the performance, nutrient digestibilities and carcass characteristics of lambs. International Journal for Agro Veterinary and Medical Sciences. 5: 472-476.

Schönfeldt, H., Naude R., Bok W., Van Heerden S., Smit R., and Boshoff E. 1993. Flavour- and tenderness-related quality characteristics of goat and sheep meat. Meat Science. 34: 363-379.

Sheridan, R., Ferreira A., and Hoffman L. 2003a. Production efficiency of South African Mutton Merino lambs and Boer goat kids receiving either a low or a high energy feedlot diet. Small Ruminant Research. 50: 75-82.

Sheridan, R., Hoffman L., and Ferreira A. 2003b. Meat quality of Boer goat kids and Mutton Merino lambs. 1. Commercial yields and chemical composition. Animal Science. 76: 63-71.

Sheridan, R., Hoffman L., and Ferreira A. 2003c. Meat quality of Boer goat kids and Mutton Merino lambs. 2. Sensory meat evaluation. Animal Science. 76:73–79

Simela, L., Webb E. C., and Bosman M. 2008. Acceptability of chevon from kids, yearling goats and mature does of indigenous South African goats: A case study. South African Journal of Animal Science. 38: 247-259.

Smith, R. A. 1998. Impact of disease on feedlot performance: A review. Journal of Animal Science. 76: 272-274.

Solaiman, S., Min, B. R., Gurung, N., Behrends, J., & McElhenney, W. 2012. Effects of breed and harvest age on feed intake, growth, carcass traits, blood metabolites, and lipogenic gene expression in Boer and Kiko goats. Journal of Animal Science. 90: 2092-2108.

Stanton, T., and Levalley, S. 2006. Lamb feedlot nutrition. Colorado State University 4: 08.

Steyn, J. 2010. Farming with Boer goats, A practical guide for Southern African conditions. First ed. Patriot Publishers. Potchefstroom, South Africa.

Taylor, M. A. 2012. Emerging parasitic diseases of sheep. Veterinary parasitology, 189(1), 2-7.

Tedeschi, L. O., Cannas A., and Fox D. G. 2010. A nutrition mathematical model to account for dietary supply and requirements of energy and other nutrients for domesticated small ruminants: The development and evaluation of the small ruminant nutrition system. Small Ruminant Research. 89: 174-184.

Thornley, J. H. M., and France J.. 2007. Mathematical models in agriculture: Quantitative methods for the plant, animal and ecological sciences. Second edition. CABI. United Kingdom.

Tshabalala, P., Strydom P., Webb E., and De Kock H. 2003. Meat quality of designated South African indigenous goat and sheep breeds. Meat Science. 65: 563-570.

Van Niekerk, W., and Casey N. 1988. The Boer goat. II. Growth, nutrient requirements, carcass and meat quality. Small Ruminant Research. 1: 355-368.

Walker, K., Fell L., Reddacliff L., Kilgour R., House J., Wilson S., and Nicholls P. 2007. Effects of yard weaning and training on the behavioural adaptation of cattle to a feedlot. Livestock Science. 106: 210-217.

Wang, D., Zhou L., Zhou H., Hou G., Shi L., Li M., Huang X., and Guan S. 2014. Effects of nutritional level of concentrate-based diets on meat quality and expression levels of genes related to meat quality in Hainan black goats. Animal Science Journal. 86: 166-173.

Warmington, B., and Kirton A. 1990. Genetic and non-genetic influences on growth and carcass traits of goats. Small Ruminant Research. 3: 147-165.

Warris, P. D. 2010. Meat Science. An Introductory Text. 2nd edition. CABI Publishing. Wallingford UK.

Webb, E. 2014. Goat meat production, composition, and quality. Animal Frontiers. 4: 33-37.

Webb, E., and O'Neill H. 2008. The animal fat paradox and meat quality. Meat Science. 80: 28-36.

Webb, E. C., and Casey N. H. 2010. Physiological limits to growth and the related effects on meat quality. Livestock Science. 130: 33-40.

Xazela, N. M., Muchenje, V., and Marume, U. 2011. Effects of different cooking methods on the consumer acceptability of chevon. African Journal of Biotechnology.10: 12671-12675.

Yiakoulaki, M., Goetsch A., Detweiler G., and Sahlu T. 2014. Effects of creep grazing and stocking rate on forage selection and nutritive value of the diet for meat goat does and kids on grass/forb pasture. Small Ruminant Research. 117: 119-123.

Zhang, C., Zhang Y., Xu D., Li X., Su J., and Yang L. 2009. Genetic and phenotypic parameter estimates for growth traits in Boer goat. Livestock Science. 124: 66-71.

Chapter 3

Comparing the effect of age and dietary energy content on feedlot production of Boer goats

Abstract

The effects of three dietary energy treatments on the feedlot production characteristics of Boer goats were investigated along with the time spent under feedlot conditions. Goat kids with an average weight of 22.2 ± 3.5 kg were housed in individual pens at Elsenburg experimental farm. At the start of the trial, the goats were randomly allocated to one of three finisher diets that vary in energy content, namely low, medium and high energy (11.3, 12.0, and 12.7 MJ ME/kg feed, respectively). The goats were divided further into groups that were slaughtered after 40, 76, 112 and 146 days in the feedlot at a registered abattoir. During the trial period, goats were supplied their respective trial diets *ad libitum*. Orts were weighed back once a week in order to determine feed intake. Growth was monitored by weighing the goats weekly. The live weight of the goats increased linearly (20.939+0.191x, where x represents days in feedlot) throughout the trial period. Overall goats on the high energy diet had the lowest growth rate (202.0 g/day versus 221.9 and 234.9 g/day for goats on the low and medium diets $P< 0.05$). This may be as a result of the high starch content affecting the rumen environment and thus the utilization of nutrients for growth. Goats fed the low and medium energy diets presented the higher feed intakes (1236.4 and 1168.6 versus 1002.4 g/day for low, medium and high energy diets, $P< 0.01$). The feed conversion ratio of the goats was not influenced by the energy content ($P= 0.06$) of the diet nor by the time spent in the feedlot ($P= 0.40$). Goats on the low energy diet had a lower dressing out percentage (45.8%, compared to 46.1 and 47.1% for the low medium and high energy diets). This may be attributed to the higher proportion of fibre in the feed, which increases the gut fill and affects the digestibility of the feed. It was also observed that goats were able to adjust their level of feed intake in response to the amount of energy supplied in the diet. It is suggested that the diet with a medium energy content (12.0 MJ ME/kg feed) closely resembles the requirements of Boer goats for growth and exhibits the best production characteristics.

3.1 Introduction

The South African Boer goat was developed by early settlers who reared goats in order to clear the bush to make way for other agricultural practices. Farmers bred the goats using existing indigenous breeds, selecting for high fertility, higher growth rates and greater body conformation (Casey & Van Niekerk, 1988). This led to the improved Boer goat as we know it today, which can be recognized by its characteristic white body, red head and greater muscularity (Malan, 2000). As the Boer goat is renowned for its good reproduction characteristics, rapid growth and greater carcass yield compared to smaller indigenous goats, it is considered to be the standard to which other meat goats are compared (Steyn, 2010). Due to their good production characteristics, the breed is ideally suited to be used in crossbreeding systems of communal farmers in order to improve the meat production characteristics of indigenous goats (Owen & Norman, 1977). Boer goats are commonly reared in extensive production systems by commercial farmers in arid and semi-arid regions where the vegetation mostly consists of bushes rather than grasses. Goats show a preference to consuming browse material rather than grass, unlike other livestock species, and exhibit a very selective feeding behaviour (Animut & Goetsch, 2008). Along with their high level of adaptability and greater tolerance towards diseases and environmental stressors, goats can thus be farmed in areas that would be otherwise considered unsuitable for the production of other livestock species.

Goat production in South Africa is less popular than sheep production, with an estimated 35 000 tonnes of goat meat being produced in 2013 compared to 143 000 tonnes of mutton produced in the same year (FAOSTAT, 2015). Meat from goats that have less than two permanent incisors is reffered to as chevon. The lower popularity of goat production can be attributed to the common perception that chevon is an inherently tough meat with a characteristic flavour that is considered undesirable by many people, although it is a lean meat which may appeal to health conscious groups (Webb, 2014). The growth rates and feed conversion efficiencies of most sheep breeds are also superior compared to goats (Sheridan *et al*., 2003), therefore making mutton and wool production a more profitable enterprise in intensive systems. In South Africa goat meat is generally consumed by the ethnic African community, who are familiar with eating goat meat and traditionally rear goats as part of their livestock. The Hindu and Muslim communities also find chevon to be an acceptable replacement for mutton or lamb. The demand for goat meat experiences drastic increases around religious or South African cultural holidays (Dubeuf *et al*., 2004). The sale of goats typically does not follow the conventional commercial channels, with the majority of goats being marketed directly from the farm at an age ranging between 3-6 months.

As the global population continues to grow (FAOSTAT, 2015), the demand for protein in the form of meat will increase. In order to reduce the levels of starvation and to produce meat of a good nutritional quality, the level of production needs to intensify for all forms of livestock production. After weaning, ruminants can be finished off in feedlots, where they are fed concentrate diets which promote rapid growth so that animals reach their desired market weight at an earlier age (da Cunha Leme *et al*., 2013). Feedlot finishing of animals on a large scale can ensure the market of a consistent supply of meat that is of uniform quality and meets the market specifications for carcass weight and degree of fatness (Duddy *et al*., 2007). The removal of animals from pasture and introducing them to intensively managed feedlots can firstly allow a greater number of animals to be finished in a small area and take advantage of optimal stocking rates (da Cunha Leme *et al*., 2013), while at the same time reducing the grazing or browsing pressure on the pasture and provide greater feed resources for the breeding dams to ensure optimal production (Ryan *et al*., 2007).

Nutrition plays an integral role in feedlot production, and is the governing factor that influences the rate of animal growth and profit margins. The main focus in feedlot nutrition is to supply the animal with sufficient energy and protein in the diet as these nutrients greatly affect growth and the level of feed intake (Wang *et al*., 2014). To do this, feedlot diets largely consist of grains and oilseeds (Stanton & Levalley, 2006), in order to provide the animals with sufficient quantities of highly digestible energy and protein sources. Dietary energy is often taken as the baseline requirement as it also affects the utilisation of other nutrients (Lawrence *et* al., 2012). Goats are able to utilize high concentrate diets just as well as sheep under feedlot conditions, though it is also suggested that goats may be better at utilizing diets with a higher roughage content (Sheridan *et al*., 2003). The growth rates exhibited by goats are generally lower than that of sheep (Van Niekerk & Casey, 1988) and the pattern of fat partitioning in goats differs from sheep; goats tend to deposit more fat in the abdominal cavity rather than in subcutaneous fat depots (Casey & Webb, 2010). The differences in growth rates and fat deposition indicate differences in the maturation rates of the two species, and therefore the nutritional requirements of goats differ from that of sheep. However, in South Africa, goats are often supplied rations that have been formulated for sheep, as it is assumed that the two species would have similar requirements (Van Niekerk & Casey, 1988). In order to optimize goat production, diets that meet the specific requirements of the growing goat should be formulated for feedlot production.

The aim of this study was to determine the effect of feeding goats finisher diets with different dietary energy levels on the feedlot production parameters. The effect of age or time spent in the feedlot was investigated along with the dietary energy treatments on the feedlot production parameters and dressing percentage over time. The objective is to thus determine an optimal dietary energy level that can be used in feed formulations to finish Boer goats, as well as to determine an optimal finishing period for goats in the feedlot.

3.2 Materials and Methods

For this trial, 71 castrated Boer goat kids were weaned at an average age of five months and were transported to Elsenburg experimental farm, where they were housed in individual pens. Upon arrival, the goat kids were drenched and vaccinated with a broad spectrum vaccine against *Pasteurella* and *Clostridia* bacteria. The slaughter kids were randomly allocated to different dietary treatments as well as to different slaughter groups (Table 3.1).

Table 3.1 The layout of the trial, to determine the effect of time in the feedlot and dietary energy content on the production parameters of goats, and the number of goats that were allocated to each treatment group.

Slaughter Group	Dietary Treatment			Total
	Low	Medium	High	
Day 40	4	5	3	12
Day 76	5	5	5	15
Day 112	5	3	5	13
Day 146	8	9	9	26
Total	22	22	22	66

The goats were assigned to one of three different feedlot diets that varied in energy content, namely a low (11.7 MJ ME/kg feed), medium (12.0 MJ ME/kg feed) and high energy (12.3 MJ ME/kg feed) diet. These diets are expressed on an as fed basis with a moisture content of 10.4%. The compositions of the diets are presented in Tables 3.2 and 3.3. Goats were gradually adapted from roughage (oat hay) to the concentrate diets using a stepup programme for a period of 10 days, after which the respective feeds were supplied to the goats *ad libitum*. During the trial period, feed refusals were weighed weekly and individual daily dry matter intake was calculated for each goat. The growth rate of the goats was also monitored through weekly weightings. During the adaptation phase, three goats died as a result of pneumonia and complications with adaption to the feedlot diet, while two goats died of other causes later in the trial. These mortalities resulted in some of the treatment groups having unequal numbers of goats.

Table 3.2 The formulation of the trial diets fed to Boer goat kids.

Ingredients	**Diets (% As fed)**		
	LE	**ME**	**HE**
Maize	44.30	54.90	65.50
Lucerne hay	39.00	24.90	10.80
Cottonseed oilcake	8.00	11.44	14.89
Molasses Powder	2.50	2.50	2.50
Salt, NaCl	1.0	1.00	1.00
Bicarbonate of Soda	2.00	2.00	2.00
Ammonium Sulphate	1.00	1.00	1.00
Slaked Lime	0.90	1.10	1.30
Urea	0.50	0.50	0.50
Mono calcium phosphate	0.34	0.18	0.02
Vitamin and Mineral premix	0.25	0.25	0.25
Sulphur	0.20	0.20	0.20
Commercial growth promoters and coccidiostat premix	0.020	0.020	0.020
Total	**100**	**100**	**100**

LE – Low energy diet. ME – Medium energy diet. HE – High energy diet.

Table 3.3 The nutrient composition of the trial diets fed to Boer goat kids.

Nutrients	**Nutrients of Diets (as fed)**		
	LE	**ME**	**HE**
In vitro organic matter digestibility, %	74.41	79.30	86.25
Total digestible nutrients (TDN) %*	64.09	68.00	70.69
Metabolisable energy, MJ/ kg ^{x}	11.30	12.00	12.70
Protein, %	14.30	14.28	14.98
Fibre, %	12.7	10.4	6.3
Neutral detergent fibre, %	29.24	28.29	22.85
Acid detergent fibre, %	15.84	12.78	8.57
Ash, %	10.12	8.63	7.57
Fat, %	1.16	1.37	1.31
Calcium, %	1.25	1.08	1.00
Phosphorous, %	0.45	0.41	0.40

LE – Low energy diet. ME – Medium energy diet. HE – High energy diet.

^{x} Formulated metabolisable energy values.

* Calculated total digestible nutrients = (0.8 x protein) + (0.4 x fibre) + (0.9 x nitrogen free extract) + (2.025 x fat).

The slaughter groups consisted of about 15 goats, about five goats per dietary treatment (Table 3.1), which were housed in the feedlot and slaughtered at five week intervals, until a production period of 20 weeks was reached when the remaining 26 goats were slaughtered. The goats were slaughtered at a commercial abattoir, Swartland abattoir in Malmesbury, according to South African Techniques as described by Cloete *et al.* (2004).

Average daily gain (ADG), daily dry matter intake (DMI) and feed conversion ratio were calculated weekly for each individual throughout the trial period and averages were calculated for these parameters per treatment group. Feed conversion ratio was computed as the dry matter intake divided by weight gained per week. Dressing percentage was defined as the cold carcass weight divided by the weight of the animal at slaughter expressed as a percentage.

The feedlot production data was analyzed using SAS 9.2. Data of the production parameters were subjected to an analysis of variance (ANOVA) to test for any significant differences. The dietary treatments and days spent in the feedlot were taken as the main effects. As the body weights at the start of the trial varied, initial body weight was used as a covariate in analyzing the final body weight, dry matter intake and dressing percentage. The results were expressed as least square means along with standard errors of the means. Regression equations were computed for each production variable and were tested for significant differences using Proc GLM (SAS, 2006). Least squared differences were used to indicate differences between the means of the production characteristics at different intervals in the feedlot.

3.3 Results

The initial body weight of the goats varied for the different treatments (P= 0.03) before being subjected to the feedlot conditions and was used as a covariate in analysing the final body weights. The final body weights showed an interaction between dietary energy content and days spent in the feedlot (P= 0.04) (Table 3.5). Goats on the high energy diet slaughtered after 40 days had the highest body weights (31.8 kg; P= 0.03) compared to goats on the low and medium diets (25.8 and 26.7 kg respectively), while goats on the high energy diet had lower body weights than goats on the low and medium energy diets when slaughtered after 76 days in the feedlot (30.1, 37.6 and 36.5 kg respectively; P= 0.03). This was probably due to sampling effects when goats were randomly allocated to the respective treatment groups, as no differences were detected in the groups that were slaughtered at later intervals. The end body weights of goats did not differ between the energy levels of the trial diets (P= 0.57), but did vary with time in the feedlot (P< 0.01), as the animals grew in size. Body weight increased in a linear fashion for all of the energy treatments (Figure 3.1), while no differences were observed between the regression parameters (P> 0.05) (Table 3.4).

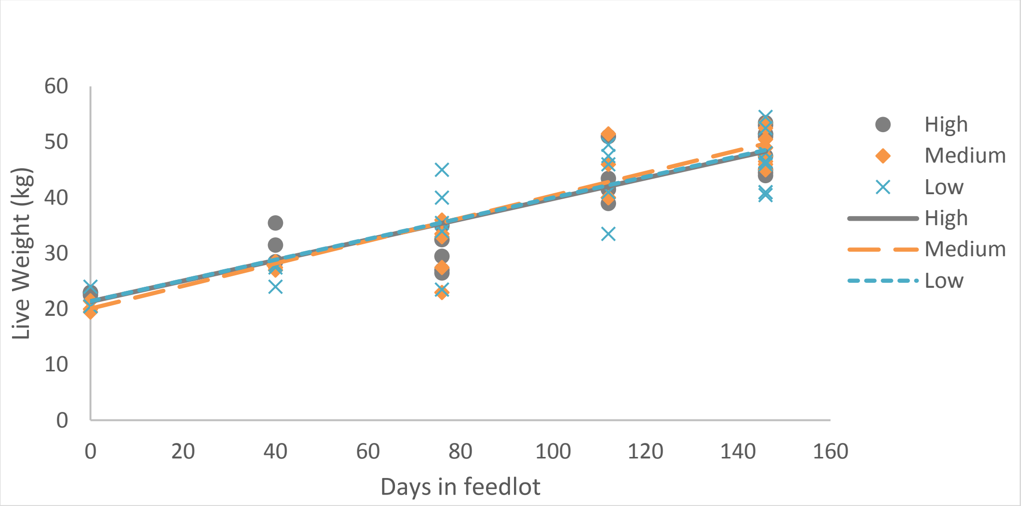

Figure 3.1 Linear regressions (y = *a* + *b*x, where x is number of days in the feedlot) of the change in end body weights of Boer goats fed diets that vary in energy content, slaughtered at different time intervals.

Table 3.4 Parameter means (± standard error) and R^2 coefficients of determination for linear regressions (y = *a* + *b*x, where x is number of days in the feedlot) seen in Figure 3.1 for the change in end body weights of Boer goats fed diets that vary in energy content, slaughtered at different time intervals.

End body weight			
	a	***b***	**R^2**
Low	21.413 ± 1.86	0.186 ± 0.02	0.82
Medium	20.066 ± 1.31	0.203 ± 0.01	0.98
High	21.337 ± 1.93	0.185 ± 0.02	0.82

$^{a-b}$ means in a column with different superscript letters differ (P< 0.05).

At slaughter, an interaction was observed between the time spent in the feedlot and the dietary energy treatment (P< 0.01) on the dressing out percentage of the goat carcass. As seen for the interaction of dietary energy and time in the feedlot on the final body weights, differences between the treatments were observed after 40 days (P= 0.01) and 76 days in the feedlot (P= 0.03), thereafter no differences were seen between the dietary energy levels and period in the feedlot (P> 0.05). This may have been due to the sampling effect seen with the end body weights, which further influenced the dressing percentage. The dressing percentage varied between the low and high energy treatments (P= 0.04), with goats on the low energy diet exhibiting a lower dressing percentage (45.8 ± 0.3%) high energy diets (47.1 ± 0.4%). The dressing percentage of goats slaughtered at the different intervals was seen to vary with time in the feedlot. Quadratic regression functions were fitted to the change in dressing percentage for the various treatments to describe the general increase in the dressing percentage of the carcass noted (Figure 3.2). These functions fitted the data well, with the models accounting for more than 70% of the variation of the data, with no significant differences being observed between the different diets for the quadratic regression parameters for the change in dressing percentage (Table 3.6).

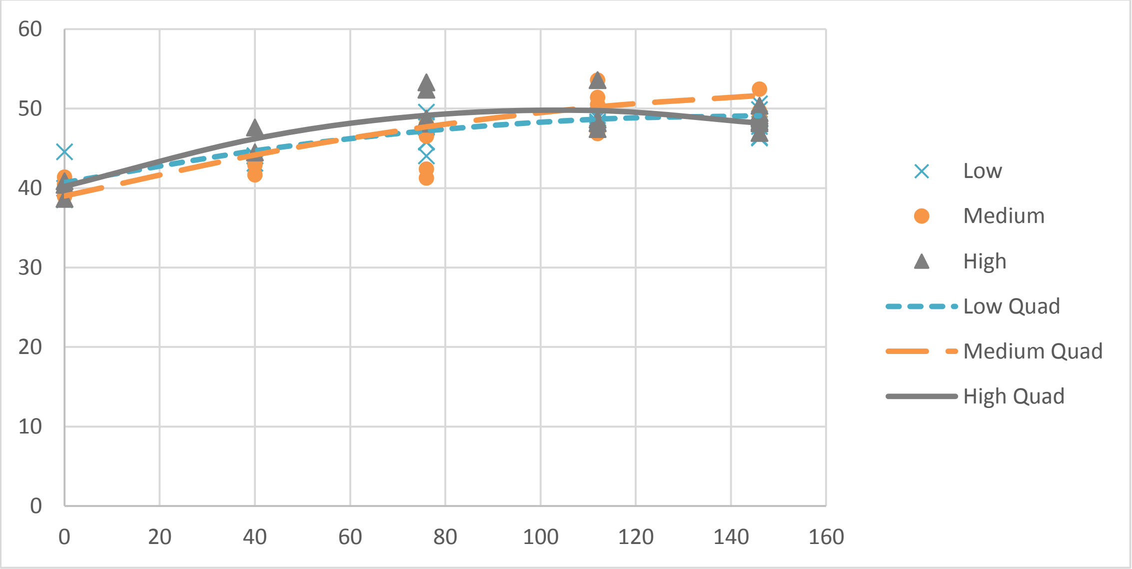

Figure 3.2 Quadratic regressions (y = *a* + *b*x + *c*x^2, where x represents days in the feedlot) for the change in dressing percentage of Boer goats fed diets varying in energy content, slaughtered after different intervals in the feedlot.

Table 3.5 Feedlot production characteristics of Boer goats fed either a low, medium or high energy diet, slaughtered at five production intervals (results expressed as least square means ± standard with least squared differences (LSD) for differences associated with time in the feedlot).

Production Trait	**Days in feedlot**				**Dietary Means**	***P*-value**	
	40	**76**	**112**	**146**		**Days in feedlot**	**Diet x Days**
End BW, kg							
Low	25.8^{b} ± 1.3	37.6^{a} ± 1.8	45.0 ± 2.1	47.1 ± 1.4	35.6 ± 0.8		
Medium	26.7^{b} ± 1.2	36.5^{a} ± 1.8	45.8 ± 2.7	49.6 ± 1.3	36.1 ± 0.8		
High	31.8^{a} ± 1.5	30.1^{b} ± 1.8	43.3 ±2.1	48.2 ± 1.3	34.8 ± 0.8	<0.01	0.04
P-value	0.03	0.03	0.73	0.49	0.57	(LSD= 3.6)	
ADG, g/day							
Low	285.7 ± 25.4	196.3^{b} ± 19.7	213.3 ± 19.7	192.2 ± 15.6	221.9^{ab} ± 10.2		
Medium	232.1 ± 22.0	252.4^{a} ± 19.7	238.1 ± 25.4	216.8 ± 14.7	234.9^{a} ± 10.4		
High	291.7 ± 25.4	122.2^{c} ± 19.7	196.9 ± 19.7	197.2 ± 14.7	202.0^{b} ± 10.1	<0.01	<0.01
P-value	0.21	0.02	0.71	0.62	0.02	(LSD= 53.7)	
DMI g/day							
Low	953.4 ± 80.6	1283.4^{a} ± 62.4	1429.7^{a} ± 62.4	1279.1 ± 49.3	1236.4^{a} ± 32.3		
Medium	863.8 ± 69.8	1316.5^{a} ± 62.4	1240.8^{ab} ± 80.6	1253.4 ± 46.5	1168.6^{a} ± 33.0		
High	848.1 ± 80.6	843.5^{b} ± 62.4	1172.2^{b} ± 62.4	1145.9± 46.5	1002.4^{b} ± 32.1	<0.01	0.01
P-value	0.36	<0.01	<0.01	0.05	<0.01	(LSD= 133.9)	
FCR							
Low	6.22 ± 1.53	4.50 ± 1.19	5.86 ± 1.19	4.88 ± 0.36	5.37 ± 0.61		
Medium	5.82 ± 1.33	5.93 ± 1.19	5.06 ± 1.53	4.57 ± 0.34	5.35 ± 0.63		
High	4.17 ± 1.53	3.57 ± 1.19	4.02 ± 1.19	4.61 ± 0.34	4.09 ± 0.61	0.40	0.34
P-value	0.35	0.38	0.59	0.81	0.06	(LSD= 1.71)	
Dressing percentage, %							
Low	43.8^{b} ± 0.51	47.6^{b} ± 0.78	48.2 ± 0.83	48.4^{a} ± 0.5	45.8^{b} ± 0.3		
Medium	42.3^{b} ± 0.46	47.3^{b} ± 0.78	51.8 ± 1.07	49.1^{a} ± 0.4	46.1^{ab} ± 0.3		
High	46.1^{a} ± 0.72	50.7^{a} ± 0.87	49.2 ± 0.83	48.8^{a} ± 0.4	47.1^{a} ± 0.4	<0.01	<0.01
P-value	0.01	0.03	0.06	0.53	0.04	(LSD= 4.4)	

$^{a-b}$ means in a column per production trait with different superscript letters differ ($P < 0.05$)

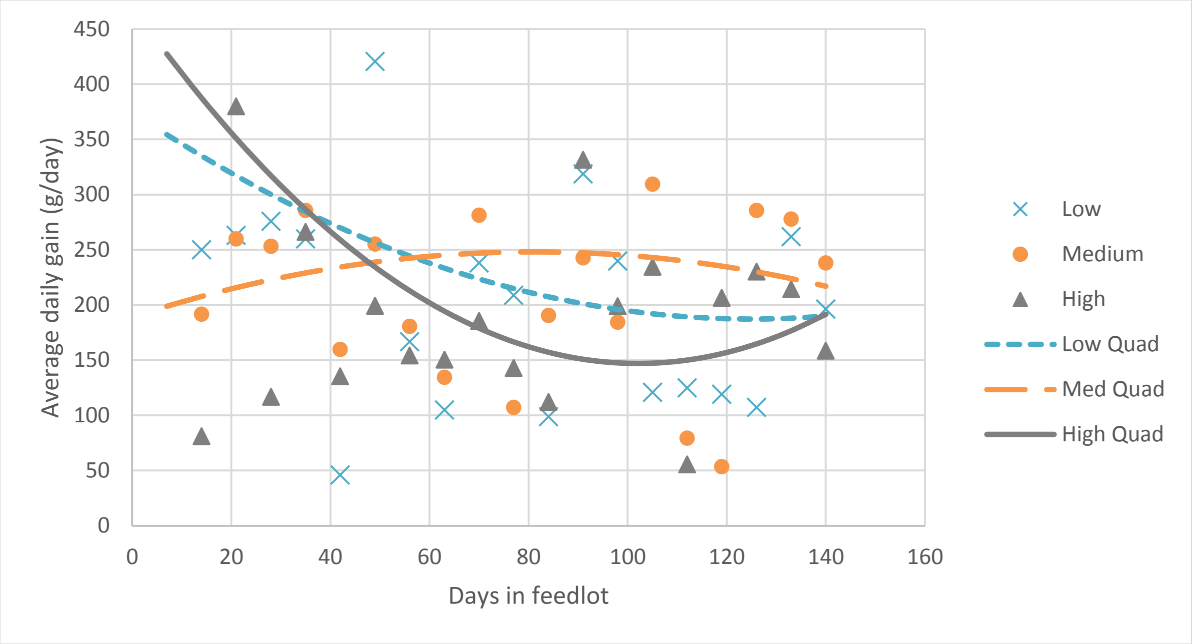

Figure 3.3 Quadratic regressions (y = a + bx + cx^2, where x represents days in the feedlot) for the change in ADG of Boer goats fed diets varying in energy content over time in the feedlot.

