Effects of feeding systems on gonadal development and semen quality of young breeding rams of different Merino breed types

by

Amelia May du Preez

BSc Agric (Animal Science) (UP)

Submitted in partial fulfilment of the requirements for the degree

MSc Agric Animal Science (Production Physiology)

In the

Department of Animal and Wildlife Sciences

Faculty of Natural and Agricultural Sciences

University of Pretoria

Pretoria

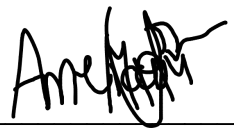
Supervisor: Prof. E.C. Webb

Co-supervisor: Prof. W.A. van Niekerk

April 2019

Declaration

I, Amelia May du Preez, hereby declare that this dissertation, submitted for the MSc (Agric) Animal Science: Production Physiology degree at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at any other University.



Amelia May du Preez

Pretoria

April 2019

“I believe in you” – the best gift you can ever give anyone.

- Nikita Gill

Acknowledgements

A special thank you to Vrede Veld Ram Club who not only helped to fund this project, but also provided the rams, facilities, and production lick needed for this project.

I would like to thank Prof Hannes Dreyer for his advice and assistance with the project.

I wish to convey my sincere gratitude to Mr Piet Potgieter and Mr Gert Smit for managing the rams.

I would like to thank Vrede Saamstaan Veevoere for formulating the commercial diets and licks used during this trial.

Much appreciation to Prof Henry Annandale for doing the semen analysis, semen defects and pathology of the testes.

Thank you to Dr Chris Wolmarans for the scrotal scans of the rams.

I would like to thank Vrede abattoir for making special arrangements for the slaughter and sampling of experimental animals.

I would like to thank my co-supervisor, Prof Willem van Niekerk, for initiating the research and acting as facilitator between Vrede Veld Ram Club and Vrede Saamstaan Veevoere.

Thank you to all my friends! Especially Jani and Rulien! Thank you for allowing me to express my excitement as well as my frustration. Thank you for your countless words of encouragement and advice, for your understanding, for always offering to help. Thank you for always being there and for believing in me.

Mummy, Pappa. I will never be able to thank you enough. Thank you for providing a home filled with love and support. A home where my tired soul can rest and rejuvenate. Thank you for your continued support and encouragement. You have never doubted my abilities, you have never thought a dream of mine was too big. You have always believed in me, and for that, I'm most grateful.

Lastly, but certainly not least, to my superb supervisor and mentor, Prof Edward Webb. I don't even know how to start to say thank you. Thank you for your confidence in me and all the opportunities you have afforded me. You seem to have seen some kind of potential in me and have pushed me to aim higher and dream bigger. Thank you for the countless cups of coffee and all the deep, meaningful conversations about life that come with them. Thank you for helping me take my first steps on the journey to becoming a great researcher.

SUMMARY

It is a widespread practice among small stock farmers in South Africa to provide supplemental feeding to rams for improved body conditioning prior to auctions. This improves the general condition of rams with the added advantages of improved growth and fertility. Better conditioned rams also look healthier and more appealing to the eye and generally attain better prices at auctions. Research suggests that producers should aim to produce “fit not fat” animals and thus not overfeed their animals. In young beef bulls fed high energy diets, significant detrimental effects on semen quality traits have been observed, due to excessive fat deposition and consequent irreversible pathology of the seminiferous tubules. The aim of the present study was to replicate the different feeding systems commonly used in South African sheep farming and to determine the related effects on selected growth and semen quality parameters of rams of different Merino breed types (representing the different production types e.g. wool, wool-mutton, mutton-wool) during the growth phase (e.g. five to twelve months of age).

The effects of extensive feeding, extensive followed by intensive feeding, and intensive feeding were evaluated in Merino (wool type), Döhne Merino (wool-mutton type), and SA Mutton Merino (mutton-wool type) (SAM) rams. Growth, anthropometric measurements, scrotal measurements and post-mortem gonadal measurements were recorded. Semen and blood samples were collected and analysed. Data were analysed by multifactorial ANOVA procedures, by using the Generalize Linear Model (GLM) in IBM SPSS V 23. Bonferroni’s multiple range test was employed to determine differences between the means of the three treatments, breeds, and treatment x breed interactions. Differences were tested at $P < 0.05$ level of confidence regression analyses and partial correlations (Pearson’s product moment partial correlation coefficients) were calculated by controlling the initial weight of rams.

Final growth and size of rams differed between treatments and breeds ($P < 0.05$). The rams in the extensive treatment were the largest, followed by rams in the extensive-intensive treatment. Treatment x breed interactions were significant for final live weight, average daily gain (ADG), body length and subcutaneous fat thickness.

Scrotal measurements of rams in the extensive treatment were larger ($P < 0.05$) for most of the testicular variables, compared with the other treatments, while breed differences ($P < 0.05$) were mostly observed between the Döhne Merinos (which had the larger body measurements) and Merino rams. Scanned scrotal neck fat (SSNF) was one of the variables to show significant treatment x breed interactions; Döhne Merino and SAM rams of the extensive-intensive treatment deposited the most SSNF (1.7 ± 0.19cm and 1.8 ± 0.17cm respectively),

while the extensively kept Merino rams had the most SSNF (1.7 ± 0.46cm). Scrotal fat weight was the highest in the extensive-intensive treatment for all three breeds.

The *Pampiniform venous plexus* circumference (PPC) of the intensive treatment rams was smaller ($P < 0.05$) than the PPC of the extensive-intensive and extensive treatments. The present study also focussed on how effectively thermoregulation was maintained and thus formulated new ratios to estimate the "Effective PPC" (PPC:SSNF). A treatment x breed interaction ($P < 0.05$) was observed for PPC:SSNF. Other ratios formulated included PPC to scrotal fat weight, PPC to testes weight, and Effective PPC to testes weight. It appeared that each of these ratios has an ideal threshold, but more research is required in this regard.

Treatment influenced semen volume and percentage normal spermatozoa. Rams in the extensive-intensive treatment had higher semen volumes ($P < 0.05$) than those in the extensive treatment, while the intensive treatment had fewer normal spermatozoa (69.0 ± 20.04%) than both the extensive-intensive treatment (81.7 ± 9.88%, $P < 0.01$) and extensive treatment (83.0 ± 10.09%, $P = 0.001$). Breed differences were noted for semen volume and sperm mass motility ($P < 0.05$), with higher values recorded in Döhne Merino rams. No significant treatment x breed interactions were observed for any of the semen quality variables. Döhne Merino and SAM rams in the intensive treatment showed beneficial correlations between testes weight and semen quality variables, but detrimental correlations between SSNF and semen quality variables. Negative correlations were recorded between percentage normal spermatozoa (PNS) and scrotal fat weight ($r = -0.80$, $P < 0.05$) in the Döhne Merino rams in the intensive treatment. Correlations between PNS and scrotal fat weight ($r = -0.71$, $P < 0.05$), and between immotile/dead spermatozoa and SSNF ($r = -0.78$, $P < 0.05$) were negative for Merinos in the extensive treatment.

Season, a random factor in this study, influenced some of the testicular variables, semen volume and percentage normal spermatozoa, and the blood hormone T_3 levels ($P < 0.05$), but did not affect testosterone concentrations, which agrees with previous studies. This nutritionally induced dissociation between season, testosterone concentrations and testicular growth is characteristic of rams living in regions of inconsistent feed supply that was not in phase with the photoperiodic responses. This may be a mechanism to ensure that the testes are well developed before testosterone-induced behavioural responses occur before the mating season.

Rams of all three breeds in the intensive treatment grew at a similar rate and benefitted from the concentrate diet. The dual purpose types (Döhne Merino and SAM rams) benefitted more from the concentrate diet fed during the second half of the extensive-intensive treatment and were of a similar size, and had similar testicular dimensions, compared to the older Döhne

Merino and SAM rams of the extensive treatment. Breeders should be cautious of over conditioning, since more fat was deposited in the scrotum of the extensive-intensive treatment rams. No testicular pathology was found in any of the rams. Young rams in the intensive treatment had smaller testicular dimensions and were not sexually mature yet. Farmers employing this system should be made aware of this and be advised to allow two to three months post feeding in order to allow for further testicular growth, before these rams are used for breeding purposes. The concentrate diet generally improved gonadal development and if the intensive treatment was extended for an additional month or two, those rams may have had comparable, or even better, testicular development, compared to the rams in the extensive treatment. However, precautions should be taken in terms of the intensive feeding of young rams for too long as it may adversely affect semen quality. This may be more important in earlier maturing type rams, due to accumulation of excess scrotal fat which may impair thermoregulation and increase the percentage of abnormal sperm. Efficient feeding programs for rams should make provision for Merino breed types (representing the different production types e.g. wool, wool-mutton, mutton-wool), fat accumulation and semen quality.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Since the domestication of farm animals, the effects of nutrition on reproduction have been evident. Walter Heape provided some of the very first experimental evidence of the effects of "flushing" in English sheep in 1899 (Martin *et al.*, 2010). However, Clark (1934) was one of the first to show that nutritional flushing influences reproduction in the ewe by increasing ovulation rate which in turn increases lambing rate. This phenomenon has always fascinated reproduction physiologists and still dominates today's research done on the nutritional influences on reproduction performance in ewes. Before the Second World War, there were some reproduction physiologists who questioned the issues regarding ram fertility.

During the Second World War, Mori (1959) conducted a controlled experiment on large groups of mature and severely underfed rams in Japan. These findings showed that semen production and sperm quality were improved within a period of one to two months when the rams started to gain weight due to additional feed supplementation. Although Mori (1959) did not formally test his assumptions, he believed that protein shortages had influenced the flocks' fertility. But, by the 1960's, less research had been done on male fertility, specifically how nutrition influenced reproduction performance, compared to research done on female fertility. Moule (1963), after reviewing literature done on ruminants, even stated that "…so far no workers seem to have attempted a systematic study of the overall effects of nutrition on semen production in male domestic animals". Due to the complexity of this area of study, many questions still remain unanswered.