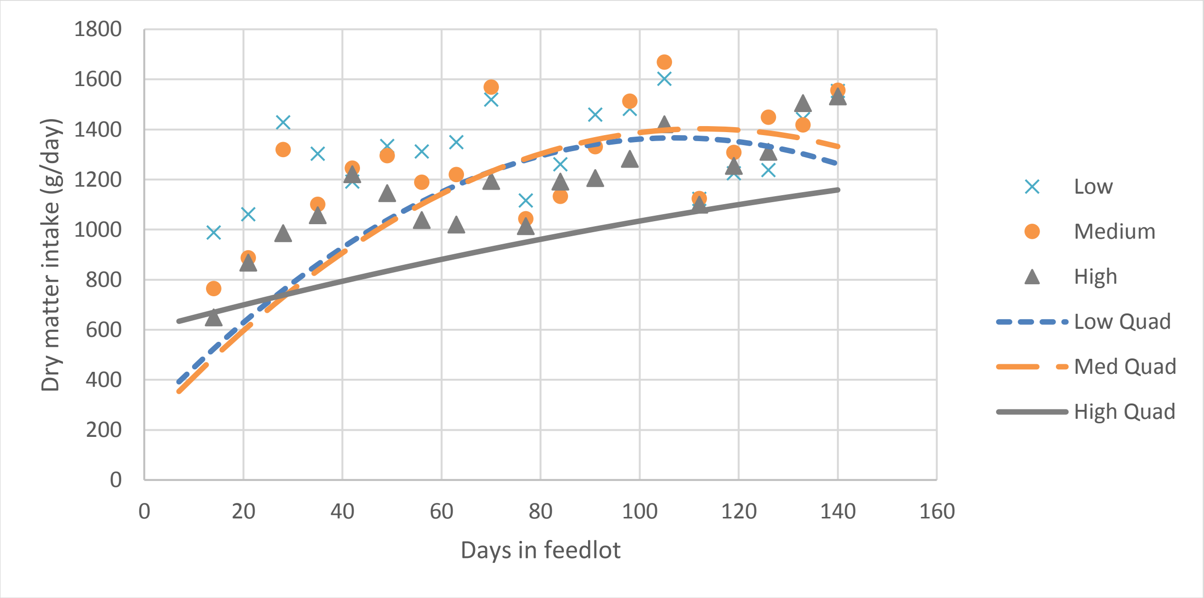

Figure 3.4 Quadratic regressions (y = *a* + *b*x + *c*x^2, where x represents days in the feedlot) for the change in DMI of Boer goats fed diets varying in energy content over time in the feedlot.

Table 3.6 Parameter means (± standard errors) and R^2 coefficients of determination for the quadratic regressions (y = *a* + *b*x + *c*x^2, were x represents days in the feedlot) of dressing percentage, ADG and DMI of Boer goats fed diets that vary in energy content, that were slaughtered after different periods in the feedlot.

Dressing percentage

	a	*b*	*c*	R^2
Low	40.69 ± 0.86	0.116 ± 0.02	-0.0004 ± 0.001	0.74
Medium	39.01 ± 0.98	0.145 ± 0.03	-0.0004 ± 0.001	0.81
High	40.22 ± 0.97	0.186 ± 0.03	-0.0009 ± 0.003	0.78

Average daily gain

	a	*b*	*c*	R^2
Low	374.75 ± 72.42	-3.00^{ab} ± 1.63	0.012^{ab} ± 0.01	0.31
Medium	188.88 ± 50.94	1.46^{a} ± 1.21	-0.009^{b} ± 0.01	0.18
High	470.00 ± 102.38	-6.33^{b} ± 2.30	0.031^{a} ± 0.01	0.29

Dry matter intake

	a	*b*	*c*	R^2
Low	250.76 ± 210.41	20.81 ± 4.74	-0.097 ± 0.02	0.59
Medium	210.77 ± 199.55	21.17 ± 4.73	-0.094 ± 0.02	0.62
High	597.39 ± 289.85	5.27 ± 6.51	-0.009 ± 0.03	0.38

$^{a-b}$ means in a column per production trait with different superscript letters differ ($P < 0.05$)

Significant interactions were observed between dietary energy content and days in the feedlot for both ADG ($P < 0.01$) and DMI ($P = 0.01$) (Table 3.5). After 76 days in the feedlot, the ADG of goats differed significantly between the dietary treatments, with the highest gains being achieved by goats on the medium diet (252.4 ± 19.7 g/day) while goats on the high diet exhibited the lowest gains (122.2 ± 119.7 g/day) in this period. Dietary energy treatment means for ADG did not vary in the remaining time intervals. The DMI intake was seen to vary between the different energy diets after 76 and 112 days in the feedlot ($P < 0.01$). In both trial intervals, goats on the high energy diet presented lower intakes than those attained by low and medium energy diets. No significant effect of diet was observed for the DMI of goats after 40 and 146 days in the feedlot. Overall it was observed that goats on the low and medium diets exhibited higher gains than goats on the high energy diet (221.9, 234.9 and 202.0 g/day respectively; P= 0.02). This was accompanied by goats on the low and medium diets exhibiting higher intakes than goats on the high energy diet (1236.4, 1168.6, and 1002.4 respectively; P< 0.01). The ADG and DMI of goats varied with time in the feedlot (P< 0.01).The trends for the change of these production traits over time in the feedlot could be described using quadratic functions (Figure 3.3 and 3.4). Generally it was observed that the curves of the low and high energy diets for ADG decreased over time, then levelling out, while the curve of the medium diet showed a trend to increase before levelling out in this time period. The curves of the different treatments tended to increase over time before levelling out and converging.

The function parameters were compared between the different energy diets (Table 3.6). The *b* parameter for the change of ADG of goats on the medium energy diet was a positive value compared to that of the other diets, and differed (P< 0.05) from the *b* parameter of the high energy diet (1.46 ± 1.21 and -6.33 ± 2.30 respectively). Conversely for the *c* parameter, the medium energy diet again differed (P< 0.05) from the high energy diet, with the medium diet now having a negative value for this parameter estimate (-0.0009 ± 0.01 and 0.031 ± 0.01 respectively). The regressions for ADG of the different treatments had moderate to low R^2 values and did not fit the data well. No significant differences were observed between the different energy diets for the parameter estimates for DMI. The R^2 values for the regressions of DMI for the different diets were moderate to high, except for the curve of the high energy diet which only accounted for about 38% of the variation of the data.

No significant interactions were observed for the feed conversion ratio of the goats (P= 0.34). The FCR remained constant throughout the trial period and did not differ over time (P= 0.40) or between the different diets (P= 0.06).

3.4 Discussion

The slaughter weights of the goats increased linearly with time spent in the feedlot (Figure 3.1), while no differences (P= 0.57) were observed between the treatments. When comparing the trends with the sigmoidal growth curve described by Owens *et al*., (1993); it can be seen that the goats were still in the rapid growth phase, indicating they have not yet reached maturity, where body weight remains relatively constant. The dressing out percentage of the goats after slaughter increased with time spent in the feedlot (P< 0.01), and the average dressing percentage of the goats on the high diet was found to be the highest (47.1%), followed by medium (46.1%) and low diets (45.8%) (P = 0.04). Ryan *et al*. (2007) found a similar trend with goats consuming higher levels of concentrate to exhibit higher dressing percentages. Solaiman *et al*. (2012) found that increasing the body weight of Boer goats from

22 to 36 kg resulted in an increase in the dressing percentage from 48.5 to 50.1%. Sheridan *et al*. (2003) reported dressing percentages greater than 52% for Boer goats reared in a feedlot, while Cameron *et al*. (2001) found that the dressing percentage of Boer goat crosses varied between 46 and 48%. The differences in carcass yield obtained in this study can be explained by an increase in the growth of muscle and adipose tissues with time on feed. As the animal grows, the muscularity of skeletal muscles increases, accompanied with an increase in fat deposition as the animal grows older (Owens *et al*., 1993). Increasing the energy content of the feedlot diet increases the amount of energy that becomes available to the animal for growth of muscle and fat tissue (Webster, 1980). Restricted movement within the feedlot, as well as the higher energy diets, promotes an increase in fat deposition of the animal. However, goats tend to deposit fat in adipose tissue of the abdominal cavity, which is considered not to be a part of the carcass, before developing subcutaneous fat depots (Webb, 2014). It is expected that the dressing percentage would increase and then level off as the animals near maturity (Owens *et al*., 1993). From the quadratic regressions, it seems as if the goats had reached the point in their growth towards the end of the trial, where dressing percentage would level off and remain constant.

The growth rate of goats tended to decrease with time spent under feedlot conditions, with the highest growth rates being achieved by goats early in the feeding period, after which growth rates declined and stabilized (Figure 3.2). Overall, the goats that received low and medium energy diets exhibited higher ADGs (221.9 and 234.9 g/day) than goats that received the high energy diet (202.0 g/day) (Table 3.5). It has been reported that goats exhibit slower growth rates than sheep (El Khidir *et al*., 1998; Sheridan *et al*., 2003), and that male goat kids grow at a faster rate than females (Van Niekerk & Casey, 1988; El Muola *et al*., 1999). The Boer goat which is regarded as one of the best meat goat breeds (Steyn, 2010), exhibits a growth rate of more than 200 g/day under favorable conditions. Under feedlot conditions, the Boer goat presents ADGs varying between 150- 220 g/day (Sheridan *et al*., 2003) while Boer crossbred kids grow at a rate of 150-160 g/day (Cameron *et al*., 2001). Luo *et al*., (2004) noted that meat goats grew at a rate of 158 g/day while dairy goats grew at a rate of 138 g/day. The higher ADGs achieved in this study indicate that improved growth rates can be achieved by feedlot finishing goats on diets with higher energy contents. The mature body weight as well as the potential growth rate of an animal is determined genetically, although it can be manipulated by nutritional factors (Owens *et al*., 1993), as was shown in this study. Dietary energy is generally considered to be the baseline requirement, as it provides the energy needed for growth, to maintain and synthesize body tissues. An understanding of the effect of varying the energy content of the diet on growth traits along with regression equations will give an indication of the maintenance requirements of growing Boer goats (Bellof & Pallauf, 2004).

Sheridan *et al*., (2003) did not find differences in ADG of Boer goats fed diets containing 9.9 and 12.1 MJ ME/kg feed. Wang *et al*. (2014) also did not detect a difference in the growth rate for Hainan black goats fed diets varying in DE (11.7- 13.4 MJ/kg). Yagoub and Babiker (2008) did note that ADG of Nubian goats did increase when the dietary energy was increased from 8.5 to 10.5 MJ ME/kg feed. Sheridan *et al*. (2003) found that the growth rate of Boer goat kids with an initial weight of about 26 kg also showed a tendency to decrease between 28 to 56 days in the feedlot. Initial post-weaning growth rates increase with improved nutrition, as the amount of metabolisable energy needed for the growth of muscle is less than that which is provided in the diet. As an animal grows, it deposits different amounts of protein in its muscles and fat in adipose tissue (Lawrence *et* al., 2012). Young animals have a relatively high muscle and low fat content compared to older animals (Owens *et al*., 1993). The amount of energy required in order to synthesize and deposit protein in muscle is lower than that of fat, although the energy density of fat is greater than that of protein (Webster, 1980). Therefore animals exhibit higher growth rates at younger ages, as seen with the high initial growth rates exhibited by the goats (Table 3.2). This is particularly the case in animals undergoing compensatory growth during realimentation after a period of limited or poor nutrition (Ryan *et al*., 1993). This is commonly seen when young animals are weaned and introduced to intensive feeding practices, as suggested by the higher gains achieved by the goats in this study after the initial 40 days in the feedlot (Table 3.5).

As the animal grows to maturity, the growth rate reaches the point where it is at its maximum, after which it declines. This decline in growth rate is due to increased energy costs for maintenance of body tissues and so less energy is available for production. This can be related to the goats passing the inflection point on the growth curve as they near maturity. However the low R^2 values associated with the curves fitted to the change in growth rate (Figure 3.3) and the linear growth exhibited by the goats (Figure 3.1), suggest that they have not yet attained this point on the growth curve. The lower ADG exhibited by goats on the high energy diet may also be attributed to the effect of the high starch content on rumen function. Boer goats are efficient utilizers of diets with a lower ME content (Sheridan *et al*., 2003), as they are adapted to consume low quality forages. Consuming grain based diets that contain high quantities of rapidly fermentable starch, which contribute to the energy density of the diet, causes the pH of the rumen to decrease, reducing the activity of rumen microorganisms (Macdonald *et al*., 2011). Ruminal fermentation of starch yields organic acids which lower the pH of the rumen to below 5.5, which causes subclinical acidosis resulting in decreased digestibility of other nutrients and decreased growth (Enemark *et al*., 2002). As the energy density of the diets increased, the proportion of maize in the formulations increased, along with a decrease with the proportion of forage (Table 3.2). The increase in energy density of the diets was accompanied by a decrease in the neutral detergent fibre (NDF) fraction (Table 3.2), owing to decreased rumination and buffering capacity in the rumen.

The regulation of dry matter intake in ruminants is governed by long term as well as short term mechanisms. Long term mechanisms involve adjusting the feed intake according to the nutrient requirements, while short term effects experienced during periods of ingestion and rumination are influenced by gut fill, passage rate and chemical feedback from the rumen (Dulphy & Demarquilly, 1994). In this study it was seen that the daily dry matter intake differed ($P< 0.01$) between the dietary treatments, with goats on the low and medium energy diets having the highest intakes (1236.4 and 1168.6 g/day respectively) compared to goats on the high energy diet (1002.4 g/day). This confirms that feed intake in goats is regulated by the long term effect of energy requirements and in goats, feed intake will decrease with an increase in dietary energy content. Solaiman *et al*. (2012) showed that between 0 to 56 days on feed, the intake of Boer goats increased from 996 g/day to 1155 g/day; however DMI decreased to 1069g/day when the period was extended to 85 days. Similar trends were discovered by Lu and Potchoiba (1990), when goats were fed diets that contained between 10.3 and 12.8 MJ ME/kg. Regression analysis of feed intake can be used to determine the energy requirements of an animal under similar conditions (Luo *et al*., 2004).

Feed intake increases with the size of an animal until the gastrointestinal organs reach maturity and so physically restrict the amount of feed that the animal can consume (Dulphy & Demarquilly, 1994). This coincides with the reduction in growth rates as the animal nears maturity and more energy is required for maintenance, and less for growth (Owens *et al*., 1993; Lawrence *et al*., 2012). The intercepts (*a* parameters) of these regression functions represents the intake of the goats when they are introduced to the concentrate diets, however as the R^2 values are moderate and not high, these values may underestimate the actual initial intakes. As the tendency of the slope of quadratic function changes after it reaches the inflection, this function can only be considered up until the endpoint of this trial and not accurately for further extrapolation. The curves of the different diets tended to converge towards the end of the feeding period (Figure 3.3). At this point the feed intake of the goats on the different diets were similar, suggesting that at this stage of their growth, the energy requirements may resemble that of the medium energy diet which is 12.7 MJ ME/ kg feed. The effect of gut fill on the physical regulation of feed intake may only have an influence on goats consuming diets containing higher fibre content (Poppi *et al*., 1994). The lower intakes seen in goats consuming diets with the higher energy density (Table 3.5) may also be influenced by metabolic and chemical feedback mechanisms. Fat deposition increases when animals consume diets with greater energy densities (Ryan *et al*., 2007), which may result in feedback from adipose tissue or greater quantities of free fatty acids in the blood to suppress hunger and reduce intake (NRC, 1987). It may also be argued that high energy diets disrupt the chemical balance that exists in the rumen, which maintains the fermentation activity of the microorganisms through rapid starch fermentation. Ruminants are especially sensitive to variations of pH and osmotic pressures in the reticulo-rumen, which trigger receptors chemically to adjust the level of intake (Dulphy & Demarquilly, 1994). This lowering of the intake may also have contributed to the lower ADG experienced by goats on the high energy diet (Table 3.5). The DMI increased in a curvilinear trend with time spent on feed (Figure 3.3), with peaks in intake being reached around 100 days in the feedlot, after which intake decreased. Similar trends in intake were described by Ryan *et al*. (1993) for cattle and sheep and by Cameron *et al*. (2001) with Boer x Spanish goat kids. Intake increases with live weight in order to meet the requirements of the growing animal. The decrease in intake may be as a result of physical restrictions due to gut fill (Lu & Potchoiba, 1990). Although the size of visceral organs are affected by the type of diet that the animal consumes (Meyer *et al*., 2015), the proportion of the alimentary tract decreases relative to the live weight of the animal as it nears maturity (Butterfield, 1988). Therefore components of the digestive tract develop to maturity earlier than the rest of the body, and so the rumen reaches a point where it can no longer expand, and so intake is physically suppressed. Unlike sheep and cattle, goats deposit large quantities of fat in the abdominal cavity (Webb, 2014), which limits the space in the abdomen and may thus contribute to the increased pressure on the rumen, thereby limiting feed intake.

Generally, goats on the low and medium energy diets consumed larger quantities of feed which resulted in higher growth rates. A lower FCR is considered to be more advantageous, as it reduces the costs of production. In this trial, the goats attained favourable FCRs that can be attributed to the balanced high concentrate rations that they were supplied. The amount of feed required in order to gain a unit of live weight remained constant throughout the trial period. As the goats were in the linear growth phase where maintenance requirements of the animal are generally low, the FCR remains constant, until the goats attain mature body weight where they have higher maintenance costs, due to higher levels of body fat where FCR would increase. This is because the energy costs in order to maintain fat tissues is higher than that of lean tissues, as proteins tend to associate with greater quantities of water, contributing to the body weight gain (Marais *et al.,* 1991; Lawrence *et al*., 2012). Goat carcasses are considered to be lean, and so one would expect high energy efficiency for growth, however goats do deposit large quantities of fat in the abdominal cavity which would increase the costs of growth. The FCR of Boer goats in this trial were superior to the findings of Sheridan *et al*. (2003) (6.37-9.09 kg feed consumed/ kg body gain). Solaiman *et al.* (2012) found that the FCR of goats finished on a combination of concentrate and hay was ~8.20 kg feed consumed/ kg weight gain. The better FCR found in the current study shows that finishing goats on balanced high energy concentrate diets improves the efficiency of slaughter kid feedlot production. Yagoub and Babiker (2008) found that the FCR of Nubian goats decreased with an increase in dietary energy content. However, the FCRs presented in their study were lower (better) than those found in this study, as Nubian goats have a lower mature weight and have not been intensively selected for improved meat production as the Boer goat breed has.

3.5 Conclusion

From this study, it was seen that goats that were supplied with the high energy diet exhibited poorer growth rates and presented lower intakes than the other treatments. The lower intake may be due to the goats adjusting their level of intake in response to the energy content of the diet. As goats have not been bred to be reared on high concentrate diets, the high energy diet (12.7 MJ ME/kg feed) may decrease the pH in the rumen environment causing sub-clinical acidosis, which contributes to lower intake levels and thus growth. Goats fed the low energy diet presented higher feed intakes in order to compensate for the difference in the energy content of the diet and the requirements of the animal. The feed conversion ratio remained constant during the feeding period and did not differ between the different diets. It can be concluded that the low and medium energy diets may be the more suitable energy levels that can be used to formulate feeds to finish goats, as they promotes good growth rates, with similar feeding efficiencies. Therefore, energy requirements for growth of Boer goats in a feedlot may resemble a metabolisable energy value that lies between the low and medium energy diets.

Live weights of the goats increased with time spent in the feedlot, with dressing percentages increasing and appearing to level off towards the end of a 20 week feeding period. As the goats exhibited high growth rates and similar feeding efficiencies during the trial, it can be concluded that goats can be finished to heavier live weights, between 40 and 50 kg. This will yield a heavier carcass at slaughter which could potentially improve profit margins in a feedlot, dependent on the input production costs.

3.6 References

Animut, G., and Goetsch A. 2008. Co-grazing of sheep and goats: Benefits and constraints. Small Ruminant Research. 77: 127-145.

Bellof, G. and Pallauf, J. 2004. Utilization of energy for growth in lambs of the breed German Merino Landsheep. Archives of Animal Nutrition. 28: 495-505.

Butterfield, R. M. 1988. New concept of sheep growth. Department of Veterinary Anatomy. University of Sydney, Australia. 1-57.

Cameron, M., Luo J., Sahlu T., Hart S., Coleman S., and Goetsch A. 2001. Growth and slaughter traits of Boer x Spanish, Boer x Angora, and Spanish goats consuming a concentrate-based diet. Journal of Animal Science. 79: 1423-1430.

Casey, N., and Van Niekerk W. 1988. The Boer goat. I. origin, adaptability, performance testing, reproduction and milk production. Small Ruminant Research. 1: 291-302.

Casey, N. H., and Webb E. C. 2010. Managing goat production for meat quality. Small Ruminant Research. 89: 218-224.

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

da Cunha Leme T. M., Titto E. A. L., Titto C. G., Pereira A. M. F., and Neto M. C. 2013. Influence of stocking density on weight gain and behaviour of feedlot lambs. Small Ruminant Research. 115: 1-6.

Dubeuf, J., Morand-Fehr P., and Rubino R. 2004. Situation, changes and future of goat industry around the world. Small Ruminant Research. 51: 165-173.

Duddy, G., Bell A., Shands C., and Hegarty R. 2007. Feedlotting lambs. Prime-Facts. (523)

Dulphy, J.P. and Demarquilly C. 1994. The regulation and prediction of feed intake in ruminants in relation to feed characteristics. Livestock Production Science 39: 1-12.

El Khidir, I. A., Babiker, S. A. and Shafie, S. A. 1998. Comparative feedlot performance and carcass characteristics of Sudanese desert sheep and goats. Small Ruminant Research. 30: 147-151.

El Muola, I. H. A., Babiker, S. A., El Khidir, I. A. and Ibrahim, S.E. 1999. Meat production from female goat kids compared with males. Journal of Agricultural Science. 133: 223-226.

Enemark, J. M. D., Jorgensen, R. J. and St Enemark, P. 2002. Rumen acidosis with special emphasis on diagnostic aspects of subclinical rumen acidosis: a review. Veterinarija ir Zootechnika 20: 16-29.

FAOSTAT. 2015. Food and Agriculture Organization of the United Nations, Statistics Division. http://faostat3.fao.org/browse/Q/*/E (Accessed September 2015).

Lawrence, T. L. J., Fowler, V. R. and Novakofksi J. E. 2012. Growth of farm animals. 2nd edition. CABI. 216-228.

Lu, C., and Potchoiba M. 1990. Feed intake and weight gain of growing goats fed diets of various energy and protein levels. Journal of Animal Science. 68: 1751-1759.

Luo, J., Goetsch A., Sahlu T., Nsahlai I., Johnson Z., Moore J., Galyean M., Owens F., and Ferrell C. 2004. Prediction of metabolizable energy requirements for maintenance and gain of preweaning, growing and mature goats. Small Ruminant Research. 53: 231-252.

Macdonald, P., Edwards R. A., Greenhalgh J. F. D., Morgan C. A., Sinclair L. A., and Wilkinson R. G.. 2011. Animal nutrition. Seventh ed. Pearson Education Limited. England.

Malan, S. 2000. The improved Boer goat. Small Ruminant Research. 36: 165-170.

Marais, P.G., van der Merwe, H.J. and du Toit, J.E.J.. 1991. The efficiency of protein and fat deposition during growth in Dorper sheep. South African Journal of Animal Science. 21: 103-107.

Meyer, A. M., Vraspir, R. A., Ellison, M. J. and Cammack K. M. 2015. The relationship of residual feed intake and visceral organ size in growing lambs fed a concentrate or forage based diet. Livestock Science. 176: 85-90.

NRC. 1987. Predicting feed intake of food-producing animals. National Academy Press, Washington, DC.

Owen, J. E., and Norman G. A. 1977. Studies on the meat production characteristics of Botswana goats and sheep-Part II: General body composition, carcass measurements and joint composition. Meat Science. 1: 283-306.

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

Poppi, D.P., Gill, M. and France, J. 1994. Integration of theories of intake regulation in growing ruminants. Journal of Theoretical Biology. 167: 129-145.

Ryan, S., Unruh J., Corrigan M., Drouillard J., and Seyfert M. 2007. Effects of concentrate level on carcass traits of Boer crossbred goats. Small Ruminant Research. 73: 67-76.

Ryan, W. J., Williams, I. H., and Moir, R. J. 1993. Compensatory growth in sheep and cattle. I. Growth pattern and feed intake. Crop and Pasture Science. 44: 1609-1621.

SAS Institute, 2006. SAS/Stat User's Guide Version 9, 1st printing, Volume 3, SAS Institute, Inc, SAS Campus Drive, Cary, North Carolina 27513.

Sheridan, R., Ferreira A., and Hoffman L. 2003. Production efficiency of South African mutton merino lambs and Boer goat kids receiving either a low or a high energy feedlot diet. Small Ruminant Research. 50: 75-82.

Solaiman, S., Min, B. R., Gurung, N., Behrends, J., and McElhenney, W. 2012. Effects of breed and harvest age on feed intake, growth, carcass traits, blood metabolites, and lipogenic gene expression in Boer and Kiko goats. Journal of Animal Science. 90: 2092-2108.

Stanton, T., and Levalley S. 2006. Lamb feedlot nutrition. Colorado State University 4: 08.

Steyn, J. 2010. Farming with Boer goats: A practical guide for Southern African conditions. First ed. Patriot Publishers. Potchefstroom, South Africa.

Van Niekerk, W., and Casey N. 1988. The Boer goat. II. Growth, nutrient requirements, carcass and meat quality. Small Ruminant Research. 1: 355-368.

Wang, D., Zhou L., Zhou H., Hou G., Shi L., Li M., Huang X., and Guan S. 2014. Effects of nutritional level of concentrate-based diets on meat quality and expression levels of genes related to meat quality in Hainan black goats. Animal Science Journal. 86: 166-173.

Webb, E. 2014. Goat meat production, composition, and quality. Animal Frontiers. 4: 33-37.

Webster, A. J. F. 1980. The energetic efficiency of growth. Livestock Production Science. 7: 243-252.

Yagoub, Y. M. and Babiker, S. A. 2008. Effect of dietary energy level on growth and carcass characteristics of female goats in Sudan. Livestock Research for Rural Development. 20: 202.

Chapter 4

Modelling the growth and feed intake of Boer goats reared under feedlot conditions

Abstract

Mathematical models can be used to describe biological processes, such as growth and feed intake in livestock production systems. The Gompertz model is ideally suited to describe the sigmoidal growth curve that is exhibited by an animal as it grows to mature body weight. Data was collected from Boer goat slaughter kids that were housed in individual pens and supplied one of three feedlot diets that varied in energy content (11.3, 12.0 and 12.7 MJ ME/ kg feed). Growth and feed intake of the goats were monitored weekly, from the start of the trial when they weighed about 22.2 ± 3.5 kg, up until the end of a 20- week period when they were slaughtered (48.3 ± 0.8 kg). The body weights and metabolic body weights were plotted against the number of weeks in the feedlot. Gompertz and linear models were fitted to the data and compared. The Gompertz function did not fit the data set ($P < 0.01$) as well as the linear model, as the goats were experiencing the phase of linear growth, and growth rates had not yet declined as would be expected when the goats near maturity. Therefore the growth rate and weights of slaughter kids under feedlot conditions between 126 and 266 days of age can be predicted using the linear model $BW = 0.202t - 5.241$ (where t= estimated age in days; $R^2 = 0.84$). Feed intake was modelled with the body weight of the goats throughout the trial period, using dry matter intake as the independent variable. Transformations of the dry matter intake, such as its natural logarithm and metabolisable energy intake, were also investigated to develop linear models to predict feed intake from body weight. It was observed that these transformations accentuated the variation of the estimated model parameters between the different feedlot diets ($P < 0.05$). Coefficients of model determination showed that models of dry matter intake and its transformation with body weight accounted for not more than 30% of the variation of the data. Therefore, these models are not sufficient to predict feed intake on their own and further analysis and a possible combination of different variables are required to accurately model feed intake with the body weight of Boer goats during the 20-week feeding period.

4.1 Introduction

Small stock production has been seen to be of great importance for the production of wool, leather, red meat as well as dairy products for human use (Sayed, 2011). Small stock production in Africa has increased tremendously since 1993, with South Africa contributing an estimated 31.2 million head of sheep and goats in 2013 (FAOSTAT 2015). The level of sheep and goat production varies from free range, extensive to intensive production systems on commercial farms, as well as a large sector comprising of communally herded livestock. The versatility of the small stock industry is made possible by having a wide selection of breeds that are suited to specific environmental and production conditions.

Increases in the prices for mutton and lamb meat and chevon have resulted in farmers finishing lambs or kids in feedlot systems in order to optimize growth rates and achieve a desirable slaughter weight at an earlier age with an optimal degree of fatness. Typically in a feedlot, animals are grouped according to gender and body weight and are slaughtered when they reach a predetermined weight, regardless of breed or level of physiological maturity. In order to ensure efficient optimal levels of production, an understanding of the growth trends and feed consumption is needed. The growth of an animal may be defined as an increase in live body weight which is accompanied by a change in size and shape (Owens *et al*., 1993), as a result of different tissues maturing at different rates (Butterfield, 1988). The rate of growth and development of fat and lean muscle tissues are of great importance in meat production, and these are largely influenced by the mature body size of the animal (Glimp, 1995). The mature body weight of an animal varies, and is dependent on factors such as species, breed, gender, selection pressure, production system and environmental conditions that the animal is exposed to (Malhado *et al*., 2009). This mature size is predetermined genetically but may be altered through nutrition and hormonal factors, with the level of nutrition in particular having a great effect on the growth rate and development of different body components (Owens *et al*., 1993; Kamalzadeh *et al*., 1998).

The growth rate of an animal varies throughout its life. The change in growth rate can be monitored by plotting the growth of an animal from birth to maturity, which produces a sigmoidal curve with an initial lag phase, followed by a period of rapid growth which stabilises as the animal attains its mature body weight (Owens *et al*., 1993). Such growth curves may be incorporated along with mathematical models in order to estimate trends, the effects of various treatments on the rate of growth, as well as the interactions between treatments over time, and also identify individuals whose performance differ from what is expected (Bathaei & Leroy, 1996; Malhado *et al*., 2009). A mathematical model is an equation, or set of equations, that can be used to represent trends of a biological system (Thornley & France, 2007). An advantage of using such a model to describe animal growth is that it condenses data collected at several stages throughout the animal's life into a few parameters that have biological meaning (Bathaei & Leroy, 1996). Analysis of such growth models can be helpful in establishing efficient feeding strategies, as well as optimal slaughter age (Malhado *et al*., 2009).

Various non-linear growth functions have commonly been used throughout literature to model the sigmoidal growth pattern of small stock breeds, including the Brody, Richards, Von Bertalanffy, Gompertz and logistic functions (Bathaei & Leroy, 1996; Malhado *et al*., 2009; da Silva *et al*., 2012). An ongoing debate exists about which function best describes sheep growth, when different models have different applications and accuracies to animals under certain conditions (da Silva *et al*., 2012). The Gompertz model is most ideally suited for describing the growth of finishing animals, as meat from livestock species generally comes from animals that never attain full mature body weight, although knowledge of the mature body weight of an animal is required in order to apply the model.

As the growth curve of the South African Boer goat has not been plotted, and trends cannot be predicted, the aim of this study was to plot the growth curves for South African Boer goat slaughter kids under feedlot conditions from about 126 to 266 days of age. Various applicable functions could then be fitted to the curves and their accuracy in predicting growth trends under specific conditions could then be evaluated. This can then be used to predict growth trends and an optimal slaughter age for slaughter goats and feedlot lambs, as well as establish efficient strategies to predict the feed intake at specific body weights.

4.2 Materials and Methods

For this study, the growth of 26 Boer goats was monitored in order to plot the change in body weight against the age of the goat. The goat kids were weaned at about 18 weeks of age (average weight 22.2 ± 3.5 kg) and transported to Elsenburg experimental farm where they were housed in individual pens. The goat kids were randomly allocated to one of three trial diets that varied in energy content (Table 4.1 and 4.2). The energy content of the diets were 11.3, 12.0 and 12.7 MJ ME/kg feed, expressed on an as fed basis with a moisture content of 10.4%, for the low, medium and high energy diets respectively . These trial diets were supplied to the goats *ad libitum*. Feed intake and growth of the goat kids were monitored weekly and daily dry matter intake was calculated for each animal up to approximately 266 days (48.3 ± 0.8). The cumulative dry matter intake was also calculated for each animal over the 20 week trial period At the end of the feeding period, the trial goats were slaughtered at a registered abattoir. As the weights of the goats were not monitored before they were introduced to the feedlot conditions, the models could only encompass growth over the 20 week feeding period.

Table 4.1 The formulation of the trial diets fed to Boer goat kids.

Ingredients	**Diets (% As fed)**		
	LE	**ME**	**HE**
Maize	44.30	54.90	65.50
Lucerne hay	39.00	24.90	10.80
Cottonseed oilcake	8.00	11.44	14.89
Molasses Powder	2.50	2.50	2.50
Salt, NaCl	1.0	1.00	1.00
Bicarbonate of Soda	2.00	2.00	2.00
Ammonium Sulphate	1.00	1.00	1.00
Slaked Lime	0.90	1.10	1.30
Urea	0.50	0.50	0.50
Mono calcium phosphate	0.34	0.18	0.02
Vitamin and Mineral premix	0.25	0.25	0.25
Sulphur	0.20	0.20	0.20
Commercial growth promoters and coccidiostat premix	0.020	0.020	0.020
Total	**100**	**100**	**100**

LE – Low energy diet. ME – Medium energy diet. HE – High energy diet.

Table 4.2 The nutrient composition of the trial diets fed to Boer goat kids.

Nutrients	Nutrients of Diets (as fed)		
	LE	**ME**	**HE**
In vitro organic matter digestibility, %	74.41	79.30	86.25
Total digestible nutrients (TDN) %*	64.09	68.00	70.69
Metabolisable energy, MJ/ kg ^{x}	11.30	12.00	12.70
Protein, %	14.30	14.28	14.98
Fibre, %	12.7	10.4	6.3
Neutral detergent fibre, %	29.24	28.29	22.85
Acid detergent fibre, %	15.84	12.78	8.57
Ash, %	10.12	8.63	7.57
Fat, %	1.16	1.37	1.31
Calcium, %	1.25	1.08	1.00
Phosphorous, %	0.45	0.41	0.40

LE – Low energy diet. ME – Medium energy diet. HE – High energy diet.

^{x} Formulated metabolisable energy values.

* Calculated total digestible nutrients = (0.8 x protein) + (0.4 x fibre) + (0.9 x nitrogen free extract) + (2.025 x fat).

The Gompertz as well as a linear function was fitted to the data to describe the growth of the goats while they were in the feedlot (Table 4.3). Normal body weight (BW), as well as the metabolic weight ($BW^{0.75}$) of the goats, was used to generate the growth models over time. Metabolic body weight was considered in order to give an indication of the increase in weight of growing body tissues. Parameters for the model functions were projected using SAS 9.2, with dietary energy treatment applied as a main effect. Individual regressions, using the Gompertz and linear functions, were generated for the predicted growth of each individual goat. Analysis of variance was used to determine whether the model parameters derived from the regressions differed between goats fed the three dietary treatments. The parameter estimates are reported as least square means along with the standard error of the means. For the Gompertz growth curve, the parameters of individuals were removed where the a parameter exceeded a value of 120. In this function, the a parameter represents the asymptotic or mature body weight. Therefore values exceeding 120 are regarded as being biologically inaccurate. For the linear regressions of growth with time, individuals were removed and regarded as outliers if the intercept was a negative value. Normal probability plots, as well as the Shapiro-Wilk test were used to test for non-normality of the residuals for feed intake. Outliers were identified and residuals greater than 3 were removed from the dataset. Correlations between feed intake and mass were determined using Pearson correlation coefficients (r). Linear models were then generated in SAS 9.2 (SAS, 2006) to predict feed intake (DMI) from the BW and the $BW^{0.75}$ of the goats. To develop more accurate models of feed intake, the natural logarithm of the dry matter intake (LnDMI) and metabolisable energy intake (MEI) were also modelled against the growth of the goats. Additionally the possibility of modelling the weekly cumulative dry matter intake and its natural logarithm with weight of the goats was investigated. The linear models used to predict feed intake variables from the independent growth variables are all of the form y= a + bx, where x is the weight (kg) of the goat. The goodness of fit of the various models was tested by calculating the R^2 coefficients of model determination (Tedeschi, 2006). As R^2 coefficients cannot be applied to non-linear models, the Pearson correlations (r) were used to determine the correlation between mass predicted by the Gompertz models and the actual mass (Tedeschi, 2006).

Table 4.3 Functions considered to model the growth of Boer goats during the 20 week feeding period from approximately 126 days of age (22.2 ± 3.5 kg) up to 266 days (48.3 ± 0.8 kg).

Model	Function	No. of parameters	Reference
Gompertz model	$W = a.e^{-e^{-b(t-c)}} + \varepsilon$	3	Thornley & France (2007)
Simple Linear model	$W = W_0 + Dt + \varepsilon$	2	Thornley & France (2007)

W = BW; W_0 = initial BW in kg; a = mature BW in kg; t = age in days; b represents the constant describing the rate of maturation; c represents the days of maximum growth; D represents the slope or the rate of growth.

4.3 Results

The weekly weights of each goat were plotted against time, the age of the goat in the feedlot (days), and Gompertz and linear functions were fitted to the curves in order to describe the growth of the goats mathematically (Table 4.4 and 4.5). Strong positive correlations were observed between the mass values predicted by the Gompertz function and the actual weekly mass values ($r = 0.92$; $P< 0.01$). The parameter estimates did not differ between goats on the different dietary energy treatments for the Gompertz models of body weight and metabolic body weight. Using the averages of the parameter estimates, overall models for the change in body weight and metabolic body weight using the Gompertz function could be generated (equations 1 and 2 respectively):

$$BW = 65.889 \times \exp(-\exp(-0.010 \times (t - 147.200))) \qquad \text{(equation 1)}$$

$$BW^{0.75} = 22.606 \times \exp(-\exp(-0.101 \times (t - 114.500))) \qquad \text{(equation 2)}$$

In both equations *t* represents the age of the goats in the feedlot in days. The Gompertz model for the change in metabolic body weight with age was found to better fit the data ($P < 0.01$) than modelling body weight with age using the Gompertz function. The coefficients of determination for the parameters of the Gompertz equation were generally low ($R^2 < 0.20$). It was also observed during the estimation of the parameters that the nonlinear regressions of a few individuals did not converge, resulting in an overestimation of parameters. These parameters were unrealistic and were regarded as outliers and removed from the data set.

Table 4.4 Least square means ± standard errors of the parameter estimates for the growth models applied to the goats under various treatments using the non-linear Gompertz function (Pearson correlation coefficient (r) is given to describe the correlations between mass predicted and actual mass).

	Treatment	***a***	***b***	***c***	**r**
BW	Low	75.27 ± 5.70	0.010 ± 0.001	151.83 ± 12.15	0.92
	Medium	69.91 ± 6.75	0.011 ± 0.001	162.50 ± 14.37	0.93
	High	75.27 ± 5.70	0.008 ± 0.001	158.64 ± 12.15	0.93
	P-value	0.68	0.34	0.84	
$BW^{0.75}$	Low	22.92 ± 1.23	0.010 ± 0.001	116.64 ± 16.42	0.92
	Medium	22.16 ± 1.55	0.012 ± 0.001	121.26 ± 8.12	0.96
	High	25.34 ± 1.31	0.009 ± 0.001	120.70 ± 6.87	0.93
	P-value	0.26	0.16	0.87	

The *a* parameter represents the mature weight of the goats, the *b* parameter represents a constant describing the rate of maturation and *c* represents the time at which maximum growth rate is observed.

It was observed that the body weights of the goats increased in a linear fashion during the feeding period (Figure 4.1b). As the Gompertz function may not give an as accurate description of the growth of the goats in this trial, a linear function was fitted to the data during this time period (Table 4.5). A comparison of the models to test the fit of the data shows that the Gompertz function does not fit the data as well as the linear function ($P < 0.01$), although the Gompertz function does account for about 85% of the variation of the data, similar to that of the linear model (Figure 4.1). A similar trend was observed with the models that describe the change in metabolic body weight with the age of the goats in the feedlot (P< 0.01).

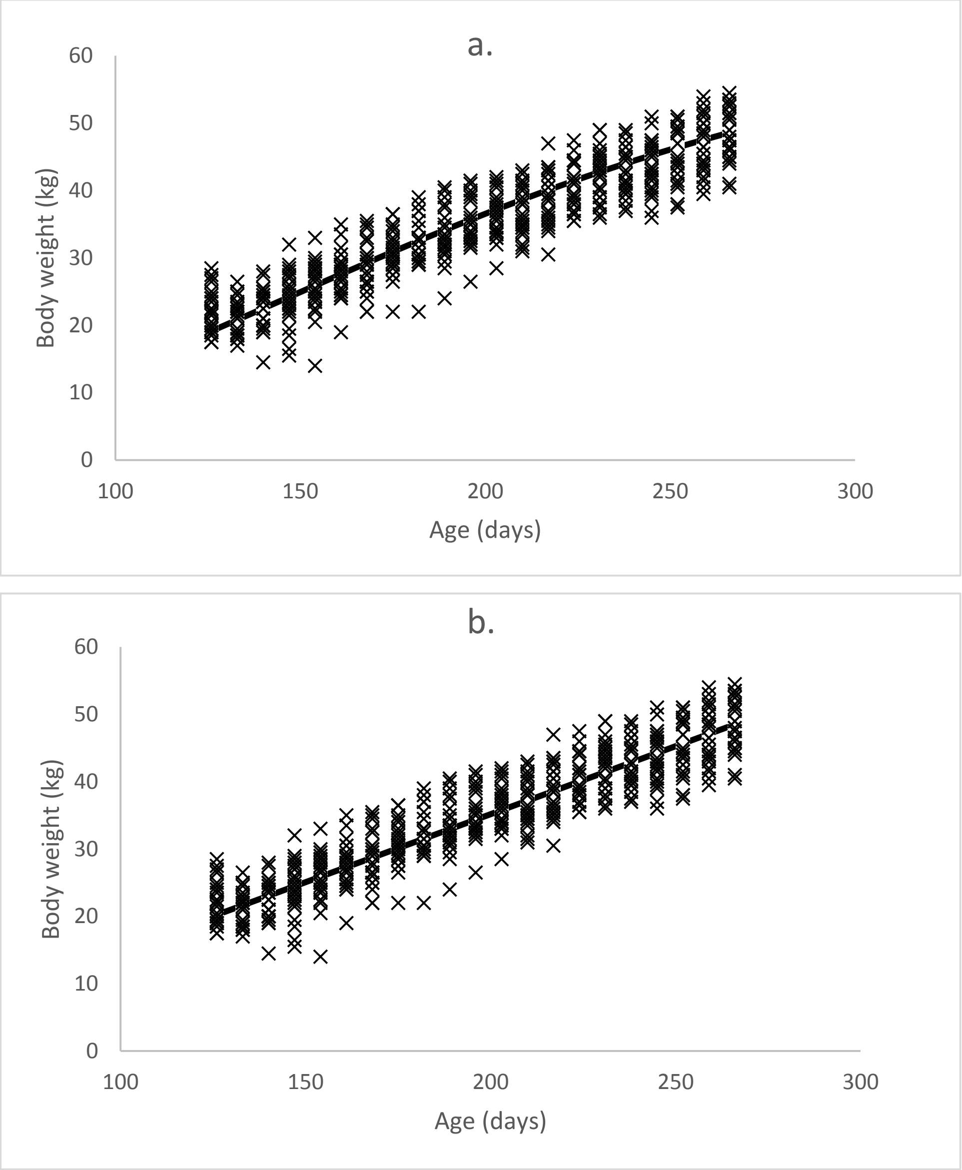

Figure 4.1 The body weight of the goats plotted against age in the feedlot (days) with (a.) Gompertz function (BW= 65.889 × exp (-exp (-0.010 × (t - 147.2))) fitted to the data (R^2= 0.85), and (b.) a linear function (BW= 0.202t - 5.241) fitted to the data (R^2= 0.84).

As with the Gompertz function, the parameter estimates did not differ between the dietary treatments (P> 0.05), indicating that the goats grew at similar rates. In the linear function, the W_0 parameter represents the intercept or the starting weight of the goats entering the feedlot, and the D parameter represents the rate of growth. As the parameters of the linear functions did not differ between the treatments, parameter means can be used to give the general functions for increase in body weight and metabolic body weight for age of the goats in the feedlot (in days):

$$BW = -5.241 + 0.202t \qquad \text{(equation 3)}$$

$$BW^{0.75} = 1.794 + 0.063t \qquad \text{(equation 4)}$$

The coefficients of determination for the models demonstrated by equations 3 and 4 were similar (R^2= 0.84), indicating that both models for body weight and metabolic body weight fit their respective datasets equally well. The model for the low energy diet had the lowest coefficient of determination for the BW model (R^2= 0.83). This indicates that the linear models of BW and $BW^{0.75}$ for the different treatments accounts for more than 80% of the variation of the data.

Table 4.5 Least square means ± standard error of the parameter estimates for the growth models applied to the goats under various treatments using the linear function (W= W_0 + Dt , where t represents age of the goats) during the 20 week feeding period. R^2 represents the coefficient of determination for the model.

	Treatment	***W_0***	***D***	**R^2**
BW	Low	-3.224 ± 2.18	0.191 ± 0.01	0.83
	Medium	-8.365 ± 2.05	0.215 ± 0.01	0.86
	High	-3.910 ± 2.05	0.200 ± 0.01	0.85
	P-value	0.19	0.29	
$BW^{0.75}$	Low	2.402 ± 0.72	0.059 ± 0.00	0.83
	Medium	0.732 ± 0.68	0.067 ± 0.00	0.86
	High	2.315 ± 0.68	0.062 ± 0.00	0.85
	P-value	0.18	0.25	

W_0 represents the intercept of the function, and D represents the slope of the line or the growth rate of the goats.

After being able to predict the body weight of the goats with time spent in the feedlot, it is also useful to determine how feed intake will vary during the feeding period in response to the growth of the goats. To do this, correlations between different intake functions were generated along with the BW and $BW^{0.75}$ (Table 4.6). It can be seen that the correlations between the various intake functions and the growth variables were all moderate. The natural logarithm of daily dry matter intake had the lowest correlation with BW ($r = 0.51$; $P< 0.01$) and the highest correlation was observed between cumulative feed intake and BW ($r = 0.93$; $P < 0.01$). The correlations relating to daily dry matter intake were all moderate and close together, while correlations of functions related to cumulative feed intake were high. Linear models to predict feed intake were generated using regressions between growth variables and each of the intake function variables.

Table 4.6 Pearson correlation coefficients (r) for correlations between dependant feed intake variables, (daily dry matter intake (DMI), LnDMI, MEI, cumulative intake and Ln cumulative intake) and the body weight (BW) and metabolic body weight ($BW^{0.75}$) of the goats.

Dependent Variable	Independent Growth Variable	Correlation Coefficient (r)	*P*- value
DMI (g/day)	BW (kg)	0.53	<0.01
	$BW^{0.75}$ (kg)	0.53	<0.01
LnDMI	BW (kg)	0.51	<0.01
	$BW^{0.75}$ (kg)	0.51	<0.01
MEI (MJ ME/day)	BW (kg)	0.55	<0.01
	$BW^{0.75}$ (kg)	0.55	<0.01
Cumulative intake (kg)	BW (kg)	0.93	<0.01
	$BW^{0.75}$ (kg)	0.93	<0.01
Ln cumulative intake	BW (kg)	0.87	<0.01
	$BW^{0.75}$ (kg)	0.87	<0.01

In the linear regressions of feed intake transformations with growth (Table 4.7-4.11), the *a* parameter represents the intercept or the intake of the goats when they enter the feedlot at t=126 (days). The *b* parameter represents the slope of the regression, or the rate at which intake increases per unit of weight gained. The parameter estimates for the regression between daily dry matter intake (DMI) and BW did not differ between the three dietary treatments ($P > 0.05$). However, in the regressions between DMI and $BW^{0.75}$ the medium energy diet had a lower value for the a parameter ($P = 0.03$) and the highest value for the *b* parameter ($P = 0.03$) (Table 4.7). The general function to predict DMI with the increase in BW can be given by:

$$DMI = 651.281 + 16.195x \qquad \text{(equation 5)}$$

Where x represents BW (kg).

The R^2 values of the parameters in the regression between the DMI and $BW^{0.75}$ were higher than that between DMI and BW (0.34 and 0.33 versus 0.26 and 0.25 respectively), indicating that a greater proportion of variation could be explained by the model parameters, although these coefficients were moderately low. The low diet presented low coefficients of model determination in both models, accounting for less than 17% of the variation. The R^2 values for the overall models show that the models of DMI with BW and $BW^{0.75}$ only account for 28% of variation within the models, which is relatively weak.

Table 4.7 Least square means ± standard error of the parameter estimates for the linear change in dry matter intake (g/day) models with body weight and metabolic body weight ($y = a + bx$), applied to the goats under various treatments (R^2 represents the coefficient of determination for the model).

	Treatment	***a***	***b***	**R^2**
BW	Low	854.39 ± 98.92	11.41 ± 2.65	0.17
	Medium	503.49 ± 93.26	20.88 ± 2.50	0.32
	High	602.16 ± 114.22	15.56 ± 3.06	0.44
	P-value	0.05	0.05	
$BW^{0.75}$	Low	727.39^{a} ± 101.08	37.07^{b} ± 7.13	0.17
	Medium	329.80^{b} ± 101.08	62.59^{a} ± 7.13	0.32
	High	701.65^{ab} ± 142.95	33.77^{b} ± 10.08	0.45
	P-value	0.03	0.03	

$^{a,-b}$ Means in columns with different superscripts vary (P<0.05).

The *a* parameter represents the intercept of the line, and the *b* parameter represents the slope of the linear regression.

In the models of LnDMI with BW, the parameter estimates for a varied between the treatments (P= 0.02), with the low diet having the highest parameter estimate (Table 4.8). The parameter estimates in the models of LnDMI and $BW^{0.75}$ both varied, with the model of the high diet having the lowest value for the *a* parameter (5.829 ± 0.19; P= 0.02) and the highest *b* parameter (0.080 ± 0.01; P= 0.03). The coefficients of model determination for the models associated with the LnDMI transformation had lower values and so account for less variation than the DMI models, making them weaker.

The parameter estimates for the model of MEI with BW both varied between the dietary treatments, with the goats on the medium diet presenting a lower value for the *a* parameter (P= 0.05) (Table 4.9) and compensating for this by having a higher value for the *b* parameter (P= 0.01). Only the *b* parameter varied between the treatments for the model of MEI with $BW^{0.75}$ where the medium diet again presented higher values (P= 0.01) (Table 4.9). In both models the coefficients of determination for the *b* parameters were higher than that of the *a* parameters (0.41 and 0.48 versus 0.30 and 0.32). The coefficients of model determination were similar to that of the DMI models for all of the treatments. However, the overall models for MEI with BW and $BW^{0.75}$ were slightly higher accounting for 30% of the variation in metabolisable energy intake.

Table 4.8 Least square means ± standard error of the parameter estimates for the linear models of the natural logarithm of dry matter intake (LnDMI) with body weight and metabolic body weight (y= *a* + *b*x), applied to the goats under various treatments (R^2 represents the coefficient of determination for the model)

	Treatment	***a***	***b***	**R^2**
BW	Low	6.78^a ± 0.16	0.01 ± 0.01	0.16
	Medium	6.42^{ab} ± 0.15	0.04 ± 0.01	0.31
	High	6.12^b ± 0.15	0.03 ± 0.01	0.38
	P-value	0.02	0.31	
$BW^{0.75}$	Low	6.67^a ± 0.20	0.03^b ± 0.01	0.16
	Medium	6.20^{ab} ± 0.19	0.06^{ab} ± 0.01	0.31
	High	5.83^b ± 0.19	0.08^a ± 0.01	0.39
	P-value	0.02	0.03	

$^{a,-b}$ Means in columns with different superscripts vary (P<0.05).

The *a* parameter represents the intercept of the line, and the *b* parameter represents the slope of the linear regression.

Table 4.9 Least square means ± standard error of the parameter estimates for the metabolisable energy intake (MJ ME/day) models with body weight and metabolic body weight

($y= a + bx$), applied to the goats under various treatments (R^2 represents the coefficient of determination for the model).

	Treatment	***a***	***b***	**R^2**
BW	Low	8.24 ± 0.79	0.11^{b} ± 0.02	0.17
	Medium	5.83 ± 0.79	0.21^{a} ± 0.02	0.32
	High	9.00 ± 1.11	0.11^{b} ± 0.03	0.44
	P-value	0.05	0.01	
$BW^{0.75}$	Low	7.79 ± 0.98	0.29^{b} ± 0.06	0.17
	Medium	4.33 ± 1.06	0.62^{a} ± 0.07	0.32
	High	7.64 ± 1.30	0.37^{ab} ± 0.08	0.45
	P-value	0.07	<0.01	

$^{a,-b}$ Means in columns with different superscripts vary ($P<0.05$).

The *a* parameter represents the intercept of the line, and the *b* parameter represents the slope of the linear regression.

Table 4.10 Least square means ± standard error of the parameter estimates for the Cumulative intake (kg) models with body weight and metabolic body weight ($y= a + bx$), applied to the goats under various treatments (R^2 represents the coefficient of determination for the model).

	Treatment	***a***	***b***	**R^2**
BW	Low	-153.03 ± 10.75	6.74^{a} ± 0.25	0.88
	Medium	-123.86 ± 10.13	5.80^{b} ± 0.23	0.90
	High	-140.89 ± 10.13	5.82^{b} ± 0.23	0.92
	P-value	0.16	0.02	
$BW^{0.75}$	Low	-226.97 ± 14.92	21.60^{a} ± 0.86	0.88
	Medium	-187.60 ± 14.07	18.63^{b} ± 0.81	0.89
	High	-208.90 ± 14.07	18.95^{b} ± 0.81	0.91
	P-value	0.18	0.04	

$^{a,-b}$ Means in columns with different superscripts vary ($P<0.05$).

The *a* parameter represents the intercept of the line, and the *b* parameter represents the slope of the linear regression.

In the linear models between cumulative feed intake and body weight, it was observed that the low energy diet presented the highest values for the *b* parameter (P= 0.02) (Table 4.10). A similar trend was observed for the regressions with metabolic body weight where the low energy diet had the highest estimates for the *b* parameter (P= 0.04). The R^2 values for all the regressions with cumulative intake were high, with more than 88% of the variation of the data being explained by the model. An overall general equation for the regression of cumulative intake with the change in body weight of the goats can be expressed as (x represents weight in kg):

$$y = 5.403x - 113.410 \qquad \text{(equation 6)}$$

Table 4.11 Least square means ± standard error of the parameter estimates for the natural logarithm (Ln) of the cumulative intake (kg) models with body weight and metabolic body weight (y= *a* + *b*x), applied to the goats under various treatments (R^2 represents the coefficient of determination for the model).

	Treatment	***a***	***b***	R^2
BW	Low	$0.25^{ab} \pm 0.23$	0.11 ± 0.01	0.79
	Medium	$0.44^{a} \pm 0.22$	0.10 ± 0.01	0.79
	High	$-0.35^{b} \pm 0.22$	0.12 ± 0.01	0.75
	P-value	0.04	0.30	
$\mathbf{BW^{0.75}}$	Low	$-1.01^{ab} \pm 0.30$	0.36 ± 0.02	0.81
	Medium	$-0.74^{a} \pm 0.28$	0.34 ± 0.02	0.80
	High	$-1.78^{b} \pm 0.28$	0.39 ± 0.02	0.77
	P-value	0.04	0.19	

$^{a,-b}$ Means in columns with different superscripts vary (P<0.05).

The *a* parameter represents the intercept of the line, and the *b* parameter represents the slope of the linear regression.

The *a* parameter estimates for the regression of the natural logarithm of the cumulative intake and body weights of the goats varied between the low, medium and high energy diets (0.444, 0.250 and -0.345 respectively, P= 0.04), while the *b* parameters did not differ between the various diets (P= 0.30) (Table 4.11). Similar results were observed in the regressions with metabolic body weight, with differences being observed for the *a* parameter between the treatments (P= 0.04). R^2 values indicate that the linear regressions with the natural logarithm of the cumulative intake explained between 75 and 81% of the variation of the data.

4.4 Discussion

The growth of an animal from birth to maturity generally follows the pattern of the sigmoidal growth curve, with an initial lag phase followed by a period of rapid growth which plateaus as the animal reaches its mature body weight (Owens *et al*., 1993). When animals are weaned and finished for slaughter, they are generally in the linear, rapid growth phase. It is during this period that the animal will exhibit its greatest growth potential, when optimal nutrition levels are maintained, and maximal profitability of feeding the animal will be attained in this time. Feedlot animals are typically slaughtered before they reach the point of inflection on the curve, when growth rates start to decrease and animals exhibit higher degrees of fatness, and do not attain mature body weights. The feeding of slaughter stock beyond this point will lead to lower production efficiencies. An understanding of the relationship of the growth stage, body size and shape and the factors which influence them, is required in order to give an accurate description of growth (Kamalzadeh *et al*., 1998). The Gompertz function is ideal to fit the sigmoidal growth curve, rather than an asymptotic curve, to which one would rather fit a function similar to the Brody equation (Lewis & Brotherstone, 2002). The Gompertz function has been found to be effective in modelling the growth of sheep and goat breeds from birth through to maturity (Najari *et al*., 2007; Malhado *et al*., 2009; Behzadi & Aslaminejad, 2010). Strong positive correlations were observed between the weights predicted by the Gompertz function and the actual weekly weights (r = 0.92). The Gompertz model of the metabolic body weight appeared to be a better prediction model (P< 0.01) than modelling the untransformed body weight, which may be due to the refining of the data by the function converting body weight to metabolic body weight. However, the Gompertz function may not have been as effective in modelling the growth data of the Boer goats in this study. The sigmoidal curve that characterises the Gompertz growth function is not evident during this feeding period (Figure 4.1a). In order to improve the accuracy of the Gompertz function in modelling the growth of Boer goats, the weights of the goats must be monitored until after they have reached the mature body weight. The a parameter of the Gompertz function is dependent on the asymptotic or mature weight of the animal, and can only be estimated accurately when animals have surpassed this point on the growth curve. The estimation of this parameter will influence the magnitude and accuracy to which the other parameters are estimated (Najari *et al*., 2007). The weight of the mature animal does not remain constant and fluctuates throughout the year according to nutrition availability and the stage of production (Bathaei & Leroy, 1998). Therefore, to make accurate predictions, a standard reference weight of the mature body weight, when body condition score is in the middle of the respective range, should be utilised (Freer *et al*., 1997). Literature on the mature body weight of Boer goats is currently limited, and the point at which the growth curve plateaus is unknown, although it has been assumed to range between 70 to 80 kg for does and 100 to 120 kg for bucks (Malan, 2000). The mature body weight of the goats was estimated to be ~66 kg in the overall model. As the goats in the current study were slaughtered while they were still exhibiting linear growth and had not yet shown signs of decelerating growth, the Gompertz function could not be fitted accurately and so a linear model was proposed for this time period and age interval.