The effects of nutrition on the fertility of rams have been researched in more recent studies, but not much has been done on the effects of different feeding systems for the conditioning of young growing rams from weaning to auction on semen quality, especially in the subtropics and tropics. In addition, the effects of different feeding systems on the growth and fertility of rams of different production types (single-purpose versus dual-purpose) have not been studied comprehensively.

It is well known that body weight is highly correlated with testis weight ($r = 0.90$) and that, in turn, testis size and sperm production are highly correlated ($r = 0.80$) (Bearden *et al.*, 2004). This implies that rams of a larger mature size have larger testes and produce more sperm. One way to determine testes size in live animals is to measure their scrotal circumference. Thus, larger scrotal circumference is indicative of larger testes, which means that there is more capacity for higher sperm production. Large or overweight males may deposit scrotal fat, but the question being, where will fat deposition in the scrotum occur? A study done by Swanepoel *et al.* (2008) showed that bulls fed a high energy diet (11 MJ ME/kg DM) had significantly

higher scrotal fat deposition around the testes compared to bulls fed a medium (7.5 MJ ME/kg DM) or low energy (7 MJ ME/kg DM) diet. If fat is deposited around the testes then, unfortunately, scrotal circumference may be misleading and not a true indicator of testes size and sperm production.

When Bester *et al.* (2004) tested the effects of different dietary energy concentrations on scrotal and semen quality traits in young Dorper rams, it was observed that most of the fat deposited in the scrotum was deposited in the neck of the scrotum, around the *Pampiniform venous plexus*, and that the amount of fat deposited was related to the energy concentration of the diet. Excess scrotal fat accumulation may impair thermoregulation of the testes, with adverse effects on sperm production. As selection responses are done from sire selection, it is important to know how fertile rams are and what influences their fertility (Elmaz *et al.*, 2007). Improved ram fertility could improve reproduction of female offspring, thus overall flock fertility could be improved (Elmaz *et al.*, 2007).

In the present study the aim was to evaluate the effects of different feeding systems – which represent different combinations of dietary energy and protein concentrations, typically associated with extensive, extensive-intensive and intensive finishing diets in South Africa – on the semen quality of Merino (wool-type), Döhne Merino (wool-mutton type), and South African Mutton Merino (mutton-wool type) rams during the growth phase (five to twelve months of age). The first objective was to determine the effects of different feeding systems on the skeletal development, gonadal development, and semen quality. The first H_0 was that the extensive-intensive finishing treatment would have detrimental effects on semen quality. The first H_1 was that the extensive-intensive finishing treatment would not have detrimental effects on semen quality. The second objective was to determine if rams of different Merino breed types (representing different production types) influenced the effects of the different feeding systems in terms of growth and semen quality. The second H_0 was that single-purpose breed types would be more affected by the extensive-intensive finishing treatment than dual-purpose breed types. The second H_1 was that single-purpose breed types would not be more affected by the extensive-intensive finishing treatment than dual-purpose breed types.

CHAPTER 1

LITERATURE REVIEW

1.1 Introduction

It is a widespread practice for farmers to feed supplements to rams eight weeks prior to mating. This improves testicular growth and maximises sperm production, but producers should have their animals “fit not fat” and thus not overfeed their rams (Combrink & Schoeman, 1993). Swanepoel *et al.* (2008) found that feeding high energy diets (11 MJ ME/kg DM) to young beef bulls recorded significant detrimental effects on many of the semen quality traits including, the percentage live sperm, percentage motile sperm, percentage dead sperm, percentage sperm defects, and semen volume. These researchers also found that bulls fed this high energy diet had 36% more inactive seminiferous tubules, and more tubuli demonstrating severe atrophy, compared to the bulls fed medium (7.5 MJ ME/kg DM) and low energy (7 MJ ME/kg DM) diets. Scrotal circumference is a trait often used to indirectly predict fertility, but the bulls fed high energy diets in the study by Swanepoel *et al.* (2008) had significantly higher scrotal fat deposition, suggesting that scrotal circumference is not a true indirect indicator of sperm production potential in young bulls fed high energy diets.

Coulter *et al.* (1997) and Lunstra & Coulter (1997) observed that the lower semen volumes recorded in young beef bulls, were due to a reduced number of spermatozoa in the ejaculate. The researchers established that this was due to increased scrotal temperatures caused by increased scrotal fat deposition. Kheradmand *et al.* (2006) did a study on Bakhtiary rams in Iran where the rams were fed a maintenance diet (control) or an above maintenance diet (formulated according to NRC (1985)). Kheradmand *et al.* (2006) found that the improved diet significantly affected scrotal size and increased sperm concentration, but the percentage normal spermatozoa and semen volume were not significantly altered.

When Bester *et al.* (2004) tested the effects of different dietary energy concentrations (8.23 MJ ME/kg DM, 9.77 MJ ME/kg DM, 11.32 MJ ME/kg DM) on scrotal and semen traits in young Dorper rams, it was observed that most of the fat deposited in the scrotum was deposited in the neck of the scrotum, around the *Pampiniform venous plexus*, and that the amount of fat deposited was related to the energy concentration of the diet. Although the fat deposition increased as energy concentration of the diets increased, Bester *et al.* (2004) found no difference between the three groups regarding semen volume, semen concentration, overall sperm motility, progressive motility or percentage normal and live sperm. This contrasts with the findings of Coulter *et al.* (1997), Lunstra & Coulter (1997) and Fourie *et al.* (2004).