The point of inflection of the Gompertz curve can be estimated by differentiating the function of the change in growth rate with time. The change of growth rate is given by differentiating the Gompertz function as proposed by Emmans (1989) (equation 7). The inflection point of the growth rate, when the change in growth rate is zero, coincides with the point of maximum growth rate. Emmans (1989) noted that the point of maximum growth rate coincides when the time t is equal to parameter *c* and weight of the animal could be given by dividing the mature weight by the Napier constant (*e*). Differentiating the Gompertz function, following these assumptions, would yield Equation 8 to determine the maximum growth rate.

$$\frac{dW}{dt} = b \cdot W \cdot \ln\frac{a}{W} \qquad \text{(equation 7)}$$

$$\frac{dW}{dt}\max = b \cdot \frac{a}{e} \qquad \text{(equation 8)}$$

By substituting the maximum growth rate achieved in equation 8 into equation 7, the weight of the animal at the inflection point of the growth curve can be accurately determined. Using the Gompertz function from equation 1 and substituting parameters into equations 7 and 8, the point of inflection appears to occur at a weight of 24.239 kg (when *t*= 147.2). This time *t* correlates with the *c* parameter, which can be expected as c indicates the age at which maximum growth is expected. However, the Gompertz model cannot be accurately used to model growth of the Boer goats in this study, as the goats did not attain mature body weights, and so other parameter estimates are not accurate. Therefore, this point of inflection cannot be regarded as an accurate standard to compare the growth stage of goats to. If this point of inflection is indeed accurate, it is not apparent from the data captured during this production period, as the growth exhibited by the goats during this time period follows a linear pattern, even after this predicted inflection point, which is better modelled by a linear model (Figure 4.1). In order to accurately estimate this point of inflection, the growth of the goats needs to be monitored further until they reach maturity and the growth curve plateaus.

Gompertz functions can be converted to a linear form by two log transformations; however, convergence and starting values of the model will be problematic (Lewis &

Brotherstone, 2002). Linear functions that modelled the increase in body weight and metabolic body weight during the 20 week feeding period had high accuracies when fitted to the data. This is due to the goats being in the phase of optimal growth, which follows a linear trend. Metabolic body weight was also modelled over time as it gives an indication of the amount of growing tissue in the body, which can be related to the requirements of the animal (Aguerre *et al*., 2013). Portolano & Todaro (1997) also found that linear models were more useful in describing the growth of lambs between 100 and 180 days of age, which also coincides with the ages when lambs would typically be finished and slaughtered. Parameter estimates did not vary between the dietary treatments (P> 0.05) in neither the Gompertz nor linear functions, showing that the goats on the different energy diets grew at similar rates. Before weaning, growth of kids would mainly be affected by the doe’s capacity to produce milk for the young (Finlayson *et al*., 1995), which results in variation in the growth rates of the kids. Directly after weaning, growth may seem irregular until after kids with lower body weights have undergone compensatory growth, after which growth will be uniform and follow the linear pattern until the animal nears maturity (Bathaei & Leroy, 1996). Linear models often do not present clear biological interpretations other than the rate at which the animal grows (Lewis & Brotherstone, 2002). Care should be taken not to extrapolate the linear model too far without an understanding of when the growth rate decelerates as the animal nears maturity, as this will lead to an overestimation of predicted body weights. Therefore the linear model can only be considered to describe the growth of goat kids from when they entered the feedlot at an approximate age of 126 days until the end of the 20 week feeding period (266 days of age). Other production factors such as the level of feed intake and feed conversion efficiency may be incorporated into a model in order to improve its accuracy of prediction and usefulness as a production model (Redden *et al*., 2013).

The level of feed intake is an important factor that influences growth and production of finishing animals. The amount of feed that an animal consumes primarily dictates the amount of protein and fat that an animal can deposit as tissue, but it is dependent on the production state and size of the animal (Gous *et al*., 2012). Thus the potential of growth is affected by the level of intake, while in turn feed intake is affected by the size and live weight of the animal (Schulze *et al*., 2003). The present study showed moderate linear correlations between feed intake and growth variables. In Chapter 3 it can be seen that the daily DMI of goats varied between the groups slaughtered at five week intervals in a quadratic fashion with time spent in the feedlot. This suggests that feed intake should increase with body weight in a quadratic fashion, although the study on this group of goats showed that feed intake increased linearly. This again proves that the trends in feed intake depend on the growth or production stage which is being investigated (Von Felde *et* al., 1996; Freer *et al*., 1997). Intake does increase in a linear fashion with live weight or metabolic body weight, up until the animal reaches a higher degree of maturity and level of fatness, which will result in feed intake stabilising (Macdonald *et al*., 2011; Gous *et al*., 2012). This results in the polynomial pattern of feed intake with live weight (Lewis & Emmans, 2010). Although models for DMI, LnDMI and MEI with body weight and metabolic body weight showed linear patterns, they exhibited low coefficients of determination and did not describe more than 30% of the variation of the data. Therefore, these models do not fit the data well. Goats used in this trial had probably not reached high degrees of fatness that would cause feed intake to stabilise, which may have allowed the use of polynomial functions that would possibly fit the data more accurately.

The natural logarithm of feed intake was modelled with the increase in live weight for further inclusion into production models, where growth would be predicted from curvilinear models such as the Gompertz function. In order to obtain the predicted daily DMI, one must remember to correct the value by using the exponential function to transform the linear relationship of LnDMI with the body weight to the true DMI. The models of LnDMI had the lowest values for the R^2 coefficients of model determination, accounting for less than 26% of the variation in the overall models, proving that the LnDMI function is not suited to be modelled with the growth of the goats.

Metabolisable energy intake is commonly used in models to predict the energy requirements of an animal (Tedeschi *et al*., 2010). In theory the MEI should be similar for each of the trial diets if goats are able to adjust their intake according to their requirements in response to deviations in the energy content of a diet (Lu & Potchoiba, 1990). However, differences in the regression parameters were observed between the treatments ($P< 0.05$). The differences observed in the parameters between the treatments, for both the models that involve LnDMI and MEI, may have been due to variation caused by initial complications in adaption to the trial diets, as the goats had not been previously exposed to concentrate feeds. This variation was in turn accentuated by the finer nature of these functions, which is why the parameters for the models that just involved DMI did not differ. The coefficients of model determination were similar for the models of the treatments for both DMI and MEI, however, the overall models of MEI had slightly stronger R^2 values, indicating that it is more suited to fit the data rather than models of DMI with BW and $BW^{0.75}$. It is suggested that because the coefficients of determination for these intake models are low, other methods of expressing the model for feed intake within this time period should be considered. This may include modelling the cumulative intake with the growth of the animal or in terms of its degree of maturity (Lewis and Emmans, 2010; Tedeschi *et al*., 2010), which can only be done when a standard reference weight has been determined. Further possibilities may be to model the difference between the DMI used for production and the DMI used for maintenance.

However, linear regressions with better accuracies can be achieved when modelling the weekly cumulative intake or its natural logarithm with the weight of the goats (Tables 4.10 and 4.11). The general model of cumulative feed intake with body weight of the goats can account for ~87% of the variation of the data. Therefore, this model is much more accurate in predicting the level of intake than regressions between daily feed intake and body weight. It is unfortunate that this model can only predict the amount of feed that the goat consumes up to a certain body weight, and not what its daily intake is at that point. Therefore, this model should be combined with additional functions in order to predict the level of daily feed intake at a specific body weight.

4.5 Conclusion

It was observed that the model parameters did not differ significantly between the dietary treatments for the linear and Gompertz models and therefore, general forms could be used. It can be concluded that during a 20-week feeding period after weaning, a linear function is better suited to fit the change in body weight over time spent in the feedlot than the Gompertz function. Therefore, when goats are weaned at about 18 weeks with an average weight of 22.2 ± 3.5 kg and finished under feedlot conditions, their growth can be predicted using the linear model up to an age of ~266 days (48.3 ± 0.8 kg). Extrapolation of the model beyond this 20 week feeding period and age should be avoided so as to avoid overestimation of the body weight when the growth rates decrease as goats near maturity. For this the Gompertz model would be better suited, but an accurate standard reference of the mature body weight of Boer goats is needed for the function. Therefore, future prospects would be to monitor the growth of Boer goat kids from birth to maturity in order to obtain the sigmoidal growth curve, to which the Gompertz function can be applied accurately. This can then be used to accurately predict the inflection point of the growth curve of the goats, which can be used to indicate up to which point they can be reared and then slaughtered.

Models for the increase in daily feed intake with body weight during the 20 week feeding period were proposed, however, these models did not account for the majority of the variation. The variation between model parameters for the dietary treatments was also accentuated when functions were applied to refine the dry matter intake. Models using the cumulative feed intake, and its natural logarithm, can be used to give accurate prediction for the amount of feed that a goat will consume in the feedlot up to a certain weight. Although further investigation is needed to generate an accurate model that can be used to predict the daily feed intake of goats from their body weight, this may involve the inclusion of other variables to improve the model.

4.6 References

Aguerre, M., Cajarville, C., Kozloski, G. V. and Repetto, J. L. 2013. Intake and digestive responses by ruminants fed fresh temperate pasture supplemented with increased levels of sorghum grain: A comparison between cattle and sheep. Animal Feed Science and Technology. 186: 12-19.

Bathaei, S., and Leroy P. 1996. Growth and mature weight of Mehraban Iranian fat-tailed sheep. Small Ruminant Research. 22: 155-162.

Bathaei, S., and Leroy P. 1998. Genetic and phenotypic aspects of the growth curve characteristics in Mehraban Iranian fat-tailed sheep. Small Ruminant Research. 29: 261-269.

Behzadi, M. R. B. and Aslaminejad, A. A. 2010. A comparison of neural network and nonlinear regression predictions of sheep growth. Journal of Animal and Veterinary Advances. 9: 2128-2131.

Butterfield, R. M. 1988. New concept of sheep growth. Department of Veterinary Anatomy. University of Sydney, Australia. 1-57.

da Silva, L. S. A., Fraga, A. B., da Silva, F. D. L., Beelen, P. M. G., de Oliveira Silva, R. M., Tonhati, H. & da Costa Barros, C. 2012. Growth curve in Santa Inês sheep. Small Ruminant Research, 105: 182-185.

Emmans G.C., 1989. Chapter 8. The growth of turkeys. In: Recent advances in turkey science (Poultry science symposium number 21). By Nixey, C. and Grey, T.C. Butterworth and Heineman. Ltd.

FAOSTAT. 2015. Food and Agriculture Organization of the United Nations, Statistics Division. http://faostat3.fao.org/browse/Q/*/E (Accessed September 2015).

Finlayson, J., Cacho O. J., and Bywater A. 1995. A simulation model of grazing sheep: I. Animal growth and intake. Agricultural Systems. 48: 1-25.

Freer, M., Moore, A. D. and Donnelly, J.R. 1997. GRAZPLAN: Decision Support Systems for Australian Grazing Enterprises-II. The animal biology model for feed Intake, production and reproduction and the GrazFeed DSS. Agricultural Systems. 54: 77-126.

Glimp, H. A. 1995. Meat goat production and marketing. Journal of Animal Science. 73: 291-295.

Gous, R. M., Emmans, G. C. and Fisher, C. 2012. The performance of broilers on a feed depends on the feed protein content given previously. South African Journal of Animal Science. 42: 63-73.

Kamalzadeh, A., Koops W., and Van Bruchem J. 1998. Feed quality restriction and compensatory growth in growing sheep: Modelling changes in body dimensions. Livestock Production Science. 53: 57-67.

Lewis, R. M. and Brotherstone, S. 2002. A genetic evaluation of growth in sheep using random regression techniques. Animal Science. 74: 63-70.

Lewis, R. M. and Emmans, G. C. 2010. Feed intake of sheep as affected by body weight, breed, sex, and feed composition. Journal of Animal Science. 88: 467-480.

Lu, C., and Potchoiba M. 1990. Feed intake and weight gain of growing goats fed diets of various energy and protein levels. Journal of Animal Science. 68: 1751-1759.

Macdonald, P., Edwards R. A., J. F. D. Greenhalgh J. F. D., C. A. Morgan C. A., Sinclair L. A., and Wilkinson R. G.. 2011. Animal nutrition. Seventh ed. Pearson Education Limited. England.

Malan, S. 2000. The improved Boer goat. Small Ruminant Research. 36: 165-170.

Malhado, C., Carneiro P., Affonso P., Souza A., and Sarmento J. 2009. Growth curves in Dorper sheep crossed with the local Brazilian breeds, Morada nova, Rabo largo, and Santa inês. Small Ruminant Research. 84: 16-21.

Najari, S., Gaddoun A., Hamouda M. B., Djemali M., and Khaldi G. 2007. Growth model adjustment of local goat population under pastoral conditions in Tunisian arid zone. Journal of Agronomy. 6: 61-67.

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

Portolano, B. and Todaro, M. 1997. Curves and biological efficiency of growth for 100- and 180-day-old lambs of different genetic types. Annales de Zootechnie. 3: 245-253

Redden, R. R., Surber, L. M. M., Grove, A. V. and Kott, R. W. 2013. Growth efficiency of ewe lambs classified into residual feed intake groups and pen fed a restricted amount of feed. Small Ruminant Research. 114: 214-219.

SAS Institute, 2006. SAS/Stat User's Guide Version 9, 1st printing, Volume 3, SAS Institute, Inc, SAS Campus Drive, Cary, North Carolina 27513.

Sayed, A. N. 2011. Effect of different energy levels of diets on the performance, nutrient digestibilities and carcass characteristics of lambs. International Journal for Agro Veterinary and Medical Sciences. 5: 472-476.

Schulze, V., Roehe, R., Lorenzo Bermejo, J., Looft, H. and Kalm E. 2003.The influence of feeding behaviour on feed intake curve parameters and performance traits of station-tested boars. Livestock Production Science. 82: 105-116.

Tedeschi, L. O. 2006. Assessment of the adequacy of mathematical models. Agricultural Systems. 89: 225-247.

Tedeschi, L. O., Cannas A., and Fox D. G. 2010. A nutrition mathematical model to account for dietary supply and requirements of energy and other nutrients for domesticated small ruminants: The development and evaluation of the small ruminant nutrition system. Small Ruminant Research. 89: 174-184.

Thornley, J. H. M., and France J.. 2007. Mathematical models in agriculture: Quantitative methods for the plant, animal and ecological sciences. Second ed. CABI. United Kingdom.

Von Felde, A., Roehe, R., Looft, H. and Kalm E. 1996. Genetic association between feed intake and feed intake behaviour at different stages of growth of group-housed boars. Livestock Production Science. 47: 11-22.

Chapter 5

Comparing the effect of age and dietary energy content on the slaughter characteristics of Boer goats

Abstract

The South African Boer goat is regarded as one of the top goat breeds used for meat production. The current trend in goat production is to market goat kids soon after weaning directly from the farm at a weight varying between 20-30 kg. In order to increase the level of slaughter kid production, goat kids can be finished in feedlots to attain desirable slaughter weights and level of fatness that will maximise profitability. The aim of this study was to compare the effects of three different diets that vary in energy content (11.3, 12.0 and 12.7 MJ ME/ kg feed) on the carcass quality characteristics after different periods in the feedlot. At the beginning of the trial, 75 goat kids weighing 22.2 ± 3.47 kg were randomly allocated to the different dietary treatments, as well as to one of five slaughter groups that were slaughtered at five week intervals. During the trial, the goats received the trial diets *ad libitum*. The first group of goats was slaughtered at the start of the trial and did not receive the trial diets. The carcasses were chilled for 24 hrs before being transported to a processing facility where the carcasses were divided into six commercial cuts. A three rib cut was made between the 9th and 12th ribs, which was used to predict the composition of the major carcass tissues. The left *Longissimus lumborum* muscle was excised and used to determine colour and physical meat quality characteristics. The energy content of the finisher diets had no effect ($P > 0.05$) on any of the traits measured. However, the time spent in the feedlot did influence ($P < 0.05$) the growth of the various tissues and the yields of the carcass and non-carcass components. The level of fat deposition increased with time in the feedlot, with most of the fat being deposited in the abdominal cavity and low levels as subcutaneous adipose. It can be concluded that goats can be slaughtered at live weights between 30 and 50 kg and still present a lean carcass with a favourable yield, regardless of the energy content of the feedlot finisher diet fed.

5.1 Introduction

The Boer goat breed was developed in South Africa by early farmers from existing indigenous breeds in order to produce a breed that is now considered to be the standard to which other meat goat breeds are compared (Casey & Van Niekerk, 1988). In comparison to other goat breeds, the Boer goat exhibits higher levels of muscularity especially in its hind-quarters which are associated with the more expensive retail cuts (Cameron *et al*., 2001).

However, when compared to mutton breeds the musculature of goats does not compare favourably, even though goats do exhibit more developed neck, thorax and forelimb regions (Sheridan *et al*., 2003b; Tshabalala *et al*., 2003).

A carcass can be defined as the portion of saleable meat after the slaughtered animal has been dressed. The commercial value of the carcass is primarily determined by the slaughter weight of the animal, its body conformation as well as the proportions and distribution of the major tissues (bone, muscle, fat) in the carcass. Offal components, removed during slaughter, have a lower economic value than that of the lean carcass muscle, but still contribute to total profit through the sale of edible offal components to poorer ethnic communities (Aduku *et* al., 1991; Glimp, 1995). A carcass with a good conformation will exhibit a greater level of musculature surrounding the skeleton, resulting in a higher lean meat yield. As an animal continues to grow the internal organs and various tissues will grow and develop at different rates (Casey & Webb, 2010). The growth rate of individual muscles is expected to be related to the level of activity being performed, as well as the importance thereof in the survival of the animal. As a result more active muscles will develop at faster rates (Butterfield, 1988). The influence of gender also affects the musculature of the animal, with mature male goats generally having more developed neck regions, while mature females have a greater conformation in their rumps (Goetsch *et al*., 2011).

A superior carcass is characterised as having a high proportion of lean muscle, a low proportion of bone and an optimal degree of fatness (Berg & Walters, 1983). Fat deposits in the body serve as energy stores which can be mobilised during periods of shortage and starvation (Negussie *et al*., 2003). The rate and manner in which fat is partitioned in the carcass is important as it affects the yield and commercial value of the carcass (Berg & Walters, 1983). The development of the various fat depots is initially slow in comparison with the rate of muscle development. As an animal grows older and approaches maturity, the rate of fat development increases and so the relative proportion of carcass fat increases, while that of muscle and bone decreases, even though the absolute weights of these tissues continues to increase (Warris, 2010). Breeds that have been selected for improved meat production tend to be early maturing and have higher levels of subcutaneous and intramuscular fat at slaughter weight (Berg & Walters, 1983). Goats, conversely, present a leaner carcass as they tend to store greater quantities of fat in the abdomen (abdominal and kidney depots), while the subcutaneous and intramuscular fat depots develop at a much slower rate, thus presenting a lean carcass (Webb, 2014). This may be due to the lack of selection pressure for higher levels of goat meat production and the adaptive nature of goats to withstand dry conditions. Boer goats tend to have slightly higher levels of fat compared to other goat breeds, suggesting that it may be an early maturing goat breed (Tshabalala *et al*., 2003).

The role of high energy concentrate diets in feedlot finishing is to provide sufficient nutrients to promote optimal growth rates so that the animals reach a desired slaughter weight and level of fatness at an earlier age. Energy is required by all tissues for ongoing maintenance and growth (Lawrence *et al*., 2012). When the animal is supplied energy above the maintenance requirements, it is utilised for muscle growth and excess is stored in adipose tissue as fat. This results in changes of the musculature and higher degrees of fatness being observed at an earlier stage (Owens *et al*., 1993). The focus of meat animal production is to optimize the amount of muscle being produced relative to the amount of feed that the animal consumes (Butterfield, 1988). Therefore, the aim of this study was to determine the effect of dietary energy content on the carcass composition of Boer goats as they grow, and to describe the changes in carcass and offal components with an increase in time spent under feedlot conditions.

5.2 Materials and Methods

For this trial, 75 castrated Boer goat kids were finished under feedlot conditions in individual pens as described in Chapter 3. The goat kids were finished on one of three trial diets that varied in dietary energy content, namely, a low energy (11.3 MJ ME/ kg feed), medium energy (12.0 MJ ME/kg feed) and high energy (12.7 MJ ME/kg feed) diet, expressed on an as fed basis with a moisture content of 10.4% (Table 5.2). The goatswere additionally randomly allocated to one of five slaughter groups (Table 5.1). A baseline group of 9 goats were slaughtered at the start of the trial without receiving the trial diets; the remaining groups were slaughtered at 5 week intervals.

Table 5.1 Layout of the trial and number of goats allocated to each treatment group.

Slaughter Group	**Dietary Treatment**			**Total**
	Low	**Medium**	**High**	
Day 0	3	3	3	9
Day 40	4	5	3	12
Day 76	5	5	5	15
Day 112	5	3	5	13
Day 146	8	9	9	26
Total	25	25	25	75

The day prior to slaughter, the goats were weighed and transported to Swartland abattoir in Malmesbury. The goats were held overnight in lairage for ~17 hours before slaughter. Due to unforeseen complications at the abattoir, the final slaughter group remained in lairage for a period of 40 hours before slaughter. In lairage, goats were not supplied with feed and had free access to water. The goats were slaughtered according to standard South African techniques. The goats were rendered unconscious by electrical stunning (5 seconds at 200 volts), they were then exsanguinated and carcasses were suspended and allowed to bleed out (Cloete *et al*., 2004). No electrical stimulation was applied to the carcass.

Table 5.2 The nutrient composition of the trial diets fed to Boer goat kids.

Nutrients	Nutrients of Diets (as fed)		
	LE	**ME**	**HE**
In vitro dry matter digestibility, %	74.41	79.30	86.25
Total digestible nutrients (TDN) %*	64.09	68.00	70.69
Metabolisable energy, MJ/ kg ^{x}	11.30	12.00	12.70
Protein, %	14.30	14.28	14.98
Fibre, %	12.7	10.4	6.3
Neutral detergent fibre, %	29.24	28.29	22.85
Acid detergent fibre, %	15.84	12.78	8.57
Ash, %	10.12	8.63	7.57
Fat, %	1.16	1.37	1.31
Calcium, %	1.25	1.08	1.00
Phosphorous, %	0.45	0.41	0.40

LE – Low energy diet. ME – Medium energy diet. HE – High energy diet.

^{x} Formulated metabolisable energy values.

* Calculated total digestible nutrients = (0.8 x protein) + (0.4 x fiber) + (0.9 x nitrogen free extract) + (2.025 x fat).

During the slaughter and evisceration, offal components including the head, skin, trotters, red offal as well as abdominal (omental) fat and kidney fat were collected and their weights recorded. The head was removed after evisceration by further cutting the neck and was severed from the spinal column at the occipito-atlantal junction. The trotters were removed by severing the joint between the humerus and the scapula (and ulna) in the forelimbs, and severing the joint between the femur and the tibia in the hind limbs. The red offal along with omental and kidney fat were plucked from the abdominal cavity during evisceration. The red offal consisted of the heart, liver, lungs, spleen and kidneys. The pH and temperature of the carcasses were measured 45 minutes after slaughter, using a Crison pH25 handheld portable pH metre (Lasec (PTY) Ltd, South Africa) which automatically adjusts to the measuring temperature. Before each session, the pH metre was calibrated using standard buffers (pH 4.0 and pH 7.0) provided by the manufacturer. The warm carcass weight was recorded before the carcasses were hung from both hindlegs in the cooler. After chilling the carcass for a period of 24 hours at 2°C, the carcasses were transported to a processing facility where the carcasses were divided into South African retail cuts which were weighed separately and recorded. These cuts consisted of the neck, raised shoulder, ribs, flank, loin and hind-legs (Figure 5.1).

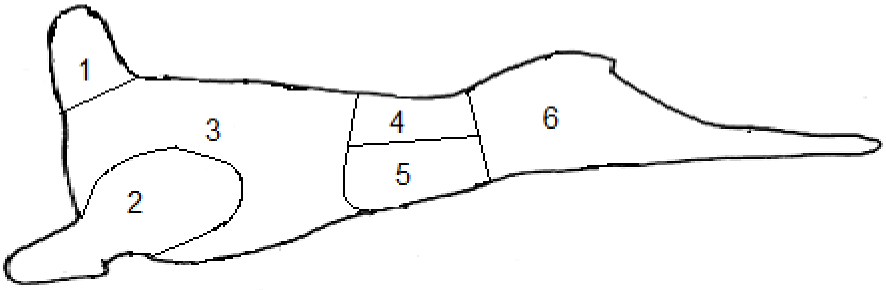

Figure 5. 1 Diagram showing how the carcass was divided into retail cuts. 1. Neck, 2. Raised shoulder, 3. Ribs, 4. Loin, 5. Flank and 6. Legs

The neck was removed at the seventh cervical vertebrae (the point at which the neck starts bending) at a right angle to the spine (Cloete *et al*., 2004). The shoulder cut was removed by slicing the scapula and its associated muscles (*Triceps brachii, Latissimus dorsi* and *Subscapularis*) from the *Serratus ventralus* muscles of the thorax. The flanks were removed by cutting the *M. obliquus abdominis internus* parallel to the spine, between the ribs and the hindlegs (Cloete *et al*., 2004). The hind quarters were removed from the ribs by sawing perpendicular to the spine at the 13th rib position. The ribs were then halved by sawing right along the spinal cord. The loin cut was removed from the hind legs, by sawing perpendicular to the spine between the third and fourth lumbar vertebrae. The hind legs were then weighed together.

In order to determine carcass composition, a three-rib cut was made between the 9th and 12th ribs on the right side of the animal to include the 9th,10th and 11th ribs (Hankins & Howe, 1946). The cut was made against the bone cranial to the 9th and 12th ribs, and extended from the spinal cord until the plane of the ribs started to curve inward. This cut was then dissected into muscle, bone and fat and their weights expressed as a percentage of the total weight of the cut.

The L*ongissimus lumborum* (LL) muscle on the left side of the loin cut was excised, between the 13th rib and the 3rd and 4th lumbar vertebrae, and was used for physical meat quality tests in the laboratory. The subcutaneous fat depth of the LL muscles was measured at the position of the 13th rib, 2.5 cm from the line cut parallel to the spinal column, using an electronic calliper. The muscles were trimmed of excess connective tissue and three chops (~2.5 cm thick) were cut from the muscle sample. The chops were allowed to bloom for 30 minutes (Honikel, 1998). Meat surface colour was then measured using a digital calibrated handheld Color-guide 45°/0° colorimeter (aperture size 11 mm; illuminant/observer of

D65/10°) (BYK-Gardner GmbH, Gerestried, Germany). Calibration of the colorimeter was done using the standards provided (BYK-Gardner). Three measurements were taken on the bloomed surface to determine the CIE L* (lightness), a* (red-green range) and b* (blue-yellow range) values. The chroma (colour intensity) and hue angle (colour definition) were calculated using a* and b* values (Honikel, 1998):

$$\text{Hue } (^\circ) = \tan^{-1} (b^*/a^*)$$

$$\text{Chroma } (C^*) = ((a^*)^2 + (b^*)^2)^{-0.5}$$

In order to determine cooking loss, two LL chops (2.5 cm thick) were cut and weighed together and inserted into a polyethylene bag. These samples were cooked in the bags, in a hot water bath (80°C) for 60 minutes. The bags were then removed from the water bath, and the exuded water drained and samples were submerged in cold water. The samples were allowed to cool for an hour at 4°C and were then removed from the bags, blotted dry using paper towels and weighed. The cooking loss was calculated as the difference and expressed as a percentage of original sample weight. The drip loss was determined by suspending a 2.5 cm thick LL steak, which had been weighed prior, from a wire in an inflated and sealed polyethylene bag. The bags were hung in a refrigerator at 4°C for 24 hours. The samples were then removed from the bags and blotted dry using paper towels to remove excess water before weighing on a digital scale. The drip loss was expressed as the percentage of weight lost over a 24 hour period.

The shear force of the cooked samples was measured instrumentally using the Warner-Bratzler shear force method (Honikel, 1998). Five 2.5 cm cores, 1.27 cm in diameter, were cut parallel to the meat fibres from the cooked meat samples after cooking loss had been determined. An Instron universal testing machine (Instron model 4444/H1028, Appollo Scientific cc, South Africa) fitted with a Warner-Bratzler attachment with a 1 mm thick triangular blade with a semi-circular cutting edge which would cut the core sample perpendicular to the grain, was used. The Instron machine was set to operate with a load cell of 2.000 kN at a speed of 200mm /min. The shear force values obtained were then expressed in Newton (N). For statistical analysis, the mean of five readings were used per sample.

Statistical analysis was performed on the data using SAS 9.2 (SAS, 2006). Data for the carcass composition, retail cut and offal yields (calculated as a % of slaughter weight), and physical measurements were subjected to analysis of variance (ANOVA) to compare the fixed effects of dietary energy treatment and time spent in the feedlot. Normal probability plots, as well as the Shapiro-Wilk test were used to test for non-normality of the residuals. In the event of non-normality, outliers were identified and residuals greater than 3 were removed.

Bonferroni pairwise tests were used to identify treatment groups that differed significantly ($P<0.05$). Regressions for the changes of the various traits over time were developed and the parameters were compared between dietary energy treatments by ANOVA using the Proc GLM (General Linear Models) method. The results are reported as least squared means along with the standard errors. Least squared differences (LSD) are used to indicate the levels at which means between different slaughter groups differ.

5.3 Results

An interaction between dietary treatment and days in the feedlot ($P= 0.01$) was observed for the slaughter weight. After 40 days in the feedlot, the goats on the high energy diet had higher slaughter weights than the other two diets ($P=0.03$), while goats on the high diet slaughtered after 76 days in the feedlot had the lowest slaughter weights ($P=0.03$). This may have been caused by a sampling effect when the goats were randomly allocated to the slaughter groups and diets. It was observed that diet did not have an effect on slaughter weights of the goats slaughtered after 76 days in the feedlot, although the slaughter weights all increased with days in the feedlot ($P< 0.01$). The warm and cold carcass weight showed a similar interaction and trends with differences only being noted on either day 40 or 76 (Table 5.3 and 5.8).

In Tables 5.3 and 5.4 it can be seen that no interactions were observed for the percentage yields (relative to the slaughter weight) of most of the offal components, except the trotters yield, where differences between the dietary treatments were observed in goats slaughtered at 76 days ($P= 0.02$). The energy content of the diets did not influence the relative yields of the offal components ($P> 0.05$), although they did vary with time spent in the feedlot ($P<0.01$). The skin yield was the only component that did not differ as the goats grew older. The head yield comprised of the head as well as the horns of the goats. The head yields generally decreased with time in the feedlot (LSD= 0.4). The proportions of omental and kidney fat relative to the slaughter weight of the goats generally increased ($P< 0.01$) with time (Table 5.4). No visible kidney fat was present in the goats that were slaughtered at the start of the trial.

Slaughter weight increased linearly with time spent in the feedlot as seen in Chapter 3. Quadratic regressions were fitted to the data in order to describe the change in the yields of the offal components over time in the feedlot. The parameter estimates of the various carcass offal components did not vary between the different energy levels that were fed to the goats (Table 5.5). The R^2 coefficients of determination for the various regressions were moderate to high, except for the regressions for the trotter yields of goats on the medium and high diets which were moderate to low, indicating that less than 40% of the variation could be described by these models.

An interaction was observed between dietary energy treatments and the time spent in the feedlot ($P< 0.01$) for the dressing percentage of the goats (Table 5.7). Differences between the dietary energy levels were observed in the dressing percentages of goats slaughtered after 40 days in the feedlot where goats in the high energy group had the highest dressing percentage (46.1 ± 0.7%; $P= 0.01$), and after 76 days where goats on the medium energy diet achieved the highest dressing percentage (50.7 ± 0.9%; $P= 0.03$). Overall, diet did not have a significant effect on the dressing percentage, which did vary between the different slaughter intervals during the feeding period (LSD= 2.8).

Table 5.3 Least square means ± standard error for the slaughter weight, warm carcass weight and offal yields of goats slaughtered after different periods in the feedlot, where they were supplied the respective trial diets differing in energy contents (LSD indicates differences between means from different slaughter intervals).

Offal component	Days in feedlot					Diet means	*P*-value	
	0	40	76	112	146		Days in feedlot	Diet x Days
Slaughter weight (kg)								
Low	21.6 ± 0.8	25.8^{b} ± 1.3	37.6^{a} ± 1.8	45.0 ± 2.1	46.9 ± 1.4	35.6 ± 0.8		
Medium	20.3 ± 0.8	26.7^{b} ± 1.2	36.5^{a} ± 1.8	45.8 ± 2.7	48.8 ± 1.3	36.1 ± 0.8		
High	22.8 ± 0.8	31.8^{a} ± 1.5	30.1^{b} ± 1.8	43.3 ±2.1	49.1 ± 1.3	34.8 ± 0.8	<0.01	0.04
P-value	0.15	0.03	0.03	0.73	0.49	0.57	(LSD= 5.1)	
Warm carcass weight (kg)								
Low	9.2 ± 0.6	11.8^{b} ± 0.7	18.2 ± 0.8	22.0 ± 0.9	23.6 ± 0.7	17.0 ± 0.4		
Medium	8.4 ± 0.6	11.8^{b} ± 0.6	17.6 ± 0.8	23.0 ± 1.2	24.9 ± 0.7	17.1 ± 0.4		
High	9.4 ± 0.6	14.5^{a} ± 0.8	15.1 ± 0.8	21.3 ± 0.9	24.8 ± 0.7	17.0 ± 0.4	<0.01	0.04
P-value	0.47	0.04	0.05	0.57	0.33	0.50	(LSD= 2.5)	
Head (%)								
Low	6.8 ± 0.2	6.4^{a} ± 0.1	6.2^{b} ± 0.1	5.9 ± 0.2	5.3 ± 0.1	6.1 ± 0.1		
Medium	6.8 ± 0.2	6.0^{b} ± 0.1	6.0^{b} ± 0.1	6.1 ± 0.3	5.2 ± 0.1	6.0 ± 0.1		
High	6.7 ± 0.2	6.1^{ab} ± 0.1	6.8^{a} ± 0.1	6.1 ± 0.2	5.3 ± 0.1	6.2 ± 0.1	<0.01	0.14
P-value	0.93	0.0282	<0.01	0.72	0.61	0.07	(LSD= 0.4)	
Skin (%)								
Low	7.4 ± 0.2	7.3 ± 0.2	8.0 ± 0.2	7.5 ± 03	7.9 ± 0.2	7.6 ± 0.1		
Medium	7.9 ± 0.2	7.5 ± 0.2	7.5 ± 0.2	7.7 ± 0.4	7.8 ± 0.2	7.7 ± 0.1		
High	7.9 ± 0.2	7.6 ± 0.2	8.2 ± 0.2	7.6 ± 0.3	8.2 ± 0.2	7.8 ± 0.1	0.10	0.75
P-value	0.41	0.54	0.08	0.96	0.41	0.12	(LSD= 0.4)	
Trotters (%)								
Low	3.3 ± 0.1	3.1 ± 0.1	3.2^{ab} ± 0.1	3.0 ± 0.1	2.8 ± 0.1	3.1 ± 0.0		
Medium	3.2 ± 0.1	3.0 ± 0.1	3.0^{b} ± 0.1	3.1 ± 0.1	2.7 ± 0.1	3.0 ± 0.0		
High	3.1 ± 0.1	2.8 ± 0.1	3.4^{a} ± 0.1	3.2 ± 0.1	2.8 ± 0.1	3.1 ± 0.0	<0.01	0.04
P-value	0.33	0.18	0.02	0.27	0.50	0.21	(LSD= 0.2)	

$^{a-b}$ means in a column per carcass component with different superscript letters differ (P<0.05).
Offal components expressed as percentage of slaughter weight of the goats.

Table 5.4 Least square means ± standard error for the yields of internal offal components of goats slaughtered after different periods in the feedlot, where they were supplied the respective trial diets differing in energy contents. (LSD indicates differences between means from different slaughter intervals).

Carcass component	**Days in feedlot**					**Diet means**	***P*-value**	
	0	**40**	**76**	**112**	**146**		**Days in feedlot**	**Diet x Days**
Red offal (%)								
Low	3.6 ± 0.2	4.5 ± 0.2	3.8 ± 0.2	4.0 ± 0.2	3.0 ± 0.1	3.8 ± 0.1		
Medium	3.9 ± 0.2	4.2 ± 0.2	4.2 ± 0.2	4.2 ± 0.2	3.2 ± 0.1	4.0 ± 0.1		
High	3.9 ± 0.2	4.5 ± 0.2	4.2 ± 0.2	4.0 ± 0.2	3.3 ± 0.1	4.0 ± 0.1	<0.01	0.48
P-value	0.28	0.44	0.30	0.61	0.11	0.20	(LSD= 0.3)	
Omental fat (%)								
Low	0.1 ± 0.0	0.4 ± 0.1	1.4 ± 0.2	2.1 ± 0.1	1.8 ± 0.1	1.2 ± 0.1		
Medium	0.1 ± 0.0	0.5 ± 0.1	1.5 ± 0.2	2.0 ± 0.2	2.0 ± 0.1	1.2 ± 0.1		
High	0.1 ± 0.0	0.7 ± 0.1	1.3 ± 0.2	1.7 ± 0.1	2.0 ± 0.1	1.2 ± 0.1	<0.01	0.53
P-value	0.45	0.05	0.74	0.27	0.38	0.60	(LSD= 0.4)	
Kidney fat (%)								
Low	-	0.4 ± 0.1	1.5^{a} ± 0.2	1.7 ± 0.1	1.2 ± 0.2	1.0 ± 0.1		
Medium	-	0.4 ± 0.1	1.7^{a} ± 0.2	1.8 ± 0.2	1.7 ± 0.2	1.1 ± 0.1		
High	-	0.5 ± 0.1	0.9^{b} ± 0.2	1.4 ± 0.1	1.5 ± 0.2	0.8 ± 0.1	<0.01	0.09
P-value		0.42	0.01	0.13	0.23	0.15	(LSD= 1.1)	

$^{a-b}$ means in a column per carcass component with different superscript letters differ ($P<0.05$).

Offal components expressed as percentage of slaughter weight of the goats.

Table 5.5 Parameter means ± standard of errors and R^2 coefficients of determination of quadratic regressions ($y = a + bx + cx^2$, where x represents days in the feedlot) used to describe the effect of different dietary energy levels on the yield of offal components over time spent in the feedlot.

Head				
	a	***b***	***c***	R^2
Low	6.736 ± 0.13	-0.005 ± 0.00	0.0000 ± 0.00	0.82
Medium	6.619 ± 0.19	-0.007 ± 0.01	0.0000 ± 0.00	0.69
High	6.535 ± 0.27	0.009 ± 0.01	-0.0001 ± 0.00	0.59
Trotters				
	a	***b***	***c***	R^2
Low	3.279 ± 0.07	-0.001 ± 0.00	0.0000 ± 0.00	0.64
Medium	3.136 ± 0.10	-0.001 ± 0.00	0.0000 ± 0.00	0.37
High	2.979 ± 0.14	0.008 ± 0.00	-0.0001 ± 0.00	0.31
Red Offal				
	a	***b***	***c***	R^2
Low	3.683 ± 0.19	0.018 ± 0.01	-0.0001 ± 00	0.69
Medium	3.833 ± 0.19	0.017 ± 0.01	-0.0001 ± 0.00	0.66
High	3.923 ± 0.18	0.015 ± 0.00	-0.0001 ± 0.00	0.67
Omental fat				
	a	***b***	***c***	R^2
Low	-0.151 ± 0.20	0.026 ± 0.01	0.0000 ± 00	0.80
Medium	-0.057 ± 0.17	0.024 ± 0.00	-0.0001 ± 0.00	0.86
High	0.052 ± 0.18	0.019 ± 0.01	-0.0001 ± 0.00	0.82
Kidney fat				
	a	***b***	***c***	R^2
Low	-0.232 ± 0.24	0.032 ± 0.01	-0.0001 ± 0.00	0.61
Medium	-0.239 ± 0.27	0.032 ± 0.01	0.0000 ± 0.00	0.65
High	-0.030 ± 0.14	0.014 ± 0.00	0.0000 ± 0.00	0.82

$^{a\text{-}b}$ means in a column per carcass component with different superscript letters differ ($P < 0.05$).

No significant interactions were observed between the effect of diet and period in the feedlot on the yields of the carcass tissues, as predicted by the three-rib cut. Dietary energy treatment had no significant effect ($P > 0.05$) on the tissue composition of the carcass, while the proportions of the tissues did vary with time spent in the feedlot (Table 5.6). The relative proportions of bone and lean muscles tended to decrease with time, while the proportion of fat increased with time spent in the feedlot. The goats that were slaughtered in the control group at day 0 did not present sufficient quantities of fat which could be used to predict the proportion of fat in the carcass. After 76 days in the feedlot, it was observed that goats on the high energy diet presented a lower carcass fat content

($P < 0.05$); this may be attributed to the differences in slaughter weights for this group observed in Table 5.3. Subcutaneous fat depth was measured throughout the study, however, only the final slaughter group presented subcutaneous fat on the LL muscle, which could be measured. The subcutaneous fat depth of goats in this group did not exceed 1.5 mm at the position of the 13th rib. These quantities were considered to be of little value from a carcass quality viewpoint. The change in the proportions of the major carcass tissues were described using linear regressions (Figure 5.2, 5.3 and 5.4). It was observed that the relative proportions of bone and lean meat decreased while that of fat increased. The parameter estimates did not differ ($P > 0.05$) between the different diets for the changes in the relative proportions of these tissues (Table 5.6). Lower R^2 values for the regressions for the change in the proportion of lean tissue with the age of the goats indicate that the models do not fit the data well.

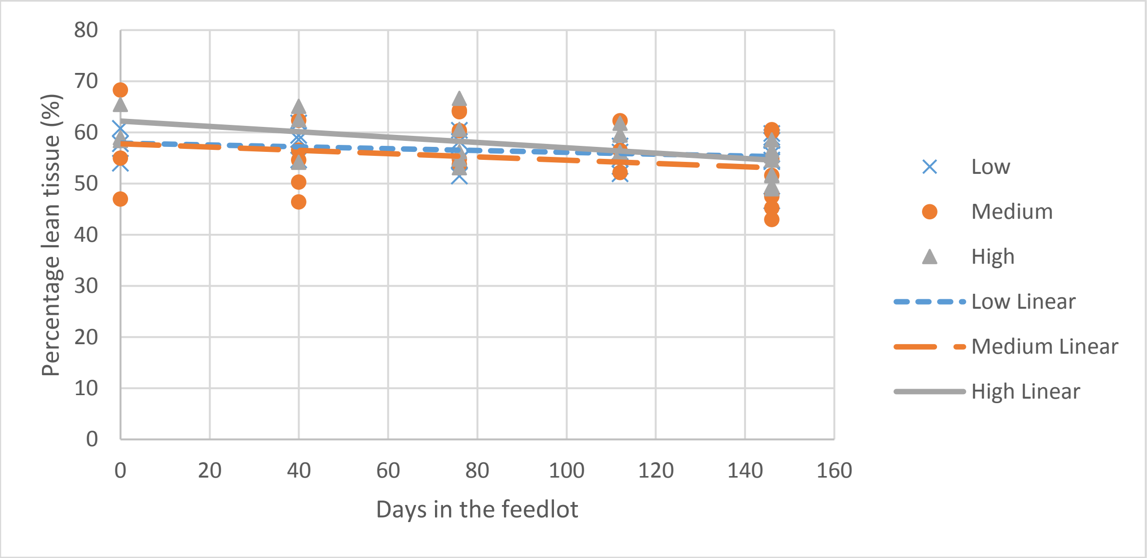

Figure 5.2 Linear regressions (y = *a*+ *b*x) for decrease in proportion of lean tissue (predicted by three-rib cut) of goats, fed diets varying in energy content, with time spent in the feedlot.

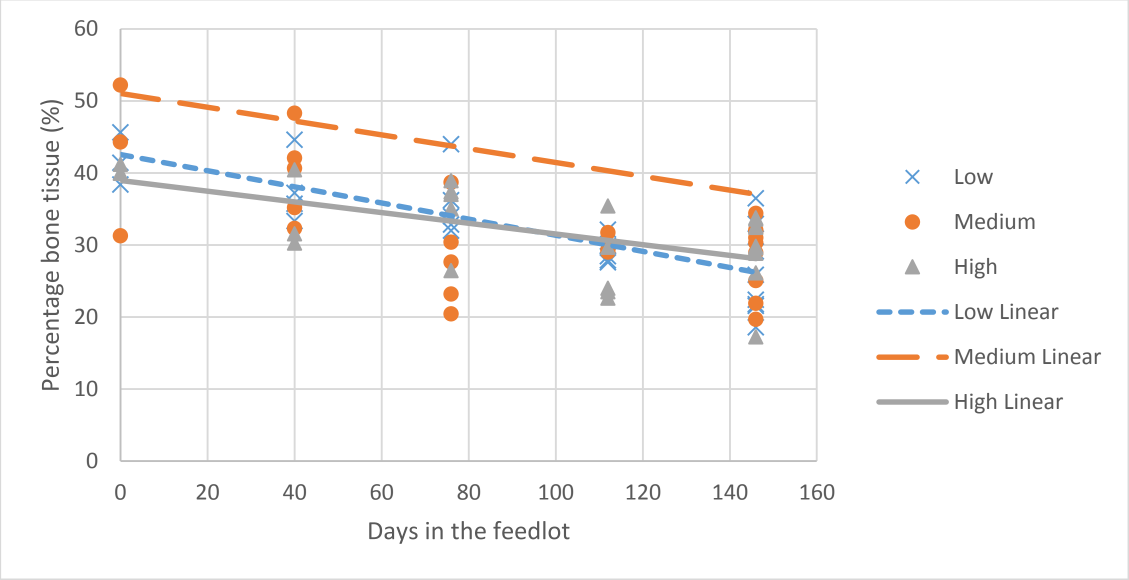

Figure 5.3 Linear regressions (y = *a*+ *b*x) for decrease in proportion of bone tissue (predicted by three-rib cut) of goats, fed diets varying in energy content, with time spent in the feedlot.

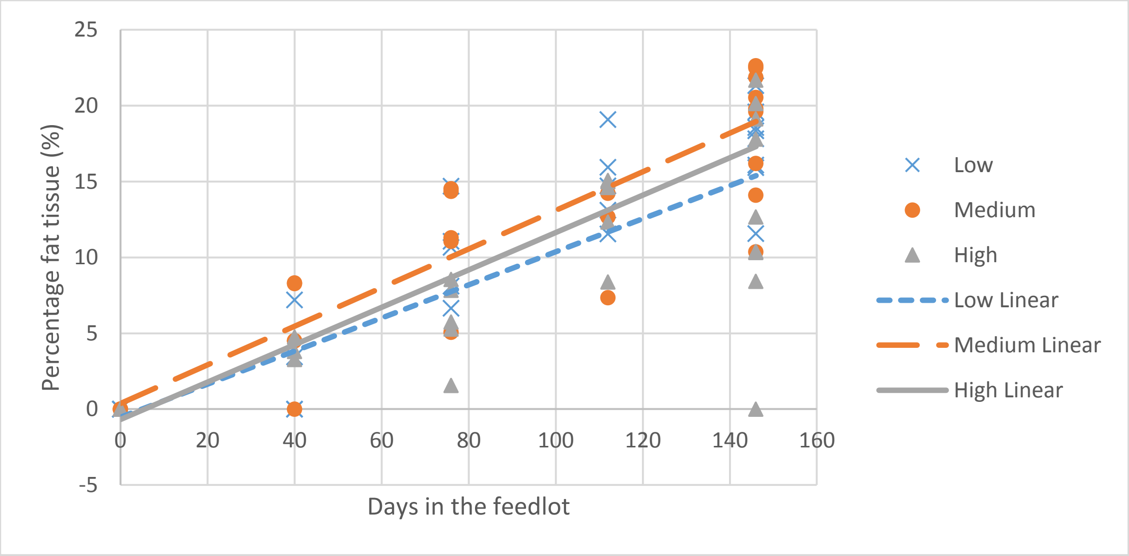

Figure 5.4 Linear regressions (y = *a*+ *b*x) for the increase in proportion of fat tissue (predicted by three-rib cut) of goats, fed diets varying in energy content, with time spent in the feedlot.

Table 5.6 Parameter means ± standard of errors and R^2 coefficients of determination of linear regressions (y = *a* + *b*x + *c*x^2, where x represents days in the feedlot) used to describe the effect of different dietary energy levels on the proportion of major carcass tissues over time spent in the feedlot.

Bone

	a	***b***	**R^2**
Low	42.550 ± 1.93	-0.1118 ± 0.02	0.61
Medium	41.041 ± 2.62	-0.0959 ± 0.03	0.38
High	38.935 ± 2.19	-0.0741 ± 0.02	0.36

Lean meat

	a	***b***	**R^2**
Low	57.917 ± 1.41	-0.0179 ± 0.01	0.07
Medium	57.793 ± 2.70	-0.0323 ± 0.03	0.06
High	62.204 ± 1.71	-0.0521 ± 0.02	0.32

Fat

	a	***b***	**R^2**
Low	-0.521 ± 1.21	0.1090 ± 0.01	0.84
Medium	0.378 ± 1.46	0.1272 ± 0.01	0.77
High	-0.667 ± 1.54	0.1231 ± 0.01	0.72

$^{a-b}$ means in a column per tissue type with different superscript letters differ ($P<0.05$).

No significant interactions ($P> 0.05$) between the main effects were observed for the yields of the commercial cuts. The proportions of the retail cuts relative to the cold carcass weight, all varied with time spent in the feedlot ($P< 0.01$) (Tables 5.9 and 5.10). The overall effect of dietary energy treatment was only seen to be significant for the proportion of the shoulder cut, where goats that received the low energy diet obtained the highest yields ($P< 0.01$).

Linear regressions were used to describe the changes of retail cut yields as the animals got older in the feedlot (Table 5.8). A quadratic function was found to be better suited to describe the change in yields of the shoulder cut. It can be seen that as the feeding period extended, the yields of the loin and rib cuts increased with the cold carcass weight, while the proportions of the neck and leg cuts decreased. Parameter estimates for the various retail cuts did not vary between the different diets that were supplied to the goats in the feedlot, except for the loin cut, where the intercept of the medium diet was higher than that of the other diets, which was accompanied by a lower slope ($P< 0.05$). The R^2 value of the regression of the change in the yield of the loin cut was low, indicating that this model does not fit the data and so parameter estimates are considered to be inaccurate.

Table 5.7 Least square means ± standard error for the carcass yield and carcass tissue composition of goats slaughtered after different periods in the feedlot, where they were supplied the respective trial diets (LSD indicates differences between means from different slaughter intervals).

Carcass composition	**Days in feedlot**					**Diet mean**	***P*-value**	
	0	**40**	**76**	**112**	**146**		**Days in feedlot**	**Diet x Days**
Dressing percentage (%)								
Low	41.0 ± 1.2	43.8^{b} ± 0.5	47.6^{b} ± 0.8	48.2 ± 0.8	48.4 ± 0.5	45.8^{b} ± 0.3		
Medium	40.3 ± 1.2	42.3^{b} ± 0.5	47.3^{b} ± 0.8	51.8 ± 1.1	49.1 ± 0.4	46.1^{ab} ± 0.3		
High	40.0 ± 1.2	46.1^{a} ± 0.7	50.7^{a} ± 0.9	49.2 ± 0.8	48.8 ± 0.4	47.1^{a} ± 0.4	<0. 01	<0.01
P-value	0.82	0.01	0.03	0.06	0.53	0.4	(LSD= 2.8)	
Bone (%)								
Low	41.8 ± 3.7	37.7 ± 2.8	35.8 ± 2.6	29.2 ± 1.7	26.1 ± 1.9	34.1 ± 1.1		
Medium	42.6 ± 3.7	39.7 ± 2.5	28.1 ± 2.6	30.0 ± 2.1	28.4 ± 1.8	33.8 ± 1.2		
High	40.4 ± 3.7	34.1 ± 3.3	35.0 ± 2.6	27.0 ± 1.7	29.3 ± 1.8	33.2 ± 1.2	<0.01	0.25
P-value	0.91	0.43	0.10	0.51	0.47	0.92	(LSD= 4.4)	
Lean meat (%)								
Low	57.5 ± 4.0	58.7 ± 2.6	55.9 ± 2.1	54.7 ± 1.4	55.9 ± 1.7	56.5 ± 1.0		
Medium	56.8 ± 4.0	54.1 ± 2.3	59.5 ± 2.1	57.0 ± 1.8	51.3 ± 1.7	55.7 ± 1.1		
High	61.0 ± 4.0	60.6 ± 3.0	58.3 ± 2.1	58.5 ± 1.4	53.6 ± 1.6	58.4 ± 1.1	0.03	0.41
P-value	0.74	0.23	0.49	0.21	0.20	0.27	(LSD= 3.6)	
Fat (%)								
Low	0	2.6 ± 1.5	10.2^{ab} ± 1.5	14.9 ± 1.5	17.4 ± 1.5	9.0 ± 0.7		
Medium	0	5.1 ± 1.4	11.3^{a} ± 1.5	11.4 ± 2.0	18.6 ± 1.4	9.3 ± 0.7		
High	0	4.0 ± 1.8	5.8^{b} ± 1.5	13.1 ± 1.5	15.1 ± 1.5	7.6 ± 0.6	<0.01	0.41
P-value		0.51	<0.05	0.32	0.2371	0.13	(LSD= 3.7)	

$^{a-b}$ means in a column with different superscript letters differ (P<0.05).

Tissue composition expressed as percentage of respective tissue in three-rib cut.

Table 5.8 Parameter means ± standard of errors and R^2 coefficients of determination of linear regressions (y = *a* + *b*x, where x represents days in the feedlot) used to describe the effect of different dietary energy levels on the cold carcass weight and retail cut yields over time spent in the feedlot.

Cold carcass weight

	a	***b***	**R^2**
Low	8.931 ± 0.90	0.1025 ± 0.01	0.85
Medium	7.897 ± 0.65	0.1000 ± 0.01	0.93
High	8.819 ± 0.87	0.1137 ± 0.01	0.87

Neck

	a	***b***	**R^2**
Low	8.202 ± 0.42	-0.0099 ± 0.00	0.21
Medium	8.927 ± 0.46	-0.0196 ± 0.00	0.46
High	9.048 ± 0.44	-0.0165 ± 0.00	0.42

Ribs

	a	***b***	**R^2**
Low	25.286 ± 0.64	0.0334 ± 0.01	0.56
Medium	23.816 ± 0.83	0.0520 ± 0.01	0.65
High	23.447 ± 0.81	0.0509 ± 0.01	0.66

Loin

	a	***b***	**R^2**
Low	5.548^{b} ± 0.27	0.0188^{a} ± 0.00	0.69
Medium	6.830^{a} ± 0.33	0.0053^{b} ± 0.00	0.12
High	5.710^{ab} ± 0.33	0.0172^{ab} ± 0.00	0.60

Legs

	a	***b***	**R^2**
Low	31.969 ± 0.66	-0.0267 ± 0.01	0.43
Medium	32.394 ± 0.48	-0.0282 ± 0.00	0.61
High	32.648 ± 0.58	-0.0340 ± 0.01	0.63

Shoulder*

	a	***b***	***c***	**R^2**
Low	21.252 ± 0.65	0.032 ± 0.02	-0.0002 ± 0.00	0.61
Medium	21.113 ± 0.61	0.002 ± 0.02	-0.0002 ± 0.00	0.77
High	20.572 ± 0.73	0.032 ± 0.02	-0.0004 ± 0.00	0.68

$^{a\text{-}b}$ means in a column per retail cut with different superscript letters differ ($P< 0.05$).

* A quadratic regression (*a* + *b*x + *c*x^2, where x is days in the feedlot) was fitted to the data to describe the trends for the yield of the shoulder cut over time.

Table 5.9 Least square means ± standard error for the forequarter retail cut yields of goat carcasses that were slaughtered after different periods in the feedlot, where they were supplied the respective trial diets (LSD indicates differences between means from different slaughter intervals).

Retail cut	**Days in feedlot**					**Diet mean**	***P*-value**	
	0	**40**	**76**	**112**	**146**		**Days in feedlot**	**Diet x Days**
Cold carcass weight (kg)								
Low	8.9 ± 0.6	11.3^{b} ± 0.7	17.9 ± 0.8	21.3 ± 0.9	22.7 ± 0.7	16.4 ± 0.4		
Medium	8.2 ± 0.6	11.3^{b} ± 0.6	17.3 ± 0.8	22.5 ± 1.1	24.0 ± 0.7	16.7 ± 0.4		
High	9.1 ± 0.6	14.1^{a} ± 0.8	14.9 ± 0.8	20.8 ± 0.9	24.0 ± 0.7	16.6 ± 0.4	<0.01	0.04
P-value	0.51	0.04	0.06	0.51	0.35	0.49	(LSD= 2.2)	
Neck (%)								
Low	9.0 ± 0.2	6.7 ± 0.5	7.4 ± 0.5	7.8 ± 0.7	6.5 ± 0.4	7.5 ± 0.2		
Medium	8.7 ± 0.2	8.3 ± 0.4	7.3 ± 0.5	7.4 ± 0.6	5.9 ± 0.4	7.5 ± 0.2		
High	9.0 ± 0.2	7.7 ± 0.6	8.0 ± 0.5	8.2 ± 0.6	6.2 ± 0.4	7.8 ± 0.2	<0.01	0.32
P-value	0.62	0.11	0.53	0.56	0.47	0.65	(LSD= 1.3)	
Shoulder (%)								
Low	21.8 ± 0.2	20.8 ± 0.4	19.9 ± 0.3	21.3 ± 0.4	17.4^{a} ± 0.3	20.3^{a} ± 0.2		
Medium	21.7 ± 0.2	20.3 ± 0.3	19.6 ± 0.3	20.8 ± 0.6	16.5^{b} ± 0.2	19.8^{b} ± 0.2		
High	21.1 ± 0.2	20.7 ± 0.4	19.7 ± 0.3	21.1 ± 0.4	16.4^{b} ± 0.3	19.8^{b} ± 0.2	<0.01	0.81
P-value	0.12	0.63	0.65	0.72	0.02	<0.01	(LSD= 0.9)	
Ribs (%)								
Low	24.2 ± 0.5	27.5 ± 0.6	28.9 ± 0.7	27.5 ± 0.5	30.4 ± 0.7	27.7 ± 0.3		
Medium	23.9 ± 0.5	26.0 ± 0.6	28.2 ± 0.7	27.0 ± 0.6	31.9 ± 0.7	27.4 ± 0.4		
High	23.3 ± 0.5	26.7 ± 0.7	27.4 ± 0.7	27.0 ± 0.5	31.7 ± 0.7	27.2 ± 0.4	<0.01	0.41
P-value	0.48	0.28	0.32	0.73	0.32	0.93	(LSD= 1.5)	

$^{a-b}$ means in a column with different superscript letters differ (P<0.05). Retail cuts expressed as percentage of cold carcass weight.