Unlike Bester *et al.* (2004), Fourie *et al.* (2004) observed that the results of certain semen parameters (progressive sperm motility, linear sperm progression, overall motility, and semen concentration) were better in the extensively fed Dorper rams compared to intensively fed (9.5 MJ ME/kg DM) Dorper rams. This was attributed to poor thermoregulation of the testes due to excessive fat deposition around the *Pampiniform venous plexus.* Both Bester *et al.* (2004) and Fourie *et al.* (2004) observed improved testicular development (heavier testes weights and higher testes volumes) as the dietary energy concentrations of the feed increased.

1.2 Overview of spermatogenesis

Spermatogenesis is the production of spermatozoa – which takes place in the seminiferous tubules of the testis. Seminiferous tubules are convoluted tubules, 200µm in diameter and constitute approximately 85% of the testis weight in rams and bulls (Beardon *et al*., 2004). When the tubules from both testes in bulls are laid end to end, they can reach lengths of three to five kilometres. The seminiferous tubules continue to form the *rete testis*, a network of tubules, which connects to 12 to 15 small ducts to form the *vasa efferentia*. The *vasa efferentia*, in turn, converge to form the head of the epididymis.

The seminiferous tubules consist of Sertoli cells (nurse cells) which provide a supporting role during spermatogenesis, and spermatogonia (germ cells) which progress to spermatozoa during spermatogenesis (Senger, 2003; Bearden *et al.*, 2004). Sertoli cells envelope and remain in contact with the germ cells until the germ cells are released into the lumen of the seminiferous tubules as spermatozoa. Thus, testes with more Sertoli cells will be able to produce more spermatozoa. Leydig, or interstitial cells, are situated between the seminiferous tubules in the parenchyma of the testis. Leydig cells are stimulated by luteinizing hormone (LH) to produce testosterone. Follicle stimulating hormone (FSH) up-regulates the LH centres found on the Leydig cells – making these cells more sensitive to LH and subsequently producing more testosterone. Follicle stimulating hormone, along with testosterone, stimulates the Sertoli cells to produce spermatozoa, inhibin, oestradiol, transferrin, and androgen-binding protein. High concentrations of testosterone in the seminiferous tubules is essential for normal spermatogenesis. Androgen-binding protein helps to maintain these concentrations by binding to testosterone. The epididymis absorb androgen-binding hormone which ensures that high concentrations of testosterone are maintained in the *rete testis*, *vasa efferentia*, and the proximal part of the epididymis. There is a close relationship between the testicular artery and the *pampiniform venous plexus*. This close relationship between arterial and venous blood supply allows for testosterone to be exchanged between the vessels. Testosterone moves

from the testosterone-rich venous blood to the testosterone-poor arterial blood; thus, some testosterone is recirculated in the testis. High concentrations of blood testosterone have a negative feedback on the hypothalamus, inhibiting the release of GnRH, LH, and FSH (Senger, 2003; Bearden *et al.*, 2004).

Spermatogenesis can be divided into three phases: spermatocytogenesis, meiosis, and spermiogenesis. In rams, it takes 46-49 days for this entire process to occur with each phase being similar in length. A series of mitotic divisions occur during the spermatocytogenesis phase, resulting in 16 primary spermatocytes (diploid) being produced from one active spermatogonium (diploid). The meiosis phase is a two-step process. Firstly, each primary spermatocyte (diploid) undergoes a meiotic division which forms two secondary spermatocytes (haploid). Secondly, each secondary haploid spermatocyte divides again forming two haploid spermatids. Thus, during this phase, four spermatids are formed from one primary spermatocyte, or 64 spermatids are formed from one spermatogonium. The final phase, spermiogenesis, is where spermatids undergo metamorphosis to form mature, elongated spermatozoa. During this phase, it is imperative that the acrosomal cap is formed properly and that the initiation of acrosomic vesicles occurs. Due to elongation and the formation of the tail, the spermatid casts off its cytoplasm and instead forms a cytoplasmic droplet. Once a spermatozoon has been formed it is released into the lumen of the seminiferous tubules through a process called spermiation. The spermatozoon will then travel from the lumen to the *rete testis*, through the *vasa efferentia* into the head of the epididymis (Senger, 2003; Bearden *et al.*, 2004).

Once spermatozoa have been formed, they need to go through two maturation processes before they can take part in the fertilization of the ovum. The first of these maturation processes occurs in the epididymis. As the spermatozoa enter the head of the epididymis, they have neither fertilising ability nor motility. As the spermatozoa are transported from the head to the body to the tail of the epididymis, the spermatozoa gain the ability to be motile and fertile. While the spermatozoa are in the epididymis, they lose the cytoplasmic droplet. The significance of this is not known, but it is used as an indicator of sufficient sperm maturation. In an ejaculate, if a spermatozoon still has a cytoplasmic droplet, it is classified as abnormal. The second maturation phase occurs in the female reproductive track. The spermatozoa must undergo capacitation as well as start an acrosome reaction before they will be able to fertilize the ovum (Senger, 2003; Bearden *et al.*, 2004).

The tail (cauda) of the epididymis provides the optimal conditions to maintain spermatozoa and thus spermatozoa are stored in the tail of the epididymis until ejaculation occurs. The concentration (sperm/ml) of spermatozoa in an ejaculate is approximately two billion in rams.

High-quality semen will consist of 80-90% normal sperm, where the 10-20% abnormal sperm will have no adverse effect on fertilisation rate. However, if the percentage of abnormal sperm in a semen sample exceeds 25%, reduced fertility may be expected.

Sperm may exhibit primary, secondary and tertiary abnormalities. Abnormal spermatozoa heads are classified as primary abnormalities. These abnormalities occur during cell differentiation. Abnormal spermatozoa tails are classed as tertiary abnormalities and occur during the transport of spermatozoa. Secondary abnormalities are when there are still cytoplasmic droplets present on the spermatozoa. This is one of the first abnormalities to appear and the last to disappear when an animal is under stress. The presence of a cytoplasmic droplet indicates that the maturation process has not been completed (Senger, 2003; Bearden *et al.*, 2004). Sperm morphology is influenced by transportation, heat stress, semen collection frequency, temperature, disease, nutrition, age and season of the year (Hafez & Hafez, 2000).

1.2.1 Photoperiodism and its effects on spermatogenesis

Photoperiod refers to the amount of time that an animal is exposed to illumination (day-length). Photoperiodic-effects (i.e. photoperiodism) thus refer to the biological effects on animals due to changes in day-length, which are typically associated with changes in the season. This results in seasonal breeders, such as sheep, entering the breeding season when the day-length decreases. There is then an increase in the frequency and amplitude of LH surges as the breeding season approaches. During the day, the light stimulates the retina, which sends signals via the retina-hypothalamo-pituitary tract to the suprachiasmatic nuclei. These nuclei then generate diurnal signals which are transmitted to the superior cervical ganglia and then, via sympathetic nerves, to the pineal gland. The pinealocytes secrete melatonin which is only synthesised and released during night hours. Melatonin, in turn, stimulates the hypothalamus to secrete GnRH which stimulates the anterior pituitary to release FSH and LH. During the day, the light sensed by the retina activates an excitatory neural pathway stimulating inhibitory neurons to fire at the level of the pineal gland, inhibiting the release of melatonin. During the night, this inhibitory pathway is removed allowing the pinealocytes to release melatonin (Senger, 2003; Bearden *et al.*, 2004).

The rate of spermatogenesis increases as day-length starts to decrease. This affects the quality of the semen of rams. The quality of the semen will differ depending on the time of year (Senger, 2003; Bearden, 2004) and is generally of better quality during autumn and early winter compared to late spring and summer (Barrell & Lapwood, 1979). Although the Dorper

breed showed little seasonality in terms of spermatogenesis, semen collected from Dorper sheep was of better quality during the summer, autumn, and spring seasons, compared to semen collected from Dorper rams during the winter season (Malejane *et al.*, 2014). In Hungarian Black Racka rams (which exhibit a strong seasonal reproduction cycle), testicular dimensions were significantly affected by season ($r = 0.87$, $P < 0.01$) and significant correlations were recorded between scrotal circumference and day-length ($r = 0.43$, $P < 0.05$), as well as between scrotal circumference and average monthly ambient temperature ($r = 0.73$, $P < 0.01$). The highest concentrations of blood testosterone were recorded during autumn (during the breeding season), while the lowest concentrations were recorded in winter. There were significant positive correlations between the scrotal circumference and testosterone concentrations (Sarlós *et al.*, 2013). Sarlós *et al.* (2013) further found that ejaculate volume to increase from spring to autumn. The highest sperm concentration was measured in summer and the lowest in winter, but that sperm count per ejaculate was highest in autumn and lowest in spring. Sperm motility was the highest during summer with the percentage abnormal sperm being the lowest during autumn and the highest during winter. The effect of seasonality on the ram can be observed in the changes in behaviour and testicular dimensions as spermatogenesis and sexual activity are uninterrupted, but these changes are not as prominent as in ewes (Pelletier & Almeida, 1987). For a ram to be qualified as a suitable breeding candidate, it must meet certain genital requirements. Based on the information received from the genital examination, it will be decided if the relative ratio, the development status and the consistency of the genital organs are in accordance to the breed's requirements (Sarlós *et al.*, 2013).