Table 5.10 Least square means ± standard error for the hindquarter retail cut yields of goat carcasses that were slaughtered after different periods in the feedlot, where they were supplied the respective trial diets (LSD indicates differences between means from different slaughter intervals).

Trait	**Days in feedlot**					**Diet mean**	***P*-value**	
	0	**40**	**76**	**112**	**146**		**Days in feedlot**	**Diett x Days**
Loin (%)								
Low	5.4^b ± 0.1	6.2 ± 0.4	6.9 ± 0.3	8.2 ± 0.3	8.1 ± 0.2	7.0 ± 0.1		
Medium	7.2^a ± 0.1	6.7 ± 0.3	7.2 ± 0.3	8.3 ± 0.4	7.4 ± 0.2	7.4 ± 0.2		
High	5.8^b ± 0.1	6.1 ± 0.4	7.0 ± 0.3	8.1 ± 0.3	8.1 ± 0.2	7.0 ± 0.2	<0.01	0.06
P-value	<0.01	0.48	0.75	0.92	0.07	0.71	(LSD= 0.7)	
Flank (%)								
Low	5.6 ± 0.4	6.3 ± 0.3	5.8 ± 0.2	6.3 ± 0.3	5.3 ± 0.2	5.9 ± 0.1		
Medium	5.2 ± 0.4	5.9 ± 0.3	6.2 ± 0.2	6.9 ± 0.4	5.2 ± 0.2	5.9 ± 0.1		
High	5.9 ± 0.4	5.9 ± 0.4	5.9 ± 0.2	5.9 ± 0.3	5.8 ± 0.2	5.9 ± 0.1	<0.01	0.19
P-value	0.63	0.63	0.48	0.14	0.18	0.83	(LSD= 0.6)	
Leg (%)								
Low	32.2 ± 0.7	31.9 ± 0.3	29.2 ± 0.4	27.3 ± 0.3	29.0 ± 0.6	29.9 ± 0.3		
Medium	32.5 ± 0.7	34.8 ± 0.3	29.5 ± 0.4	28.5 ± 0.4	28.6 ± 0.6	30.2 ± 0.3		
High	32.0 ± 0.7	32.1 ± 0.4	30.6 ± 0.4	28.0 ± 0.3	27.8 ± 0.6	30.1 ± 0.3	<0.01	0.36
P-value	0.90	0.90	0.11	0.07	0.37	0.40	(LSD= 1.3)	

$^{a-b}$ means in a column with different superscript letters differ (P<0.05).

Retail cuts expressed as percentage of cold carcass weight.

Due to complications with the apparatus, the warm carcass temperature could not be measured for the baseline slaughter group. An interaction between dietary energy content and time spent in the feedlot was observed for the warm carcass temperature (P= 0.03) (Table 5.12). It was observed that the warm carcass temperature of goats slaughtered after 40 days in the feedlot differed between the different energy diets (P= 0.04) with temperature of goat carcasses on the high diet being higher than that of the other diets (32.8°C versus 29.0°C and 29.8°C for low and medium diets respectively). Overall, carcass temperatures and pH did not vary between the different energy diets (P> 0.05) but did vary between the different slaughter intervals.

No interactions were observed between energy content of the trial diets and time spent in the feedlot for the meat colour parameters (Table 5.13). The colour parameters for the goat meat samples also did not vary between the dietary energy treatments (P> 0.05), although the parameters did vary with time that goats spent in the feedlot. Linear regressions were used to describe the change in meat colour parameter values with the age of the goats in the feedlot. The model parameter estimates did not differ (P> 0.05) between the dietary energy levels of any of the colour parameters. It was observed that lightness (L*), yellowness (b) and chroma values of the meat decreased with the age of the goats in the feedlot, while meat redness (a*) and chroma values increased (Table 5.11). The lower R^2 values for the regressions of lightness and chroma indicate that these linear models do not fit the data accurately.

The effect of diet and time in the feedlot on the physical meat quality attributes of cooking loss, drip loss and shear force are depicted in Table 5.14. Interactions between dietary energy and days spent in the feedlot were observed for all three of the physical meat quality attributes (P< 0.01). The cooking loss of meat from goats slaughtered at day 76 differed between the treatments, (P= 0.01) with meat from goats on the high diet having the highest losses (35.5%), but did not differ further between the different diets at the remaining slaughter intervals. Drip loss between the treatments was seen to vary for the meat from goats that were slaughtered at days 40 and 76 (P= 0.04). The Warner-Bratzler shear force of the samples did not vary between the diets within the slaughter groups (P> 0.05). No differences were observed between the dietary energy levels (P> 0 .05), while cooking loss and shear force of the goat meat samples did vary over time (P< 0.01).

Table 5.11 Parameter means ± standard of errors and R^2 coefficients of determination of linear regressions (y = *a* + *b*x, where x represents days in the feedlot) used to describe the effect of different dietary energy levels on the meat colour parameters over time spent in the feedlot.

L*			
	a	***b***	**R^2**
Low	41.573 ± 1.00	-0.0284 ± 0.01	0.27
Medium	40.748 ± 0.92	-0.0137 ± 0.01	0.09
High	40.553 ± 1.12	-0.0136 ± 0.01	0.07
a*			
	a	***b***	**R^2**
Low	7.821 ± 0.54	0.0271 ± 0.01	0.54
Medium	9.149 ± 0.69	0.0169 ± 0.01	0.23
High	7.916 ± 0.81	0.0235 ± 0.01	0.30
b*			
	a	***b***	**R^2**
Low	10.730 ± 0.47	-0.0163 ± 0.00	0.36
Medium	10.429 ± 0.48	-0.0133 ± 0.00	0.26
High	10.407 ± 0.59	-0.0127 ± 0.01	0.19
Hue			
	a	***b***	**R^2**
Low	53.826 ± 2.11	-0.1080 ± 0.02	0.63
Medium	48.452 ± 2.66	-0.1273 ± 0.03	0.31
High	52.928 ± 3.23	-0.0791 ± 0.03	0.36
Chroma			
	a	***b***	**R^2**
Low	13.437 ± 0.50	0.0087 ± 0.00	0.13
Medium	13.170 ± 0.57	0.0075 ± 0.01	0.07
High	13.026 ± 0.62	0.0089 ± 0.01	0.09

$^{a-b}$ means in a column per colour parameter with different superscript letters differ (P< 0.05).

Table 5.12 Least square means ± standard error for carcass temperature and pH of the various treatment groups that was measured at slaughter and after chilling for 24 hours (LSD indicates differences between means from different slaughter intervals).

Trait	Days in feedlot					Diet mean	*P*-value	
	0	**40**	**76**	**112**	**146**		**Days in feedlot**	**Diet x Days**
Warm carcass temperature (°C)								
Low	-	29.0^{b} ± 0.8	29.1 ± 0.7	27.2 ± 0.7	21.1 ± 0.5	26.6 ± 0.3		
Medium	-	29.8^{b} ± 0.7	28.8 ± 0.7	26.5 ± 0.9	21.5 ± 0.5	26.7 ± 0.3		
High	-	32.8^{a} ± 0.9	28.5 ± 0.7	26.8 ± 0.7	20.5 ± 0.5	27.1 ± 0.3	<0.01	0.03
P-value		0.04	0.78	0.79	0.35	0.71	(LSD= 1.1)	
Cold carcass temperature (°C)								
Low	4.6 ± 0.4	8.8 ± 0.9	9.1 ± 0.4	8.1 ± 0.3	7.6 ± 0.6	7.6 ± 0.3		
Medium	5.3 ± 0.3	9.2 ± 0.8	9.2 ± 0.4	7.9 ± 0.4	7.3 ± 0.5	7.8 ± 0.3		
High	6.1 ± 0.3	9.1 ± 1.0	9.2 ± 0.4	7.8 ± 0.3	8.8 ± 0.5	8.2 ± 0.3	<0.01	0.69
P-value	0.09	0.93	0.98	0.82	0.09	0.31	(LSD= 0.1)	
pH after slaughter								
Low	7.01 ± 0.1	6.63 ± 0.1	6.43 ± 0.1	6.17 ± 0.1	6.28 ± 0.1	6.51 ± 0.1		
Medium	6.70 ± 0.1	6.79 ± 0.1	6.47 ± 0.1	6.60 ± 0.2	6.25 ± 0.1	6.56 ± 0.1		
High	6.54 ± 0.1	6.57 ± 0.2	6.47 ± 0.1	6.30 ± 0.1	6.29 ± 0.1	6.43 ± 0.1	<0.01	0.46
P-value	0.06	0.51	0.98	0.43	0.96	0.44	(LSD= 0.29)	
pH after chilling for 24 hours								
Low	6.17 ± 0.2	5.76 ± 0.1	5.90 ± 0.1	5.42 ± 0.1	5.63 ± 0.1	5.78 ± 0.1		
Medium	5.83 ± 0.2	5.77 ± 0.1	5.63 ± 0.1	5.31 ± 0.1	5.64 ± 0.1	5.64 ± 0.1		
High	5.98 ± 0.2	5.89 ± 0.1	5.67 ± 0.1	5.48 ± 0.1	5.61 ± 0.1	5.73 ± 0.1	<0.01	0.56
P-value	0.39	0.73	0.35	0.43	0.90	0.49	(LSD= 1.06)	

$^{a-b}$ means in a column with different superscript letters differ (P<0.05).

Table 5.13 Least square means ± standard error for colour parameters for goat meat samples from the various treatment groups (LSD indicates differences between means from different slaughter intervals).

Colour parameter	Days in feedlot					Diet mean	*P*-value	
	0	40	76	112	146		Days in feedlot	Diet x Days
L*								
Low	41.46 ± 1.4	42.57 ± 1.1	36.59 ± 1.3	39.20 ± 1.2	37.67 ± 0.6	39.50 ± 0.5		
Medium	41.88 ± 1.4	40.43 ± 0.9	37.55 ± 1.3	40.57 ± 1.6	38.99 ± 0.5	39.88 ± 0.5		
High	41.12 ± 1.4	39.34 ± 1.2	39.94 ± 1.3	37.98 ± 1.2	38.96 ± 0.5	39.46 ± 0.5	<0.01	0.12
P-value	0.93	0.1654	0.22	0.45	0.16	0.71	(LSD= 2.29)	
a*								
Low	7.28 ± 0.6	10.68 ± 0.4	8.77 ± 0.6	10.12 ± 0.4	12.24 ± 0.3	9.82 ± 0.2		
Medium	8.54 ± 0.7	11.68 ± 0.4	8.56 ± 0.6	9.59 ± 0.5	12.24 ± 0.3	10.12 ± 0.2		
High	7.53 ± 0.6	11.73 ± 0.5	8.17 ± 0.6	9.32 ± 0.4	12.06 ± 0.3	9.76 ± 0.2	<0.01	0.61
P-value	0.43	0.17	0.79	0.34	0.88	0.12	(LSD= 0.81)	
b*								
Low	10.98 ± 0.4	9.56 ± 0.5	9.18 ± 0.6	10.18 ± 0.5	7.91 ± 0.4	9.56 ± 0.2		
Medium	11.27 ± 0.4	9.13 ± 0.4	9.05 ± 0.6	10.59 ± 0.7	8.28 ± 0.4	9.66 ± 0.2		
High	10.11 ± 0.4	9.20 ± 0.6	10.02 ± 0.6	9.88 ± 0.5	8.08 ± 0.4	9.46 ± 0.2	<0.01	0.69
P-value	0.13	0.80	0.47	0.73	0.77	0.99	(LSD= 0.87)	
Hue (°)								
Low	56.52 ± 2.6	41.84 ± 1.6	46.39 ± 1.5	45.19 ± 1.2	32.75 ± 1.5	44.54 ± 0.8		
Medium	53.98 ± 3.1	37.97 ± 1.5	46.54 ± 1.5	47.75 ± 1.6	34.48 ± 1.5	44.14 ± 0.9		
High	53.45 ± 2.6	38.03 ± 1.9	50.95 ± 1.5	46.48 ± 1.2	33.91 ± 1.4	44.56 ± 0.8	<0.01	0.27
P-value	0.69	0.21	0.09	0.46	0.71	0.42	(LSD= 5.55)	
Chroma (C*)								
Low	13.18 ± 0.7	14.36 ± 0.5	12.71 ± 0.8	14.35 ± 0.6	14.60 ± 0.3	13.84 ± 0.3		
Medium	13.33 ± 0.7	14.84 ± 0.4	12.46 ± 0.8	14.30 ± 0.6	14.80 ± 0.3	13.95 ± 0.3		
High	12.66 ± 0.7	14.91 ± 0.6	12.97 ± 0.8	13.60 ± 0.6	14.58 ± 0.3	13.75 ± 0.3	<0. 01	0.96
P-value	0.80	0.69	0.90	0.62	0.84	0.79	(LSD= 0.99)	

$^{a-b}$ means in a column with different superscript letters differ (P<0.05).

Table 5.14 Least square means ± standard error for physical meat quality attributes for goat meat samples from the various treatment groups (LSD indicates differences between means from different slaughter intervals).

Trait	**Days in feedlot**					**Diet mean**	***P*-value**	
	0	**40**	**76**	**112**	**146**		**Days in feedlot**	**Diet x Days**
Cooking loss (%)								
Low	33.1 ± 0.9	44.9 ± 1.0	31.8^{b} ± 0.7	36.2 ± 0.8	34.5 ± 0.5	36.1 ± 0.3		
Medium	31.7 ± 0.9	43.8 ± 0.9	33.2^{b} ± 0.7	36.6 ± 1.0	33.7 ± 0.4	35.8 ± 0.3		
High	36.5 ± 1.1	42.9 ± 1.1	35.5^{a} ± 0.7	35.6 ± 0.8	34.3 ± 0.4	37.0 ± 0.4	<0.01	<0.01
P-value	0.05	0.44	0.01	0.70	0.41	0.71	(LSD= 1.9)	
Drip loss (%)								
Low	2.2 ± 1.3	0.0^{b} ± 1.3	2.6^{a} ± 0.7	2.3 ± 0.8	2.2 ± 0.1	1.9 ± 03		
Medium	2.6 ± 1.3	1.9^{ab} ± 1.0	0.0^{b} ± 0.7	3.6 ± 1.0	2.1 ± 0.1	2.0 ± 0.3		
High	1.3 ± 1.3	5.6^{a} ± 1.3	2.4^{a} ± 0.7	2.8 ± 0.8	2.1 ± 0.1	2.8 ± 0.3	0.36	<0.01
P-value	0.78	0.04	0.04	0.62	0.75	0.19	(LSD= 0.1)	
Shear Force (N)								
Low	40.42 ± 2.6	62.07 ± 4.0	44.38 ± 4.2	39.13 ± 3.7	38.80 ± 2.4	44.96 ± 1.6		
Medium	46.71 ± 2.6	50.76 ± 3.6	54.64 ± 4.2	46.04 ± 4.8	38.94 ± 2.2	47.42 ± 1.7		
High	49.63 ± 2.6	49.17 ± 4.6	58.35 ± 4.2	34.50 ± 3.7	37.76 ± 2.2	45.88 ± 1.7	<0.01	0.01
P-value	0.10	0.10	0.09	0.21	0.92	0.48	(LSD= 7.10)	

$^{a-b}$ means in a column with different superscript letters differ (P<0.05)

5.4 Discussion

The lack of differences observed between the dietary energy treatments on carcass components, non-carcass components and meat quality attributes, indicates that goats can be finished on concentrate diets that vary in energy content between 11.3-12.7 MJ ME/kg feed, to yield a carcass of a similar uniform quality. The energy content of the trial diets exceeded the maintenance requirements of the animal, which resulted in growth and an increase in tissue mass (Lawrence et al., 2012). It was proposed that varying the energy content of the diet would influence the growth of certain tissue groups, which would lead to changes in conformation, composition and quality. However, the range with which the energy content of diets varied may not have been wide enough in order to present any marked differences between these traits. Ryan *et al*. (2007) found that feeding goats at different concentrate levels does not influence carcass characteristics However, differences were noticed when goats fed concentrate based diets were compared to goats that were reared on pasture, which has a lower energy density. Feedlot rations with high energy contents are formulated in order to promote optimal growth of the animal (Goetsch *et al*., 2011). Conversely, it has been shown that goats do possess the ability to adjust the level of feed intake according to the energy density of the diet, provided it is not limited by the physical form of the feed (Lu & Potchoiba, 1990). In Chapter 3, it was noted that goats on the low energy diet had higher intake levels than goats fed higher diets with energy levels. Therefore the lack of differences in fat deposition may be as a result of goats offsetting the amount of energy in the trial diet by adjusting the level of feed intake.

The differences associated with time spent in the feedlot can be attributed to normal growth of goats as they age when fed sufficient nutrients as the goats were supplied a balanced concentrate ration which would promote optimal growth and development allowing tissues to mature earlier (Owens *et al*., 1993). The weight of the goats at slaughter increased linearly with the time that the goats spent in the feedlot, which was also reflected by the linear increase in the cold carcass weight (Table 5.8). Patterns of animal growth and development occur as two waves that spread over the body; the first starting at the head and spreading caudally down the trunk of the animal, while the second wave starts at the extremities and spreads dorsally up the limbs to the torso (Berg & Walters, 1983). These principles can be applied to the retail cut yields as well as the body parts that constitute the outer offal components. It was seen that the proportions of the head and trotters decreased with time in the feedlot. This can be expected as the growth rate of the head and limbs decreases relative to that of the rest of the body as an animal gets older (Butterfield, 1988). Solaiman *et al*. (2012) also found that the relative proportions of the feet/trotters decreased over time. Tshabalala *et al*. (2003), reported head, skin and trotter yields of 7.9%, 9.9% and 3.9% respectively for young for Boer goats weighing less than 30 kg, which were greater than the yields of these components found in this study. These differences may be due to the fact that the goats used in the study by Tshabalala *et al*. (2003) were probably reared on extensive grazing and thus exhibited slower growth, and thus may have been chronologically older, but physiologically less mature than most of the goats slaughtered in this trial. However, the differences found between these components in the feedlot trials are small and would probably have very little impact on the economic value of the carcass. The proportion of skin did not vary with age of the goats, and was found to contribute 7-8% of the body weight. This indicates that the skin grows at the same relative rate as the body as a whole (Butterfield, 1988). Goat skins can be used to manufacture goat leather as well as cashmere products. Boer goats produce good quality cashmere with an average fibre diameter of 12 µm, but the overall cashmere fibre production is low (Van Niekerk *et al*., 2004).

The effect of diet did not influence the yield of the red offal components, which did, however, tend to increase with time spent in the feedlot. Again the differences observed were small and the red offal yield would have little economic significance. When a carcass is sold along with the offal, the overall value of the carcass increases, however, profit margins can be increased by selling the offal separately from the carcass at a relatively lower asking price (Aduku *et al*., 1991). The absolute offal weight, which increases with the age of the animal, would then generate a larger profit for the abattoir.

Fat deposition characteristics of goats differs from that of sheep, with goats depositing less fat in subcutaneous fat depots and more in the abdominal cavity, thus presenting a leaner carcass compared to lambs, slaughtered at the same age (Casey & Webb, 2010; Sheridan *et al*., 2003a; Kaic *et al*., 2012). The percentages of kidney and omental fat (caul fat) relative to slaughter weight, increased with time spent in the feedlot, while the maturing rate of the subcutaneous fat depot was still slow. Adipose tissues in the abdominal cavity are regarded as early maturing fat depots, while the subcutaneous fat layer develops later as the animal nears maturity (Negussie *et al*., 2003). The consumption of high energy diets promotes increased levels of fat deposition, which accelerates the rate of deposition as the animal gets older. The low levels of subcutaneous fat observed on the LL muscle (< 1.5 mm) were regarded to have little value on the quality and grading of the carcasses, as at these low levels, the layer measured would mostly consist of the superficial fascia connective tissues. It is also known that goats to tend to deposit less fat in subcutaneous adipose tissues and rather deposit fat in the abdominal cavity (Webb, 2014), and higher levels would be deposited as goats near maturity. Ryan *et al*. (2007) also found that the subcutaneous fat depth on the LL muscle did not exceed 1mm thickness when fed different levels of concentrate. Solaiman *et al*. (2012) found that the subcutaneous fat thickness of Boer goats increased between 0.63 to 1.29 mm after being finished for a period of 85 days. Female goats present larger quantities of fat in the abdominal cavity than males (Hogg *et al*., 1992). It is suggested that these patterns of fat partitioning in goats are related to the potential of the animal to adapt to certain conditions (Negussie *et al*., 2003). These characteristics may allow goats to survive in harsh, dry climatic conditions, with less subcutaneous fat in order to help cope with the heat, while accreting more fat in other depots such as the abdominal cavity, to serve as reserves during periods of drought (Epstein, 1960)..

The proportions of the various retail cuts were seen to differ with time in the feedlot, with the effect of dietary treatment only being noticed for the yield of the shoulder cut. The muscle component makes up the greatest proportion of the cuts and also carries the strongest economic value. Muscle size varies according to the location of the muscle on the body, the age of the animal, as well as the level of muscle activity (Butterfield, 1988). The rump or hind-leg region of the animal contains a high muscle content (yields more tender meat) and therefore it represents the more expensive meat cuts. Generally it was observed that the yield of the hindquarter, neck and shoulder joints decreased while that of the forequarter joints increased, although the absolute weights of the cuts increased with the increase in carcass weight. These trends may be explained by two theorems; the first corresponds to the patterns of growth and development outlined by Berg and Walters (1983). After the initial development, the relative growth rates of the muscle groups associated with the neck and limbs are seen to decrease relative to the rest of the body (Butterfield, 1988). The second theorem is related to the change in the animal's body conformation, which is associated with the onset of puberty. With the onset of puberty, animals start to develop secondary sexual characteristics which adapt the musculature for survival and reproduction (Berg & Walters, 1983). Therefore males will have a more developed neck and thorax while females will exhibit a greater rump region to aid with birthing (Lawrie & Ledward, 2006). As the goats used in this trial were castrates, they still exhibit the body shape changes that are associated with puberty in intact males, although to a lesser extent, while generally exhibiting a higher degree of fatness (Kemp *et al*., 1970). Goats also have a larger neck and thorax region than seen in sheep (Riley *et al*., 1989; Sheridan *et al*., 2003a).

The proportions of bone, lean meat and fat which were predicted using the three-rib cut did not differ in response to the different dietary energy levels that were fed to the goats. This suggests that the different dietary energy levels had a similar effect on fat deposition in the carcass. The proportions of these major tissue groups did however vary with the time that the goats spent in the feedlot. The proportions of bone and lean muscle decreased, while the proportion of fat increased with time in the feedlot. Solaiman *et al*. (2012) also noticed that the proportion of bone and lean muscle decreased (from 31 to 25% and 56 to 54%, respectively), while the percentage of fat increased (from 12 to 19%) in carcasses of Boer goats that were finished over a period of 85 days. Safari *et al*. (2009) found that the percentage of bone decreased and percentage fat increased while the proportion of lean muscle of small East African goats remained constant with increased concentrate supplementation. Different tissues develop and mature at different rates, with growth starting at the neural tissues followed by bone which precedes muscle and finally adipose tissue (Owens *et al*., 1993). Therefore carcasses of young goat kids, pre-weaning, will have a large proportion of bone and generally no or very little fat. As the young kid grows, its musculature will increase with increased activity levels (Berg & Walters, 1983; Butterfield 1988) resulting in a higher proportion of muscle. Generally, confined feeding conditions and high energy concentrate diets promote high levels of fat deposition (Goetsch *et al*., 2011) and so this occurs at an earlier chronological age.

The pH of the LL of the goats did not vary according to dietary treatments (P= 0.44), but it did differ between the slaughter groups (P< 0.01), although no specific trend was noticed. Goats are sensitive to ante-mortem stress and have a high glycolytic potential which affects the level and rate of pH decline (Webb & Casey, 2010). This may explain the differences in pH between the slaughter dates, as the environmental conditions which the goats were exposed to during transport and lairage could not be controlled. The cold carcass temperature of the baseline slaughter group was lower than that of the other groups (P< 0.01). This may have been as a result of complete lack of subcutaneous fat cover which acts to insulate the carcass, as well as the low carcass weight, which results in a high surface area to volume ratio. It has been seen that goats are prone to cold shortening during chilling due to goats generally having low levels of subcutaneous fat, and carcasses are cooled more rapidly (Kannan *et al*., 2006). Muscle temperature and pH decline were not monitored in this study during the chilling of the carcasses and it cannot be concluded whether cold shortening of the muscles did take place in this study. However, owing to the leanness of the goat carcasses, cold shortening could potentially have taken place if the carcasses were chilled too rapidly in the cooler.

The level and rate of pH decline are important as they influence the water binding capacity and colour characteristics of the muscles. Dietary energy treatment had no effect (P> 0.05) on the meat colour parameters or the physical meat quality characteristics, while these attributes did vary between the groups slaughtered after different periods in the feedlot. Meat lightness (L*), yellowness (b*) and hue generally decreased with time, while redness (a*) and chroma values typically increased with time (P< 0.01). Therefore, as the goats got older, the meat got darker and redder. Solaiman *et al*. (2012) found that the values of the L*, a* and b* meat colour parameters all decreased in Boer goats slaughtered at intervals within an 85 day feeding period. Chevon typically has a darker, redder appearance compared to lamb, due to goat meat having less intramuscular fat and higher levels of sarcoplasmic proteins (Babiker *et al*., 1990). Sheridan *et al*. (2003b) did not observe any differences for the colour parameters of meat from Boer goats fed either a low or high energy diet, or between goats slaughtered after 28 and 56 days in the feedlot. Ryan *et al*. (2007) found that a*, b*, hue and chroma colour values were greater in goats fed high levels of concentrate than in range fed goats.

Differences observed in cooking loss between dietary treatments within slaughter groups may have differed statistically; however, as it only varied by 4%, it is debatable whether this has any sensory significance. Muscle pH is a main factor that influences the water binding capacity of muscle proteins. A lower muscle pH would alter the shape of the proteins, allowing them to lose larger amounts of bound water, which would in turn affect the level of cooking and drip loss. However, these traits did not differ within slaughter groups (Table 5.14). As the live weights of the goats slaughtered at days 40 and 76 were seen to vary between treatments (P< 0.05) (Table 5.3), the size of the LL muscle in heavier goats may have been larger. This would mean that the chops? that were cut for drip loss, had a larger surface area for exudate to be released, which could possibly explain the differences in drip loss in these slaughter groups. The shear force varied over time, with a decrease in shear force being observed in the meat from goats that were slaughtered towards the end of the study. Muscle fibre diameter is known to increase with the age of an animal, which is accompanied by a relative decrease in the proportion of collagen surrounding the fibres (Joo *et al*., 2013). Therefore, there may have been a smaller proportion of collagenous tissue in the fixed volume cut by the Warner-Bratzler apparatus in the meat samples from goats slaughtered at the later slaughter groups, leading to the decrease in shear force.

5.5 Conclusion

It was noted that the carcass yield, offal yield, carcass composition and meat quality attributes did not differ when Boer goats were finished off on concentrate diets with energy contents that vary between 11.3 and 12.7 MJ ME/kg feed. Therefore, goats can be finished on diets with a metabolisable energy content that falls within this range, and still yield a carcass of similar, uniform quality. However these carcass and meat quality traits did vary in response to the time spent in the feedlot which can be related to the growth stage of the kids.

It was postulated that high energy feedlot diets fed in combination with the time spent in the feedlot would promote growth of the animal, as well as increase levels of fat deposition. However, it seems as if the energy levels used in this trial did not span a wide enough range to observe significant differences for these traits, especially fat deposition, and the growth of carcass and non-carcass tissues were found to be similar. Nonetheless, higher levels of fat deposition were observed as the animals got older, with the majority of the fat being deposited in the abdominal cavity and relatively low levels in subcutaneous adipose tissues. From this study it is concluded that goats can be slaughtered at live weights ranging between 30 and 50 kg when fed in a feedlot with the above mentioned dietary energy levels and still present a lean carcass with a favourable yield.

5.6 References

Aduku, A. O., Aganga, A. A., Okoh, P. N., Ingawa, S. A., & Phillip, D. O. A. 1991. Contribution of offals to the gross value of goat carcasses in Nigeria. Small Ruminant Research. 6: 179-184.

Berg, R., and Walters L. 1983. Meat animal: Changes and challenges. Journal of Animal Science. 57:133-146.

Butterfield, R. M. 1988. New concept of sheep growth. Department of Veterinary Anatomy. University of Sydney, Australia. 1-57.

Cameron, M., Luo J., Sahlu T., Hart S., Coleman S., and Goetsch A. 2001. Growth and slaughter traits of Boer x Spanish, Boer x Angora, and Spanish goats consuming a concentrate-based diet. Journal of Animal Science. 79: 1423-1430.

Casey, N., and Van Niekerk W. 1988. The Boer goat. I. Origin, adaptability, performance testing, reproduction and milk production. Small Ruminant Research. 1: 291-302.

Casey, N. H., and Webb E. C. 2010. Managing goat production for meat quality. Small Ruminant Research. 89: 218-224.

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

Epstein, H. 1960. History and origin of the Ronderib and Namaqua Afrikaner sheep. Zeitschrift Für Tierzüchtung Und Züchtungsbiologie. 74: 267-292.

Glimp, H. A. 1995. Meat goat production and marketing. Journal of Animal Science. 73: 291-295.

Goetsch, A., Merkel R., and Gipson T. 2011. Factors affecting goat meat production and quality. Small Ruminant Research. 101: 173-181.

Hogg, B. W., Mercer, G. J. K., Mortimer, B. J., Kirton, A. H., and Duganzich, D.M. 1992. Carcass and meat quality attributes of commercial goats in New Zealand. Small Ruminant Research. 8: 243-256.