Hafez (1952) was one of the first to realise that sheep breeds in the northern hemisphere are more sensitive to seasonal changes and tend to have stricter breeding seasons compared to sheep breeds in the southern hemisphere. Martin *et al.* (1999) and Blache *et al.* (2002) have reaffirmed this statement. Blache *et al.* (2002) described temperate breeds as "highly photoperiodic", thus their body weight, appetite, and reproductive activity varies significantly through the year. While Martin *et al.* (1999) showed that the photoperiodism of the Australian Merino breed is easily dominated by the response caused by change in nutrition, thus there was no, or very little, inhibitory effect of photoperiod (Blache *et al.*, 2003). This could be due to the little variation in day-length: night-length ratio between summer and winter in the southern hemisphere compared to the large variation experienced in the northern hemisphere. However, there could be another factor at play here e.g. season or month. It would appear to be a difference between photoperiod and season and that these two factors could produce different results. Boland *et al.* (1985) found that month, or season, had a significant effect on semen quality, while photoperiod did not. The results obtained by Langford *et al.* (1987) which

showed that testicular size was influenced by photoperiod, were contradictory to those of Boland *et al.* (1985) who ascertained that season, rather than photoperiod, influenced testicular dimensions. The change in season will cause a change in the quality of the pasture and the amount of available grazing. Young Australian Merino rams kept on pasture for 13 months, lost and gained testes weight during the summer and winter/spring months respectively (Masters & Fels, 1984). It was stated that the change in testes weight was independent of photoperiod and was rather the result of declined energy and protein content of the pasture during the autumn months. Barrell & Lapwood (1979) found that there was a breed effect on certain semen parameters. It was also recorded that seasonal changes had a significant effect on ejaculate volume and semen fructose content, but not on other semen characteristics such as concentration, the morphology of spermatozoa, or motility. There has been little further research done to determine and define if there is a difference between seasonal effects and photoperiodism, and how each parameter influences reproduction in sheep.

1.3 Overview of thermoregulation in the ovine testes

Testicular temperature is regulated in two ways in rams (Bearden *et al.*, 2004). The first way is through the actions of two muscles, namely the *tunica dartos* and the cremaster muscles. The *tunica dartos* is a smooth muscle layer interspersed with fibroelastic tissue, lining the thick, outer skin layer of the scrotum and dividing the scrotum into two compartments (one for each testis). The cremaster muscle is striated muscle continuous with the internal abdominal oblique muscle, which is formed around the spermatic cord in the neck of the scrotum. These muscles are sensitive to temperature: when the ambient temperature is low, both muscles contract to bring the testes closer to the body, while in warm temperatures these muscles relax allowing the testes to swing away from the body. The relaxation of the muscles also increases the surface area of the scrotum which is lined with sweat and sebaceous glands allowing for more evaporation to occur. The *tunica dartos's* ability to contract is under androgen control (Bearden *et al.*, 2004).

The second mechanism is via a network of veins, the *pampiniform venous plexus*, located in the spermatic cord surrounding the testicular artery (Senger, 2003; Bearden *et al.*, 2004). The testicular artery transports warmer (39˚C) blood from the body to the testis, while the veins transport cooler (33˚C), testicular blood from the testis to the body (cooled by direct heat loss through the scrotal skin). This counter-current heat exchange mechanism allows for arterial blood to lose some of its heat to the *venous plexus* and be cooled before it enters the testis.

During warm temperatures, when the *tunica dartos* and cremaster muscles are relaxed, the spermatic cord is lengthened providing a larger surface area for heat exchange. The larger surface area allows for a faster and more efficient rate of evaporative cooling. Due to low blood pressure, caused by the large surface area of the *venous plexus*, and the lack of muscular contractions, blood flow from the testes to the body is sluggish. The contraction and relaxation of the cremaster muscle facilitate blood flow and heat exchange. Both scrotal cooling and the vascular counter-current mechanism are important for efficient testicular cooling. If there is not sufficient cooling of the scrotal skin, the venous blood in the testicle will not be cooled and the vascular counter-current mechanism will not function optimally (Senger, 2003; Bearden *et al.*, 2004).

The necessity of these mechanisms is due to spermatogenesis being compromised at higher temperatures. Spermatogenesis cannot occur at body temperature, explaining why the testes are outside the body – the testes have to be 4-6˚C cooler than the body (Senger, 2003; Bearden *et al.*, 2004). When the temperature is too high the cells lining the walls of the seminiferous tubules start to degenerate and complete degeneration and irreversible damage may occur if the testes are not returned to their natural state. If the testes are returned to their natural state before irreversible damage has occurred, fertility will be restored, but this will take a few weeks as new, fertile sperm will have to be produced. Often during very hot summer months, lower quality spermatozoa will be produced as a result of the body's inability to adequately cool the testes through its cooling mechanisms. The production of spermatozoa might not decrease during hot temperatures, but there is a decrease in motility. The DNA found in the nucleus of the spermatozoon could also be potentially damaged by hot temperatures. Leydig cell function is not influenced by normal body temperatures and will continue to produce testosterone. The male will thus continue to show secondary sex characteristics (Senger, 2003; Bearden *et al.*, 2004).

There tends to be very little fat in the scrotal skin and spermatic cord of mammals. However, under management conditions where animals receive maximum nutrient intake, fat accretion may occur in the spermatic cord and scrotal skin. This accumulation of fat is problematic as it decreases the scrotum and *pampiniform venous plexus*'s ability to effectively cool the testes, resulting in reduced spermatozoal viability, spermatogenic efficiency, and fertility (Senger, 2003).