Honikel, K. O. 1998. Reference methods for the assessment of physical characteristics of meat. Meat Science. 49: 447-457. Joo, S. T., Kim, G. D., Hwang, Y. H., and Ryu, Y. C. 2013. Control of fresh meat quality through manipulation of muscle fiber characteristics. Meat Science, 95: 828-836.

Kaić, A., Cividini, A., and Potočnik, K. 2012. Influence of sex and age at slaughter on growth performance and carcass traits of Boer kids. Acta agriculturae Slovenica 3: 281-285.

Kannan, G., Gadiyaram, M., Galipalli, S., Carmichael, A., Kouakou, B., Pringle, T. D., McMillim, K.W. and Gelaye, S. 2006. Meat quality in goats as influenced by dietary protein and energy levels, and postmortem aging. Small Ruminant Research 61: 45-52.

Kemp, J. D., Crouse, J. D., Deweese, W., and Moody, W. G. 1970. Effect of slaughter weight and castration on carcass characteristics of lambs. Journal of Animal Science, 30: 348-354.

Lawrence, T. L. J., Fowler, V. R. and Novakofksi J. E. 2012. Growth of farm animals. Second edition. CABI. 216-228

Lawrie, R. A. and Ledward, D. A. 2006. Lawrie's meat science. Seventh edition. Woodhead publishing limited. Cambridge, England.

Lu, C., and Potchoiba M. 1990. Feed intake and weight gain of growing goats fed diets of various energy and protein levels. Journal of Animal Science. 68: 1751-1759.

Negussie, E., Rottmann, O. J., Pirchner, F., and Rege, J. E. O. 2003. Patterns of growth and partitioning of fat depots in tropical fat-tailed Menz and Horro sheep breeds. Meat Science, 64: 491-498.

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

Riley, R. R., Savell, J. W., Johnson, D. D., Smith, G. C. and Shelton, M. 1989. Carcass grades, rack composition and tenderness of sheep and goats as influenced by market class and breed. Small Ruminant Research, 2: 273-280.

Ryan, S., Unruh J., Corrigan M., Drouillard J., and Seyfert M. 2007. Effects of concentrate level on carcass traits of Boer crossbred goats. Small Ruminant Research. 73: 67-76.

SAS Institute, 2006. SAS/Stat User's Guide Version 9, 1st printing, Volume 3, SAS Institute, Inc, SAS Campus Drive, Cary, North Carolina 27513.

Safari, J., Mushi D., Mtenga L., Kifaro G., and Eik L. 2009. Effects of concentrate supplementation on carcass and meat quality attributes of feedlot finished small East African goats. Livestock Science. 125: 266-274.

Sheridan, R., Hoffman L., and Ferreira A. 2003a. Meat quality of Boer goat kids and Mutton Merino lambs. 1. Commercial yields and chemical composition. Animal Science. 76: 63-71.

Sheridan, R., Hoffman L., and Ferreira A. 2003b. Meat quality of Boer goat kids and Mutton Merino lambs. 1. Sensory meat evaluation. Animal Science. 76: 73-79.

Solaiman, S., Min, B. R., Gurung, N., Behrends, J., & McElhenney, W. 2012. Effects of breed and harvest age on feed intake, growth, carcass traits, blood metabolites, and lipogenic gene expression in Boer and Kiko goats. Journal of Animal Science. 90: 2092-2108.

Tshabalala, P., Strydom P., Webb E., and De Kock H. 2003. Meat quality of designated South African indigenous goat and sheep breeds. Meat Science. 65: 563-570.

Van Niekerk, W.A., Keva, S., Roets, M. and Coertze, R.J. 2004. The influence of age and reproductive status on quality and quantity of cashmere produced by Boer goats under South African conditions. South African Journal of Animal Science. 34:141-142.

Warris, P. D. 2010. Meat Science. An Introductory Text. 2nd edition. CABI Publishing. Wallingford UK.

Webb, E. C. 2014. Goat meat production, composition, and quality. Animal Frontiers. 4: 33-37.

Webb, E.C. and Casey, N. H. 2010. Physiological limits to growth and related effects on meat quality. Livestock Science. 130: 33-40.

Chapter 6

The effect of dietary energy content on meat quality characteristics of Boer goat meat

Abstract

In South Africa, the Boer goat is regarded as the ideal breed for chevon production. Goats are typically reared on extensive grazing and are marketed directly from the farm. An increased demand for meat production, as well as higher mutton and lamb prices have led to consumers searching for a suitable, cheaper substitute. To meet this demand, the level of goat meat production can be improved by finishing goats in commercial feedlots with high energy diets. The aim of this study was to investigate the palatability, as well as the chemical composition of chevon from goats that were finished on diets varying in energy content. The *Longissimus lumborum* muscles from 24 Boer goat castrates, finished under feedlot conditions for a period of 20 weeks, where they were supplied either a low, medium or high (11.3, 12.0 and 12.7 MJ ME/kg feed) energy diet *ad libitum*, were evaluated by a trained sensory panel on a line scale ranging from 0 (low intensity) to 100 (high intensity) for aroma, flavour and texture attributes. Physical measurements, including Warner-Bratzler shear force, were taken for each sample, while proximate analysis was also conducted on the cooked meat samples. No differences ($P > 0.05$) were found between the dietary treatments for any of the sensory attributes, physical measurements or for the chemical composition of the meat. This may have been as a result of the energy contents of the diets not varying within a wide enough range to influence the level of fat deposition and thus the sensory characteristics. No off odours or flavours associated with goat meat were detected in this study. Lamb flavour and aroma were the most prominent attributes that were detected, whilst low levels of goat-like flavours were detected. Juiciness and tenderness showed strong correlations ($r = 0.864$) and were rated in the middle of their respective scales. Therefore, goats can be finished on feedlot diets that vary in energy content between 11.3- 12.7 MJ ME/kg feed and still produce chevon with uniform eating quality characteristics.

6.1 Introduction

Goat meat remains an important source of nutrients for people in developing regions, particularly around the tropics. Traditionally goats are reared in extensive free-range systems or herded communally with low management inputs. Goats are well adapted to drier climates and exhibit selective foraging preferences (Casey, 1992). This allows them to consume a wider spectrum of plant material than other livestock species. The Boer goat breed was developed by South African farmers who selected traits from indigenous goats for a highly adaptable breed that exhibited good fertility, high growth rates and good body conformation (Casey & Van Niekerk, 1988). This successfully resulted in the improved Boer goat as it is known today, which is regarded as the standard to which other meat goat breeds are compared to (Steyn, 2000).

The level of meat consumption, as well as the type of meat consumed, varies between different population groups according to traditions and gross income (Sans & Combris, 2015). In South Africa, goat meat is generally consumed by the ethnic population, who traditionally herd goats as part of their livestock whilst the Hindu and Muslim populations find chevon a suitable, cheaper substitute for mutton. The demand for goat meat in South Africa peaks around the periods of religious festivals and cultural rituals (Malan, 2000). People in more developed urbanised areas are prejudiced against the consumption of goat meat due to its toughness and flavour qualities, and its acceptance may be improved by expanding the familiarity of the consumers (Borgogno *et al*., 2015). Also, these negative meat quality attributes may be linked to the past where older goats were consumed and the effect of age on tenderness and goat-like flavour is well known. However, there is a new modern trend to market chevon (young goat/kid meat). The perceptions of the modern consumer may be further altered by the nutritive quality of chevon which has a low fat and cholesterol content, which is appealing to health conscious consumers, while still resembling the flavour attributes of lamb or mutton (Webb, 2014).

Chevon is regarded as a lean red meat with favourable nutritive characteristics that is derived from young goat kids (Babiker *et al*., 1990; Webb *et al*., 2005; Webb, 2014). The leanness of goat meat can be attributed to the nature of goats to deposit greater quantities of fat internally in the form of caul and kidney fat and less in subcutaneous and intramuscular fat depots (Casey, 1992; Goetsch *et al*., 2011). This in turn affects the cooling characteristics of the carcass soon after slaughter as the lack of subcutaneous fat surrounding the muscles results in rapid cooling and possible cold shortening of the muscles, which contributes to the inherent toughness of goat meat (Kannan *et al*., 2014). The lack of tenderness of meat from older goats can also be ascribed to higher levels of collagen in the muscles, which have a lower solubility when compared to mutton (Schönfeldt *et al*., 1993; Tshabalala *et al*., 2003). The collagen solubility decreases with the age of the animal as crosslinks between the collagen molecules become more stable and therefore meat from older animals will be tough (Schönfeldt *et al*., 1993). The concept of juiciness is the release of moisture from meat during chewing, which is ascribed to the quantity of water and intramuscular fat in the meat. It is particularly the intramuscular fat which strongly influences sustained juiciness due to the role that fat plays in stimulating saliva production. This juiciness also serves as a dilution factor which consumers indirectly correlate to the tenderness of meat (Webb & O'Neill, 2008). As goat meat is considered to be leaner than lamb when slaughtered at a similar age, it is perceived as being less juicy due to a lower intermuscular fat content (Sheridan *et* al., 2003b; Tshabalala *et al*., 2003).

The palatability of meat is determined by its complex flavour attributes that are perceived from interactions with sensory systems associated with taste and smell. The concepts of meat flavour and aroma are developed from interactions of fatty acids (Webb & O'Neill, 2008), as well as volatile compounds, and non-volatile precursors such as amino acids, reducing sugars and nucleotides during heating (Madruga *et al*., 2010). The components that contribute to species specific flavours are found in the lipid fractions of meat (Webb & O'Neill, 2008; Madruga *et al*., 2010). Chevon meat is described as having a flavour and aroma profile which resembles that of mutton or lamb (Sheridan *et al*., 2003 b). This sheep-like flavour has been seen to be stronger in fat tissues (Schönfeldt *et al*., 1993). However, goat meat does present an additional species specific flavour and odour although the intensities of these attributes is seen to be weaker than in lamb or mutton (Madruga *et al*., 2009). The intensity of these species flavours and aromas become stronger as the animals grow older and fatter (Schönfeldt *et al*., 1993). The musty-sour aromas that are experienced from cooked sheep and goat meat, can be associated with higher levels of 4-methyloctanoic, 4-ethyloctanoic and 4-methylnonanoic branched chain fatty acids (Wong *et al*., 1975), while the goat-like species flavour has also been associated with hexanoic (caproic) acid and other volatile components (Madruga *et al*., 2010).

In intensive animal production systems, young animals are finished in feedlots in order to reach a desirable slaughter weight (and level of fatness) at an earlier age. In finishing systems, animals are fed concentrate based diets with high energy and protein contents in order to promote optimal growth. Limited movement and the high energy diets supplied in feedlots also promote fat accretion in the various depots, which in turn affects the chemical and sensory characteristics of meat (Webb & O'Neill, 2008). As goats are more commonly reared extensively in semi-arid regions it is uncommon to finish goats in a feedlot. An increase in demand for chevon/goat meat applies pressure to increase the volume of goat meat produced and farmers opt to finish goats in feedlots where they will typically use diets that have been formulated for sheep (Van Niekerk & Casey, 1988). Therefore, the aim of this study was to investigate the effect of finisher rations formulated for goats, with different energy levels on the chemical and sensory properties of Boer goat meat.

6.2 Materials and Methods

The experimental layout is outlined in Table 6.1. The meat samples for this study were obtained from 24 Boer goats that were housed in individual pens at Elsenburg experimental farm and supplied one of three trial diets under feedlot conditions. Goats were weaned from their dams at an average age of ~18 weeks of age and introduced to the intensive feeding conditions (for the adaptation program and housing conditions, see Chapter 3). The diets were similar in composition and only varied in energy content to give a low energy (11.3 MJ ME/ kg feed), medium energy (12.0 MJ ME/kg feed) and high energy (12.7 MJ ME/kg feed) diet, expressed on an as fed basis with a moisture content of 10.4%. The composition of the diets is described in Chapter 3. The trial diets were supplied to the goats *ad libitum* for a period of 20 weeks. The goats were then slaughtered at an average live body weight of 48.3 ± 3.8 kg, and carcasses were divided into retail cuts as described in Chapter 5. The left *Longissimus lumborum* muscle was excised from the loin cut of each animal and used for descriptive sensory analysis of the meat.

Table 6.2 Experimental design for meat quality analysis

Dietary energy treatments	Number of goats analysed
Low	8
Medium	8
High	8

The *Longissimus lumborum* muscles were weighed before vacuum packaging and frozen at -18°C for approximately 3 weeks. The frozen muscles were removed from the freezer 24h before testing and were allowed to thaw in a refrigerator at 4°C. A thermocouple probe attached to a handheld temperature monitor (Hanna Instruments, South Africa) was inserted into the centre of the muscle, which was placed in an oven bag (GLAD®) and closed. The muscles in the oven bags, along with the inserted temperature probes, were placed in an industrial oven (Hobart, France) which was preheated to 160°C. The samples were then cooked in the oven until an internal temperature of 72°C was reached (AMSA, 1995). No salt was added to enhance the flavour. The cooked muscles were then allowed to cool before the outer edges were trimmed off and the muscles were cut into 1 cm^3 blocks. These blocks were then wrapped in 10 cm^2 tin foil squares and two wrapped samples per judge were placed into ramekins, which were coded with randomised three-digit codes, and covered with a petri dish. Before the samples were evaluated by the panel, the ramekins with the samples wrapped in tin foil were heated in the industrial oven at 70°C for 10 minutes before being placed in cups in water baths which were set at 70°C, from where they were served to the panel.

Descriptive sensory analysis (DSA) was performed on the meat from the goats fed the three different energy treatments. A tasting panel consisting of 10 judges with previous experience in meat evaluation was selected, and judges were trained to evaluate the attributes associated with the goat meat/chevon. The tasting panel was trained according to the guidelines for sensory analysis of meat (AMSA, 1995) over a period of three days consisting of six training sessions. During these sessions, the left *Longissimus lumborum* muscles from additional goats that were in the same feedlot trial were used. During the training sessions the judges were provided with 1 cm x 1 cm cubes of meat from eight additional reference samples, as indicated in Table 6.2, which were used to illustrate the respective aroma, flavour and texture attributes associated with chevon and goat meat. The goat flavour that is associated with chevon, especially with older animals, is often described as a strong, slightly sour flavour that can be associated with goat products (Schönfeldt *et al*., 1993; Sheridan *et al*., 2003 b). The panel was thus also provided with goat hair, goat milk and two caproic acid solutions that were diluted to sensory threshold levels, to serve as reference samples for varying degrees of goat-like aroma and flavour of the meat. After the training sessions the judges were able to select 24 sensory attributes for evaluating goat meat/chevon and were also able to determine a range in order to score the various attributes. These attributes along with the description for the respective attribute are described in Table 6.2.

Table 6.2 The aroma, flavour and texture attributes, along with their respective descriptors, which were evaluated during the descriptive sensory analysis of goat meat and chevon samples, along with the reference samples that these attributes were associated with.

Attribute	Description	Reference Sample
Aroma	Impression after a few short sniffs when opening the package (0= None, 100= Prominent)	
Lamb fat	Aroma associated with cooked lamb fat	Lamb fat
Lamb meat	Aroma associated with cooked lean lamb muscle	Lamb meat
Beef meat	Aroma associated with cooked lean beef muscle	Beef rump steak
Goat-like	Strong odour that is associated with goat hair, goat products or caproic acid	Chevin goat cheese, goat hair and caproic acid
Sweet associated	Sweet, sugary aroma from meat	Beef rump steak
Oily	Aroma associated with fats and oils	Lamb fat
Herbal	A mild aroma that is associated with herbs or bushes	Karoo lamb meat
Rancid	Aroma associated with oxidised fats and oils	
Metallic	Aroma that resembles metal coins	Ostrich meat
Livery	Aroma associated with cooked liver	Beef Liver
Flavour	Impression after tasting the sample (0= None, 100= Prominent)	
Lamb meat	Flavour associated with cooked lean lamb muscle	Lamb meat
Beef meat	Flavour associated with cooked lean beef muscle	Beef rump steak
Goat-like	Strong or sour taste that is associated with goat products	Chevin goat cheese and goat milk
Sweet associated	Sweet or caramelised sugar flavours from meat	Beef rump steak
Fatty	Lingering taste or mouth-feel associated with cooked fat	Lamb meat
Oily	Flavour associated with fats and oils	Lamb fat
Herbal	Mild flavour associated with herbs and bushes	Karoo lamb meat
Rancid	Flavour associated with oxidised fats and oils	
Metallic	Flat flavour similar to metal coins	Ostrich meat
Livery	Flavour associated with cooked liver meat	Beef liver

Texture		
Initial juiciness	Amount of fluid exuded when pressed between thumb and index finger. (0= Dry, 100= Juicy)	Chicken breast and beef forequarter meat
Sustained juiciness	Impression of juiciness formed after first 5 chews using molar teeth. (0= Dry, 100= Juicy)	
Tenderness	Impression of tenderness formed after first 5 chews using molar teeth. (0= Tough, 100= Tender)	Chicken breast and beef forequarter meat
Residue	Amount of residue left in mouth after 10 chews using molar teeth. (0= None, 100= Abundant)	Chicken breast and beef forequarter meat

Panel assessment occurred over a period of three days consisting of eight sessions. During each session, three samples, one from each dietary energy treatment, were evaluated. Each cooked muscle was given a blinding code so that panellists would not know which treatment they were evaluating. Each panel member received two 1 cm x 1 cm cubes for each of the samples that were evaluated in the testing session. The first cube was used to evaluate aroma and initial juiciness and the second cube used to evaluate flavour and texture attributes. Panellists were seated in individual tasting booths fitted with the Compusense® five (Compusense, Guelph, Canada) software programme. PanelCheck software (Version 1.3.2, www.panelcheck.com) was used to monitor the accuracy of the DSA panel performance. The samples were analysed for the respective sensory attributes on a line scale that ranged from 0 (low intensity) to 100 (high intensity) (AMSA, 1995). The testing sessions took place in a room that was temperature-controlled (25°C) and light-controlled with artificial daylight. Members of the judging panels were supplied with apple slices, water biscuits (Carr, UK) and mineral water in order to cleanse and refresh their palates between samples.

The pH of the three meat samples for each of the eight replications was measured after the meat had thawed at 4°C for 24h. The pH was measured directly after the vacuum packaging was removed, before the sample was prepared for DSA for each session. A Crison pH25 handheld portable pH metre (Lasec (PTY) Ltd, South Africa) which automatically adjusts to the measuring temperature was used. Before each session, the pH metre was calibrated using standard buffers (pH 4.0 and pH 7.0) provided by the manufacturer.

When the muscles were removed from the carcass, prior to vacuum packaging, excess connective tissue was trimmed and the muscles were weighed prior to freezing (-18°C). Before the DSA sessions, the meat samples were thawed at 4°C for 24h. Upon removal from the packaging before each session, the muscle was blotted dry using paper towels and weighed. The thaw loss was then calculated as the percentage of the original mass of the meat sample before freezing. Following the cooking process, the meat samples were allowed to cool for 15 minutes before being blotted dry and weighed. The cooking loss was expressed as a percentage of the difference between the cooked and thawed samples.

The Warner-Bratzler shear force was measured as described by Honikel (1998) with adjustments. Five 2.5 cm long cores, 1.27 cm in diameter, were cut parallel to the meat fibres from the cooked meat samples from each treatment for each session. These cores were wrapped in aluminium foil and placed in a refrigerator (4°C) for 24 h. An Instron universal testing machine (Instron model 4444/H1028, Appollo Scientific cc, South Africa) fitted with a Warner-Bratzler attachment with a 1 mm thick triangular blade with a semi-circular cutting edge, which would cut the core sample perpendicular to the grain, was set to operate with a load cell of 2.000 kN at a speed of 200mm /min to measure the shear force. The shear force values obtained were then expressed in Newton (N). For statistical analysis, the mean of five readings were used per sample.

The cooked muscles that remained after testing were collected and each sample was homogenised and used to determine the moisture, protein, fat and ash content of the cooked chevon. The moisture content of each muscle sample was obtained by drying a 2.5 g sample in an oven at 100°C for 24 h, according to the AOAC official method 934.01 (AOAC, 2002a). The dried sample was then ashed in an oven at 500°C for 6 h (AOAC official method 942.05; AOAC, 2002b). The fat content of the cooked meat was determined from a 5 g sample using the 2:1 chloroform/methanol rapid solvent extraction method as described by Lee *et al.* (1996). The de-fatted meat samples collected in the filtrate from the fat extraction were dried for 48 h at 60°C to remove any moisture and finely ground to determine the crude protein content by the Dumas combustion method 992.15 (AOAC, 2002c), using a Leco FP 528 machine for 0.1000 g of sample. This presents the results as the nitrogen content (% nitrogen) which is then multiplied by a conversion factor of 6.25 to determine the crude protein. A calibration sample of EDTA was run prior to each batch of protein samples in the Leco Nitrogen/Protein analyser. The chemical analyses methodologies described above are all tested bi-monthly in order to ensure accuracy and repeatability by analysing blind samples as part of a National Inter-laboratory Scheme (AgriLASA: Agricultural Laboratory Association of South Africa).

The study consisted of a randomised block design consisting of three treatments and eight replications per treatment. Statistical analysis was performed on the data using SAS 9.2 (SAS, 2006). The sensory, physical and chemical data were subjected to analysis of variance (ANOVA). The results are reported as LSMeans and the standard error of the mean. Normal probability plots, as well as the Shapiro-Wilk test, were used to test for non-normality of the residuals. In the event of non-normality, outliers were identified and residuals greater than 3 were removed. Using XLStat software, Pearson's correlation coefficients (r) for sensory, physical and chemical attributes were calculated where applicable. XLStat software was also used to perform principal component analysis (PCA) using the correlation matrix, along with discriminant analysis (DA) in order to indicate and clarify relationships between sensory physical and chemical attributes.

6.3 Results

For the descriptive sensory analyses (DSA) of the influence of dietary energy content on the sensory attributes of chevon, the mean scores for aroma, flavour and texture attributes are presented in Tables 6.3-6.5. There were no significant differences (P> 0.05) between the dietary treatments for any of the attributes associated with the meat aroma.

Table 6.3 LSMeans and standard error of the mean (SEM) of aroma attributes (0=low, 100=high) for descriptive sensory analysis of chevon from goats that received either a low, medium or high energy diet.

Attribute	**Treatment**			**SEM**	***P*-value**
	Low	**Medium**	**High**		
Lamb Fat Aroma	30.21	30.11	30.21	1.07	0.9971
Lamb Meat Aroma	62.96	64.22	62.88	1.36	0.7383
Beef Meat Aroma	24.99	25.56	26.10	0.90	0.6897
Goat-like Aroma	1.57	1.95	0.89	0.5	0.3313
Sweet Associated Aroma	26.20	26.38	25.94	0.43	0.7624
Oily Aroma	21.34	21.17	22.50	0.78	0.4357
Herbal Aroma	16.50	16.31	15.32	0.89	0.5599
Rancid Aroma	0.00	0.00	0.00	0.00	-
Metallic Aroma	5.35	6.41	5.27	0.98	0.6598
Livery Aroma	6.86	7.55	7.08	0.66	0.7531

The meat from all the treatments presented a characteristic aroma that resembles that of lamb. This is shown by the prominence of lamb meat and lamb fat aromas that were detected in the goat meat samples. These aroma traits for lamb fat and lamb meat were scored higher than the other attributes (scores of ~30 and ~62 respectively) (Table 6.3). The lamb fat aroma was also moderately correlated with herbal aromas (r = 0.57; P< 0.01). Beefy, oily and sweet associated aromas were also identified in the meat samples, whilst hints (low scores) of livery and metallic odours were noticed. The liver and metallic aromas presented moderate to strong correlations (r = 0.68; P< 0.01) with each other. No rancid odours were noted and only traces of goat-like aromas were detected.

Flavour attributes also did not differ significantly (P< 0.05) between the three dietary treatments. The flavour profile of the chevon samples followed a similar trend to that observed with the aroma attributes, with lamb flavour being very prominent during tasting (Table 6.4). The lamb meat flavour showed a moderate correlation with lamb meat aroma (r = 0.59; P< 0.01). Beefy, oily and sweet associated flavours were detected by the panel at similar levels (score ~25), along with the presence of a fatty mouth-feel. Flavours associated with herbs or bushes were also noticed in the chevon samples. As with the corresponding aroma attributes, livery and metallic flavours were detected at low levels. Again, only trace levels of rancid and goat-like flavours were detected in the goat meat. The goat-like flavour and aroma showed a moderate correlation (r = 0.58; P< 0.01), while the flavour also showed to be moderately correlated with the presence of a livery flavour (r = 0.49; P= 0.02).

Table 6.4 LSMeans and standard error of the mean (SEM) of flavour attributes for descriptive sensory analysis (0=low, 100=high) of chevonfrom goats that received either a low, medium or high energy diet.

		Treatment			
Flavour Attribute	**Low**	**Medium**	**High**	**SEM**	***P*-value**
Lamb Meat Flavour	64.78	64.07	64.11	1.07	0.8705
Beef Meat Flavour	26.03	26.87	26.47	0.83	0.7762
Goat-like Flavour	1.30	1.67	0.97	0.37	0.4161
Sweet Associated Flavour	25.30	25.95	25.63	0.48	0.6435
Oily Flavour	25.49	26.38	27.01	0.75	0.3726
Fatty Mouth-feel	23.69	25.71	25.39	0.69	0.1051
Herbal Flavour	16.53	15.01	16.25	0.66	0.2452
Rancid Flavour	0.47	0.92	0.53	0.26	0.4372
Metallic flavour	6.69	8.37	8.65	1.18	0.4597
Livery Flavour	8.46	9.88	9.88	0.73	0.3097

No significant differences (P> 0.05) were detected between the treatments for any of the attributes relating to meat texture. The texture attributes of the chevon samples were all judged by the panel to be moderate and were rated around the middle of the scale (Table 6.5). The sensory scores for tenderness and juiciness were also found to be rated around the middle of the respective scales.

Table 6.5 LSMeans and standard error of the mean (SEM) of texture attributes for descriptive sensory analysis (0=low, 100=high) of chevon from goats that received either a low, medium or high energy feedlot diet.

	Treatment			**SEM**	***P*-value**
Texture Attribute	**Low**	**Medium**	**High**		
Initial Juiciness	49.27	48.02	49.66	3.64	0.9461
Sustained Juiciness	49.50	46.83	50.83	3.54	0.7212
Tenderness	50.34	49.04	48.73	3.19	0.9304
Residue	44.73	45.77	45.88	2.58	0.9411

As with the sensory attributes, no differences ($P \geq 0.05$) were observed between the treatments for the physical measurements, or for the chemical composition of the cooked meat (Table 6.6). The pH of the muscles was found to be 5.75 and the amount of moisture lost from the muscles during thawing was about 5-6%.Cooking losses were calculated to be about 28%. The average shear force of the cooked samples was observed to be 30.11 N. The average values for the moisture, protein, fat and ash components of the cooked meat samples were found to be 59.9, 31.7, 8.1 and 4.4% respectively.

Table 6.6 LSMeans and standard error of the mean (SEM) of physical meat quality parameters and the chemical composition of cooked goat meat from goats that received either a low, medium or high energy feedlot diet.

Attribute	Treatment			SEM	*P*-value
	Low	Medium	High		
Thaw Loss (%)	6.5	4.9	5.4	0.65	0.2336
Cooking Loss (%)	28.1	28.1	28.2	2.83	0.9998
Thaw Temperature (°C)	10.3	9.2	10.0	0.79	0.6452
pH	5.75	5.80	5.75	0.05	0.7211
Shear Force (N)	31.98	26.10	32.24	2.39	0.1455
Moisture (%)	59.8	60.2	59.8	1.30	0.9688
Protein (%)	31.3	31.6	32.0	1.33	0.9209
Fat (%)	8.7	7.8	7.6	1.07	0.7672
Ash (%)	4.2	4.1	5.0	0.55	0.4312

The PCA bi-plot (Figure 6.1) gives an indication of the associations of various sensory attributes when comparing the different dietary treatments that were supplied to the trial animals, as well as associations of the attributes with the physical and chemical properties of the samples. The F1 principal axis accounts for 29.7% of the variation between the attributes, while the F2 axis accounts for 13.7%. From Figure 6.1 it is clear that the dietary energy treatments are spread throughout all of the quadrants, showing no clear association with any of the attributes. This confirms that there were no significant differences for any of the attributes between the three treatments.

As can be seen in the top left quadrant of the PCA plot, tenderness, moisture and sustained juiciness are correlated, while in the opposite quadrant it can be seen that residue and shear force share a relationship. The moisture content of the meat shares a positive moderate correlation with sustained juiciness (r = 0.60; P< 0.01), which in turn shows a strong positive correlation with tenderness (r = 0.86; P< 0. 01). Tenderness in turn shares a negative correlation with Warner-Bratzler shear force (r = -0.50; P= 0.01). The initial juiciness of the meat sample and the cooking losses are negatively correlated (r = -0.89; P< 0.01), with a similar relationship being observed between cooking loss and the sustained juiciness.