1.4 The influence of nutrition on reproduction performance of rams

There are four factors which influence the reproduction performance in livestock: the animal's genetic make-up, nutrition, environment and management. Literature has shown that the most crucial of these four factors, in terms of direct effects on reproduction, is nutrition. Nutritional factors have the potential to moderate other factors – high-quality diets help animals reach their genetic potential, can reduce the effects of poor management, and help sustain animals in harsh environments (Kheradmand *et al.*, 2006).

As early as the Second World War, there was already an understanding that, somehow, improved feeding improved the fertility of males. During the Second World War, Mori (1959) did a study on a large group of severely underfed mature Merino rams. Once the rams received supplements, which helped them gain weight, semen quality and sperm production improved significantly within a few months. The work of Mori (1959) was soon supported by Salamon (1964) and Setchell *et al.* (1965) who both did studies on the Merino breed. Salamon (1964) collected semen at high frequencies, while Setchell *et al.* (1965) assessed the histology of the epididymis and seminiferous tubules. Both found that undernutrition reduced the daily rate of sperm production and that improved nutrition increased the daily rate of sperm production. When undernutrition occurred for a period longer than the seven-week duration of spermatogenesis, sperm quality (sperm motility and sperm count) was reduced (Parker & Thwaites, 1972; Robinson *et al.*, 2006). There is a wide acceptance that in small stock there are strong, direct relationships between the plane of nutrition, testes weight, and the number of sperm (Figure 1.1). It has been well established that nutrition influences testicular size and the production of spermatozoa by changing the testicular tissue (Cameron et al., 1988).

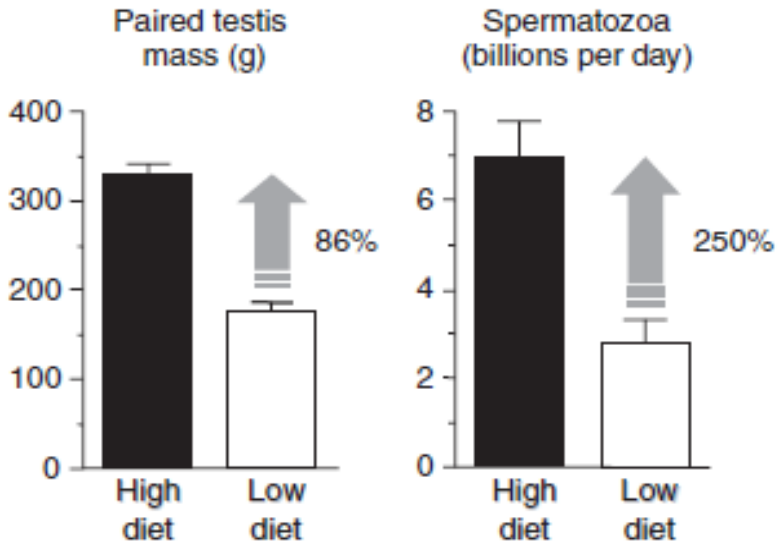


Figure 1.1 Effect of nutrition on testicular growth and production of spermatozoa in one-year-old Merino rams ($P < 0.01$) (Cameron *et al.*, 1988)

The rate of spermatozoa production is correlated with testicular weight (Pomares *et al.*, 1991; Walkden-Brown *et al.*, 1994). Sperm production had greater proportional changes than testes size which proves that the change in nutrition in rams altered both the total testes weight and the efficiency of gamete production (Martin *et al.*, 2010). These greater proportional changes in sperm production relative to testes size were previously stated by Oldham *et al.* (1978) and Cameron *et al.* (1988). Oldham *et al.* (1978) showed that a 25% increase in testicular size resulted in an 81% increase in sperm production, while Cameron *et al.* (1988) recorded a 250% increase in sperm production when testes size increased by 86% (Figure 1.1). The change in testicular weight was due to the change in the amount of seminiferous tissue which changed the spermatogenic capacity and efficiency of the testes (Pisselet *et al.*, 1984).

Histological studies showed that nutrition altered the diameter of the seminiferous tubules, the proportion of the seminiferous tubules occupied by seminiferous epithelium, and the proportion of the testes occupied by seminiferous tubules (Setchell *et al.* 1965; Oldham *et al.*, 1978; Hötzel *et al.*, 1998). Braden *et al.* (1974) found that diets with a higher protein content increased the testicular weight of rams, while testicular weight was further increased when the diets were high in energy and protein content. The protein content of a diet recorded an indirect effect on spermatogenesis, by increasing testicular size. The increase in testicular size was caused by the increase in the diameter of the seminiferous tubules and an increase in the volume of the seminiferous epithelium (Oldham *et al.*, 1978; Hötzel *et al.*, 1998; Fernandez *et al.,* 2004; Kheradmand *et al.*, 2006). Hötzel *et al.* (1998) documented that the length and the diameter of the seminiferous tubules in the testes of rams fed a high energy diet, were greater than those of rams fed a low energy diet. The absolute volume of the interstitial tissue was not affected by diet, but the absolute volume of the seminiferous tubules per testis was higher in the rams fed the high energy diet, because the proportion of the testis taken up by seminiferous tissue, increased. The number of spermatogenic cells was lower in the rams fed the low energy diet compared with the rams fed the high energy diet – due to the reduced tubule diameter, an infolding of the basement membrane of the seminiferous epithelium was observed in the rams fed the low energy diet. The number of Leydig cells found in the testis did not differ between the two diets, but the volume that the Leydig cells occupied was up to 30% greater in rams fed the high energy diet, thus testosterone production rate was affected (Hötzel *et al.*, 1998). Alternatively, Martin *et al.* (2010) recorded that these effects did not result in changes in testosterone production.