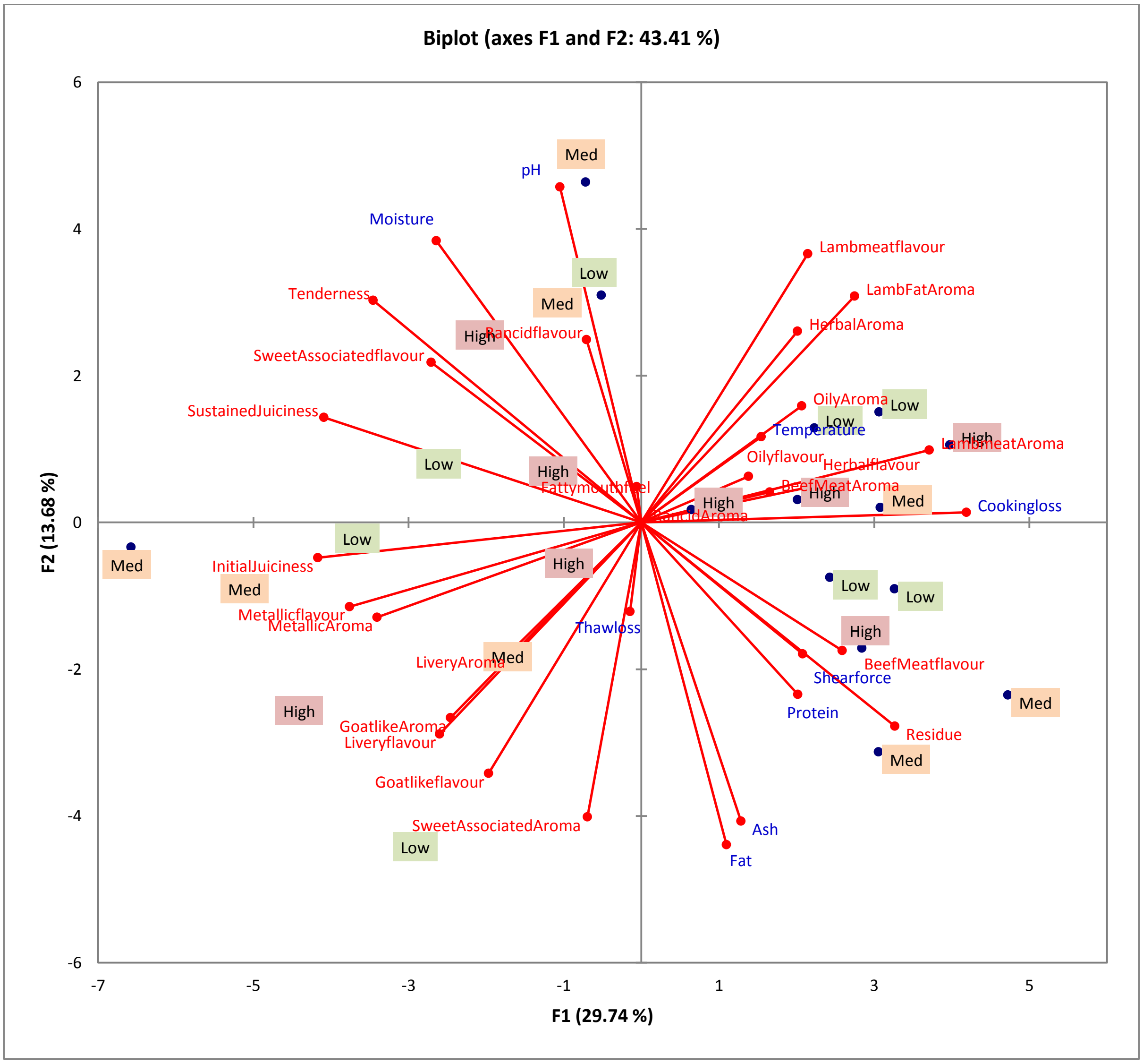

Figure 6.1 PCA bi-plot showing correlations between sensory attributes, physical measurements and chemical composition of meat from goats fed either a low, medium or high energy diet.

6.4 Discussion

Goat meat is often characterised as being inherently tough as well as having a distinct flavour (Kannan *et al*., 2014). People not accustomed to consuming goat meat often discriminate against it (Simela *et al*., 2005 ; Borgogno *et al*., 2015), with tenderness being the main deterrent (Swan *et al*., 1998). However, care should be taken when interpreting published results as there are distinct differences between chevon and goat meat; just as one would expect differences between lamb and mutton. Chevon and lamb are derived from young animals that have less than two permanent incisors, thereafter the meat is classed as goat or mutton. Typically kids and lambs will be finished directly after weaning and are slaughtered before they can acquire permanent incisors. Feedlot finishing of animals entails feeding concentrate grain based diets to animals in order to promote high growth rates, so that animals attain an ideal slaughter weight at an earlier age. The high energy diets provided to animals in a feedlot also account for higher levels of fat deposition especially in early maturing animals. This increase in carcass fat alters the physical as well as chemical properties of the meat (Webb & O'Neill, 2008).

No significant differences between the dietary treatments (P> 0.05) were found for any of the sensory attributes (Tables 6.3 – 6.5), physical or chemical characteristics (Table 6.6). The lack of differences between sensory attributes and chemical composition of goat meat may possibly be due to the noticeable variation in the fat content within treatments (ranging from 3.5% to 13.9%). Hoffman *et al*. (2003) also found no differences in the eating quality of meat from six crossbred lamb types, which may have been as a result of large variation in the fat content of the meat within the breed type. Generally, fat is accreted in the intramuscular fat (IMF) depot at a slower rate compared to the other early maturing fat depot (Warris, 2010). Therefore, this depot only becomes mature later in the animal's life. However the goat species is unique in that it tends to deposit the majority of its fat in the abdominal cavity rather than in subcutaneous and intramuscular depots (Casey & Webb, 2010). In Chapter 5 it was observed that the proportion of abdominal and kidney fat depots increased with the age of the goats while the proportions of fat did not differ between the three dietary treatments.

It could be argued that the range of dietary energy levels varied in this study may not have been wide enough to cause any significant differences in fat deposition and thus the sensory characteristics of the meat. Differences in the flavour attributes have been recorded when goats are supplied a diet that consists of 90% concentrate, compared to goats that where reared on pasture or goats supplied 50 or 70% concentrate (Ryan *et al*., 2007). Sheridan *et al*. (2003b), however, did not notice any differences in the sensory characteristics of meat from Boer goats that were fed diets containing 9.9 MJ/kg DM and 12.1 MJ/kg DM. As studies on the influence of different nutritional levels on the sensory characteristics of chevon and goat meat are limited, comparisons can be made with other ruminant species, specifically sheep. In the same study, Sheridan *et al*. (2003b) found that although goat meat could be distinguished from meat from South African Mutton Merino lambs, diet also did not affect the sensory qualities of lamb meat. Crouse *et al*. (1981) detected sensory differences of mutton from mature rams that were fed diets containing 9.1 and 11.7 MJ ME/kg. Priolo *et al.* (2002) investigated the effect of pasture versus feedlot finishing of lambs, and found that meat from lambs consuming concentrate was more tender and had a stronger flavour profile. French *et* *al*. (2001) also did not notice any differences between steers that consumed either forage or concentrate diets and attributed any variation to the pre-slaughter growth rate.

The lack of differences in meat quality in this study may also be attributed to the same raw materials being used in the formulation of the trial diets. It has been seen that the type of raw materials included in the diet affect the fat content and the fatty acid profile of meat (Russo *et al*., 1999). These differences are greater in monogastric animals than in ruminants, due to bio-hydrogenation of fatty acids in the rumen (Calkins & Hodgen, 2007). Webb *et* al. (2005) nonetheless still found that the levels of margaric, stearic and oleic acid could be increased by increasing the level of maize included in lamb diets. The same trend has been noticed for goats consuming different concentrate levels (Ryan *et al*., 2007; Lee *et al.,* 2008). However, branched shortchain unsaturated fatty acids which are often found in low amounts in adipose and muscle tissue, have been closely linked in contrubting to the intensity of lamb or goat flavour (Wong *et al*., 1975; Kaffarnik *et al*., 2014). Further research may be warranted on the effect of diet on branched short-chain fatty acids. Goats are typically finished on pasture systems as they are adapted to consuming low quality forage that has a low energy content (Morand-Fehr, 2005). Therefore, one cannot increase the energy content of the diet too much, in order to promote increased fat deposition, as it will increase the risk of goats developing metabolic disorders such as acidosis and result in a decrease in production.

Intramuscular fat (IMF) is an important constituent of meat, as it influences the eating quality of meat. The level of IMF, age, breed and the composition of the diet that the animal is supplied, affect the fatty acid composition of the meat (Wood *et al.*, 2008). The aroma and flavour of meat are developed from aldehydes, ketones, non-volatile precursors such as sugars, peptides as well as fatty acids, which give rise to species specific flavours (Webb & O'Neill, 2008; Madruga *et al*., 2010). An increase in the IMF content has been found to increase the intensity of the aroma and flavour profiles of goat meat (Calkins & Hodgen, 2007; Leick *et al*., 2012). This may be as a result of increased fat deposition due to increased concentrate feeding and length of the feeding period (Calkins & Hodgen, 2007; Ryan et al., 2007; Leick *et al*., 2012). The flavour intensity of chevon has been observed to be lower than lamb (Babiker *et al*., 1990; Schönfeldt *et al*., 1993), while Tshabalala *et al*. (2003) found that the intensity of Boer goat meat was stronger than that of indigenous goat breeds.

No differences were found for the aroma and flavour attributes between the dietary treatments in this study, with the goat-like species aroma and flavour being scored at the lower range of the scale. It is suggested that individuals that are not accustomed to consuming chevon or goat products and possibly lamb, would be more sensitive to the associated flavours (Leick *et al*., 2012; Borgogno *et al*., 2015). The higher scores given to lamb aroma and flavour support the findings of Schönfeldt *et al*. (1993) and Sheridan et al. (2003b), that goat meat closely resembles that of lamb. Sheridan *et al*. (2003b) concluded that although similarities do exist for the flavour profiles of chevon and lamb when fed the same diet, species differences in the flavour profile do exist. Although the aroma attributes of lamb and chevon do not differ distinctly, lamb is perceived to be more juicy and tender, and presents a stronger flavour intensity (Swan *et al*., 1998). Literature commonly refers to a goat aroma or flavour (Madruga & Bressan, 2011; Leick *et al*., 2012; Borgogno *et al*., 2015), however, this may refer to the combination of attributes that are associated with lamb, or mutton, along with the goat species specific attributes. Leick *et al*. (2012) described the aroma of goat meat to include musty odours with sweet and sour notes, with off odours described as urine-like being present in intact male goats. These off flavours are also more commonly found in older goats that weighed more than 30 kg (Cividini *et al*., 2014). The goats used in this trial were all castrated males and were possibly slaughtered before the off odours or flavours could become pronounced, and therefore only slight hints were picked up in the sensory evaluation. Crouse *et al*. (1981) also found that sheep weighing heavier than 60 kg had a stronger flavour intensity than wethers used in the same study. The PCA bi-plot (Figure 5.1) shows that goat-like aroma and flavour were associated with the occurrence of livery flavour (aroma, r = 0.43; flavour, r = 0.49). Leick *et al*. (2012) found that the intensity of the livery flavour and goat flavour increased with the length of the feeding period. Goat-like flavour shared a weak correlation with the fat content of the meat (r = 0.29; P= 0.17), which corresponds with the findings of Leick *et al.* (2012). Therefore, fatty acids may not be solely responsible for the goat-like flavour and aroma as was shown by Madruga *et al*. (2010). Moderate to strong correlations (r = 0.68; P< 0.01) were observed for the incidence of livery and metallic aromas. Leick *et al*. (2012) also found association between metallic and livery aromas which may have been related to levels of unsaturated fatty acids in the meat.

Cividini *et al.*, (2014) found that oleic, palmitic and stearic acids are the most abundant fatty acids in meat from Boer goats. Wong et al. (1975) found that C8 – C10 branched chain unsaturated fatty acids, especially 4-methyloctanoic acid, are responsible for the strong mutton flavour associated with lamb and chevon. Caproic or hexanoic acid have also been associated with the sour goat-like flavours (Calkins & Hodgen, 2007; Madruga *et al.*, 2010). It is possible that the correlation between goat-like flavour and IMF will be stronger in older animals. An increase in the feeding duration would show a shift in the fatty acid profile (Leick *et al*., 2012), where higher levels of the above mentioned fatty acids may be expected, resulting in a stronger, more pronounced species specific flavour. Meat goats are typically slaughtered and marketed as chevon at live weights that range between 20 - 40 kg, before they are able to deposit high levels of fat. Therefore, there is a low likelihood of goats developing off flavours or odours when slaughtered at this stage.

The IMF not only influences the aroma and flavour profiles of the meat but also the juiciness and apparent tenderness of meat (Webb & O'Neill, 2008). The capacity of a muscle to release constitutive water contributes to the perceived initial juiciness, while the IMF content provides the sustained juiciness experienced during chewing, which is facilitated by stimulating saliva secretion in the mouth (Dryden & Maechello, 1970). The moisture content of the meat can be linked to meat juiciness as it gives an indication of the amount of water that could potentially be released from the muscle fibres during chewing. Chevon has been found to be less juicy and less tender than lamb (Schönfeldt *et al*., 1993; Sheridan *et* al., 2003b). This is not surprising considering that goat meat is regarded to be leaner than lamb, when slaughtered at the same age, and that chevon does have a greater water holding capacity than lamb (Babiker *et al*., 1990). Leick *et al*. (2012) found that the juiciness of chevon improved with an increase in feeding time, with an increase in fat deposition, while Sheridan *et al.* (2003b) and Ryan *et al.* (2007) also did not detect significant differences in the juiciness and tenderness attributes with higher concentrate diets. From Figure 6.1, it is evident that a strong correlation exists between tenderness and sustained juiciness (r = 0.86; P< 0.01) and with initial juiciness (r = 0.72; P< 0.01). The amount of residue left in the mouth after chewing shares a strong inverse relationship with tenderness (r = -0.91; P< 0.01). It is expected that tough, dry meat will result in a greater quantity of residue left in the mouth, which corresponds to the moderate correlation between residue and the Warner-Bratzler shear force of the samples (r = 0.42; P= 0.04). Meat tenderness was negatively correlated with the Warner-Bratzler shear force (r = -0.50; P= 0.01). This can be expected as a higher shear force value is indicative of tougher meat. Weak correlations exist between the fat content of the meat and the shear force and residue (r = 0.18 and r = 0.33). It is expected that an increase in IMF content of the meat would result in an increase in sustained juiciness, however, a weak negative correlation was observed (r = -0.29). Weak correlations between the fat content of the meat and juiciness and tenderness scores have also been noted by French *et al*. (2001), while Priolo *et al*. (2002) found that these traits were moderately correlated. The deposition of fat increases in older animals, with an increase in IMF deposition as the animal nears maturity (Berg & Walters, 1983). As animals get older, the cross-links between collagen molecules in the connective tissues become more stable and so causes meat to be tough and will result in a greater amount of residue in the mouth (Schönfeldt *et al*., 1993). The relationship seen in the bottom right quadrant of Figure 6.1 between fat, residue and Warner-Bratzler shear force, supports the argument that meat from older goats will be tougher and have a greater fat content and should exhibit stronger flavour intensities, therefore stronger correlations may be expected in older, more mature animals.

The level of cooking loss does affect the moisture content as well as the juiciness of meat. It was found that cooking loss in this study was about 28%, which is lower than the cooking loss reported for samples in Chapter 4, which can be expected as different cooking methods were used. The cooking losses found in this study were higher than that observed by Ryan *et al*. (2007), although Sheridan *et al.* (2003b) and Leick *et al*., (2012) reported cooking losses greater than 30%. As cooked meat samples were used for proximate analysis, the chemical composition will differ from that found in literature, as most studies have looked at the composition of raw chevon samples. Meat used in this study had a lower moisture and fat contents, and higher protein and ash contents than trials done by Sheridan *et al.,* (2003a), Tshabalala *et al*. (2003) and Lee *et al*. (2008). This can be expected as portions of the moisture and fat components are lost during the cooking process and so the relative proportions of fat increase.

6.5 Conclusion

The energy content of the finisher diet fed to Boer goats has no effect on the sensory attributes, physical or chemical properties of the meat even though it is known that dietary energy intake influences the level of fat deposition in the carcass. Therefore, goats that are slaughtered at a live weight lower than 50 kg can be fed diets that vary in energy content between 11.3 and 12.7 MJ ME/kg feed, without affecting the eating quality of the chevon. No pronounced off odours or flavours were detected in the chevon that was sampled, while the aroma and flavour was found to resemble that of lamb. The detection of off flavours and aromas may only be more distinct in goats that are slaughtered at heavier live weights. Possible areas that warrant further research may include investigating the effect of gender on the eating quality of goat meat from goats slaughtered at heavier live weights.

6.5 References

AMSA 1995. Research guidelines for cookery, sensory evaluation and instrumental tenderness measurements of fresh meat. Chicago, USA: National Livestock and Meat Board.

AOAC International 2002a. Loss on drying (moisture) at 95-100°C for feed. AOAC Official Method 934.01. In: Official Method of Analysis, 17th ed. Arlington, Virginia, USA: Association of Official Analytical Chemists Inc.

AOAC International 2002b. Ash of animal feed. AOAC Official Method 942.05. In: Official Method of Analysis, 17th ed. Arlington, Virginia, USA: Association of Official Analytical Chemists Inc.

AOAC International 2002c. Dumas combustion method. AOAC Official Method 992.15. In: Official Method of Analysis, 17th ed. Arlington, Virginia, USA: Association of Official Analytical Chemists Inc.

Babiker, S., El Khider I., and Shafie S. 1990. Chemical composition and quality attributes of goat meat and lamb. Meat Science. 28: 273-277.

Berg, R., and Walters L. 1983. Meat animal: Changes and challenges. Journal of Animal Science. 57:133-146.

Borgogno, M., Corazzin M., Saccà E., Bovolenta S., and Piasentier E. 2015. Influence of familiarity with goat meat on liking and preference for capretto and chevon. Meat Science. 106: 69-77.

Casey, N. 1992. Goat meat in human nutrition. Proceedings V International Conference on Goats. March 1992. New Delhi.

Casey, N., and Van Niekerk W. 1988. The Boer goat. I. Origin, adaptability, performance testing, reproduction and milk production. Small Ruminant Research. 1: 291-302.

Casey, N. H., and Webb E. C. 2010. Managing goat production for meat quality. Small Ruminant Research. 89: 218-224.

Cividini, A., Kaić A., Kompan D., and Potočnik K. 2014. Fatty acid composition and sensory analysis in Boer kids meat. Archiv Fur Tierzucht-Archives of Animal Breeding. 57:1-9.

Crouse, J., Busboom J., Field R., and Ferrell C. 1981. The effects of breed, diet, sex, location and slaughter weight on lamb growth, carcass composition and meat flavour. Journal of Animal Science. 53: 376-386.

Dryden, F., and Maechello J. 1970. Influence of total lipid and fatty acid composition upon the palatability of three bovine muscles. Journal of Animal Science. 31: 36-41.

French, P., O'riordan E., Monahan F., Caffrey P., Mooney M., Troy D., and Moloney A. 2001. The eating quality of meat of steers fed grass and/or concentrates. Meat Science. 57: 379-386.

Goetsch, A., Merkel R., and Gipson T. 2011. Factors affecting goat meat production and quality. Small Ruminant Research. 101: 173-181.

Hoffman, L., Muller M., Cloete S., and Schmidt D. 2003. Comparison of six crossbred lamb types: Sensory, physical and nutritional meat quality characteristics. Meat Science. 65: 1265-1274.

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

Kaffarnik, S., Preuß S., and Vetter W. 2014. Direct determination of flavor relevant and further branched-chain fatty acids from sheep subcutaneous adipose tissue by gas chromatography with mass spectrometry. Journal of Chromatography A. 1350: 92-101.

Kannan, G., Lee J., and Kouakou B. 2014. Chevon quality enhancement: Trends in pre- and post-slaughter techniques. Small Ruminant Research. 121: 80-88.

Lee, J., Kannan G., Eega K., Kouakou B., and Getz W. 2008. Nutritional and quality characteristics of meat from goats and lambs finished under identical dietary regimes. Small Ruminant Research. 74: 255-259.

Lee, C.M., Trevino, B. & Chaiyawat, M. 1996. A simple and rapid solvent extraction method for determining total fats in fish tissue. Journal of Association of Official Analytical Chemists International, 79: 487-492.

Leick, C., Behrends J., Solaiman S., Broadway P., Min B., Mikel W., Williams J., and Schilling M. 2012. Sensory properties and instrumental texture analysis of chevon patties from intact male Boer and Kiko goats harvested at four endpoints. Meat Science. 91: 215-222.

Madruga, M., and Bressan M. 2011. Goat meats: Description, rational use, certification, processing and technological developments. Small Ruminant Research. 98: 39-45.

Madruga, M. S., Elmore J. S., Dodson A. T., and Mottram D. S. 2009. Volatile flavour profile of goat meat extracted by three widely used techniques. Food Chemistry. 115: 1081-1087.

Madruga, M., Elmore J., Oruna-Concha M., Balagiannis D., and Mottram D. 2010. Determination of some water-soluble aroma precursors in goat meat and their enrolment on flavour profile of goat meat. Food Chemistry. 123: 513-520.

Malan, S. 2000. The improved boer goat. Small Ruminant Research. 36: 165-170.

Morand-Fehr, P. 2005. Recent developments in goat nutrition and application: A review. Small Ruminant Research. 60: 25-43.

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

Ryan, S., Unruh J., Corrigan M., Drouillard J., and Seyfert M. 2007. Effects of concentrate level on carcass traits of Boer crossbred goats. Small Ruminant Research. 73: 67-76.

Russo, C., Preziuso G., Casarosa L., Campodoni G., and Cianci D. 1999. Effect of diet energy source on the chemical–physical characteristics of meat and depot fat of lambs carcasses. Small Ruminant Research. 33: 77-85.

Sans, P. and Combris, P. 2015. World meat consumption patterns: An overview of the last fifty years (1961-2011). Meat Science. 109:106-111.

SAS Institute, 2006. SAS/Stat User's Guide Version 9, 1st printing, Volume 3, SAS Institute, Inc, SAS Campus Drive, Cary, North Carolina 27513.

Schönfeldt, H., Naude R., Bok W., Van Heerden S., Smit R., and Boshoff E. 1993. Flavour- and tenderness-related quality characteristics of goat and sheep meat. Meat Science. 34: 363-379.

Sheridan, R., Hoffman L., and Ferreira A. 2003a. Meat quality of Boer goat kids and Mutton Merino lambs. 2. Sensory meat evaluation. Animal Science. 76:63–71

Sheridan, R., Hoffman L., and Ferreira A. 2003b. Meat quality of Boer goat kids and Mutton Merino lambs. 2. Sensory meat evaluation. Animal Science. 76:73–79

Simela, L., Webb E. C., and Bosman M. 2008. Acceptability of chevon from kids, yearling goats and mature does of indigenous South African goats: A case study. South African Journal of Animal Science. 38: 247-259.

Steyn, J. 2010. Farming with Boer goats, a practical guide for Southern African conditions. First ed. Patriot Publishers. Potchefstroom, South Africa.

Swan, J., Esguerra C., and Farouk M. 1998. Some physical, chemical and sensory properties of chevon products from three New Zealand goat breeds. Small Ruminant Research. 28: 273-280.

Tshabalala, P., Strydom P., Webb E., and De Kock H. 2003. Meat quality of designated South African indigenous goat and sheep breeds. Meat Science. 65: 563-570.

Van Niekerk, W., and Casey N. 1988. The Boer goat. II. Growth, nutrient requirements, carcass and meat quality. Small Ruminant Research. 1: 355-368.

Warris, P. 2010. Meat science. An Introductory text. School of Veterinary science University of Bristol, Bristol UK.

Webb, E., and O’Neill H. 2008. The animal fat paradox and meat quality. Meat Science. 80: 28-36.

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

Webb, E., Casey N., and Simela L. 2005. Goat meat quality. Small Ruminant Research. 60: 153-166.

Webb, E. 2014. Goat meat production, composition, and quality. Animal Frontiers. 4: 33-37.

Wong, E., Nixon L. N., and Johnson C. B. 1975. Volatile medium chain fatty acids and mutton flavor. Journal of Agriculture and Food Chemistry. 23: 495-498.

Wood, J. D., Enser, M., Fisher, A. V., Nute, G. R., Sheard, P. R., Richardson, R. I., Hughes, S. I. and Whittington, F. M.. 2008. Fat deposition, fatty acid composition and meat quality: A review. Meat science 78: 343-358.

Chapter 7

General Conclusion

It was hypothesized that the different dietary energy levels would influence the level of feed intake and growth of Boer goats under feedlot conditions. It was also expected that the level of energy in the diet would influence the degree of fat deposition in the carcass and therefore influence meat quality characteristics. An additional effect that was monitored was the time spent in the feedlot, or age of the goats, on the growth and yields of carcass and non-carcass components. The Boer goats used in this study were finished under feedlot conditions, where they were supplied either a low, medium or high energy diet (11.3, 12.0, 12.7 MJ ME/ kg feed respectively) *ad libitum*. Five groups of goats were slaughtered at five week intervals during a 20-week production period. An initial group of goats was slaughtered at the start of the trial to serve as a baseline reference.

During the feedlot production trial, it was observed that goats receiving the high energy diet showed a lower feed intake compared to goats on the other diets. It was concluded that goats are able to adjust their level of intake in response to the energy content of the diet. Boer goats have also been bred for extensive production systems and so have not adapted to consume high energy concentrate diets. This makes the goats more susceptible to subclinical acidosis, caused by the lowering of the ruminal pH, resulting in decreased intakes. The lower intake of goats on the high energy diet was accompanied by lower growth rates of 200 g/day, whilst growth rates higher than 220 g/day were attained by goats on the low and medium energy diets. During the production trials, live weights of the goats increased linearly, while the amount of feed required for gaining a unit of body weight remained constant at about 4.63 kg feed consumed per 1 kg live weight gained. Therefore, it can be concluded that diets formulated with energy levels that range between 11.3 and 12.0 MJ ME/ kg feed would ensure optimal production of Boer goat slaughter kids in a feedlot.

At slaughter it was observed that the energy content of the feedlot diets did not influence the yields of carcass and non-carcass components. The relative yields of these components did, however, differ with the age of the goats at slaughter, although differences in the yields were small and would have little economic value. A three-rib cut was used to predict the proportions of the major carcass tissues of the goats at each slaughter interval. As goats got older, the relative proportions of bone and lean muscle decreased, while the proportion of fat tissue increased. Fat partitioning in goats differs from other livestock species, in that goats tend to deposit the majority of fat internally in the abdominal cavity, rather than in subcutaneous and intramuscular depots, thus the meat from goats is very lean. These patterns were reflected in this study, even with the provision of high energy feedlot diets which promote fat deposition.

Descriptive sensory analysis of the meat from goats, with an average slaughter weight of 48.3 kg, revealed that the energy content of the diet did not influence its eating quality. Meat texture, aroma and flavour attributes of the samples from the different diets were scored similarly, with no off flavours or odours being presented. Further chemical analysis of the cooked meat samples showed that the intramuscular fat contents did not differ between the different energy diets, which explained the lack of differences detected during sensory analysis. Therefore, feeding goats feedlot rations with energy levels that fall within the range of 11.3-12.7 MJ ME/kg feed would produce meat with a uniform eating quality, regardless of the energy content of the diet supplied to the goats.

As the growth of the goats followed a linear trend throughout the production period, it can be concluded that the goats had not reached the point of inflection on the sigmoidal growth curve where growth rates start to decrease as the goats near maturity. Therefore, linear models could be used to describe the growth and feed intake of the goats, rather than the use of a Gompertz model, which would describe the S-shape of the sigmoidal curve that was not demonstrated in this study. As the growth of the goats was linear the amount of energy required for maintenance of the body tissues is relatively low and therefore excess energy consumed in the diet is used for the growth of the animal. This is expected to change as the animal reaches maturity and the increased maintenance requirements of the larger body would result in decreased growth. In this study it is uncertain whether the goats in the final slaughter group had reached the point of inflection or not, without further investigating of the production of Boer goats to heavier live weights. It is only after the goats have reached this point of inflection, which is often associated with puberty that the growth rates of goats would decrease, fat deposition would increase and the development of secondary sexual characteristics will account for major changes in the conformation and composition of the carcass. The weights of the goats will then stabilise and plateau at the mature body weight. With increased fat deposition in the more mature goats, it is expected that the intensity of specie specific off flavours or aromas would increase, decreasing the acceptability of the goat meat. In conclusion, it can be said that goats can be finished on high energy feedlot diets to heavier live weights (40- 50 kg) than what goats are conventionally slaughtered at, while still exhibiting good production characteristics to produce a high quality, lean goat carcass with good eating quality.

General comments:

Decide whether an **s** or **z** is going to be used in the words utilis/ze, optimis/ze, stabilis/ze, mobilis/ze, hypothesis/ze, etc. Some are written in the text with a **s** and others with a **z**.

The word **chevon** is explained in the literature review. However, in the different chapters it is not done. It is advised that it should be explained in each chapter, in order for someone who just read one chapter, to be clear on the meaning of the word.

Chapter 3: The body weights at slaughter of the High energy diet animals at 40 days and 76 days respectively, is somewhat confusing, difficult to explain and seems not very logical. The explanation given for this seems valid: **Goats on the high energy diet slaughtered after 40 days had the highest body weights (31.8 kg; P= 0.03)) compared to goats on the low and medium diets (25.8 and 26.7 kg respectively), while goats on the high energy diet had lower body weights than goats on the low and medium energy diets when slaughtered after 76 days in the feedlot (30.1, 37.6 and 36.5 kg respectively; P= 0.03)). This was probably due to sampling effects when goats were randomly allocated to the respective treatment groups, as no differences were detected in the groups that were slaughtered at later intervals.** However, it is expected that when a similar experiment is done again, the results of this part will probably be different. Animals fed for 76 days on any finishing diet will in most instances have a much higher body weight than after 40 days of feeding, which was not the case in this study. The results of this part of the study had an influence on the overall results, discussion and conclusions with regard to ADG, FCR, etc., which might have looked a bit different if normal growth rates were recorded for the 76 day feeding period on the High energy diet.