A change in the concentration of sperm ejaculated was only documented seven weeks after a change in nutrition occurred, thus the effects on spermatogenic efficiency were only exerted after the last spermatogonial division. It has long been believed that Sertoli cells are established before puberty (Monet-Kuntz *et al*., 1984), however other studies done by Hötzel

et al. (1998) and Tarulli *et al.* (2006) have reported that there were changes in Sertoli cell numbers after puberty and that nutrition affected the number of Sertoli cell nuclei per testes (but not the proportion of testes occupied by Sertoli cell nuclei). In rams fed a high energy diet, more Sertoli cell nuclei were recorded compared with the rams fed a low energy diet. This supports the idea of an improved spermatogenic efficiency, but is contradictory to Monet-Kuntz's *et al*. (1984) notion that Sertoli cell numbers are established before puberty. From studies done on hamsters, Tarulli *et al*. (2006) proposed that Sertoli cells in adults are not terminally differentiated and that Sertoli cells enter a transitional state exhibiting differentiated and undifferentiated features. Also, the nuclear size of the Sertoli cells is correlated to cell function and thus sperm production (Sinha Hikim *et al.*, 1988). Testicular size and the maximum rate of spermatogenesis are highly correlated to the number of Sertoli cells (Bielli *et al.*, 2002) which means that there exists a correlation between scrotal circumference and sperm production (Kheradmand *et al.,* 2006). Kheradmand *et al.* (2006) reported that nutrition had an effect on semen volume, although the results were not significant. What should be kept in mind is that nutrition during pregnancy is vital as it affects foetal programming and the development of the placenta. The consequences of nutritional mismanagement only become evident after birth and sometimes only after sexual maturity, and are associated with reduced lifetime performance (Bell, 1984). The development of reproductive tissue can even be compromised (Martin *et al.*, 2004), as the study of Bielli *et al.* (2002) proved. The study found that when ewes were underfed during the second half of pregnancy, their ram lambs had fewer Sertoli cells in their testes at birth compared with ram lambs whose mothers were not underfed.

The testosterone concentrations from blood samples taken from the jugular vein were significantly higher in the Merino rams fed a high energy diet, but these differences were not observed in the blood samples taken from the testicular vein (Hötzel *et al.*, 1998). This was accredited to the differences in blood flow through the testes between the rams of the different diets. Blood flow through the testes is related to testicular weight, thus the blood and lymph vessel volumes were indirectly affected by diet due to the change in testicular size. Thus, more testosterone was produced by the testes and reached the peripheral circulation of the rams fed the high energy diet. It was these changes in vasculature and blood flow, which assisted in the transport of testosterone to the peripheral circulation (Setchell *et al.*, 1965, Setchell, 1986; Setchell, 1990; Hötzel *et al.*, 1998). Oestradiol mean plasma concentrations were significantly higher in the rams fed the high energy diet, suggesting that nutrition either influenced the rate of aromatization of testosterone to oestradiol or its metabolic clearance. A strong correlation between the effect of time and the effect of diet, for both testicular and peripheral circulations, was recorded. However, the duration and the severity of the dietary

treatments need to be taken into consideration (Setchell *et al.*, 1965; Hötzel *et al.*, 1998; Martin *et al.*, 2010). The differences in severity and duration of dietary treatments would explain the contradictions observed in studies which reported no effects of nutritional treatments on peripheral testosterone concentrations (Martin *et al.*, 1994). Serum testosterone concentrations increased and decreased more slowly in rams fed the low energy diet compared with rams fed the high energy diet (Hötzel *et al.*, 1998). Serum testosterone secretion is correlated to the number and size of Leydig cells, but more so to the surface area of the endoplasmic reticulum (Ewing & Zirkin, 1983; Lunstra & Schanbacher, 1988). The number of LH receptors on the Leydig cells influences the cells' sensitivity to LH and thus the regulation of steroidogenic activity (Barenton *et al.*, 1983). The delay of testosterone secretion in response to LH stimulation was also recorded in rams immunized against GnRH (Chase *et al.*, 1988), suggesting that the delay was caused by gonadotrophin deprivation. In Figure 1.2, Blache *et al*. (2002) showed that a two-fold increase in diet may cause a two to three-fold increase in plasma LH and FSH pulses. It takes two to three days for the LH pulses to start to increase, and five to ten days for FSH pulses to increase. Furthermore, if a high plane of diet is maintained, LH pulses will persist for three weeks and then start to decline.

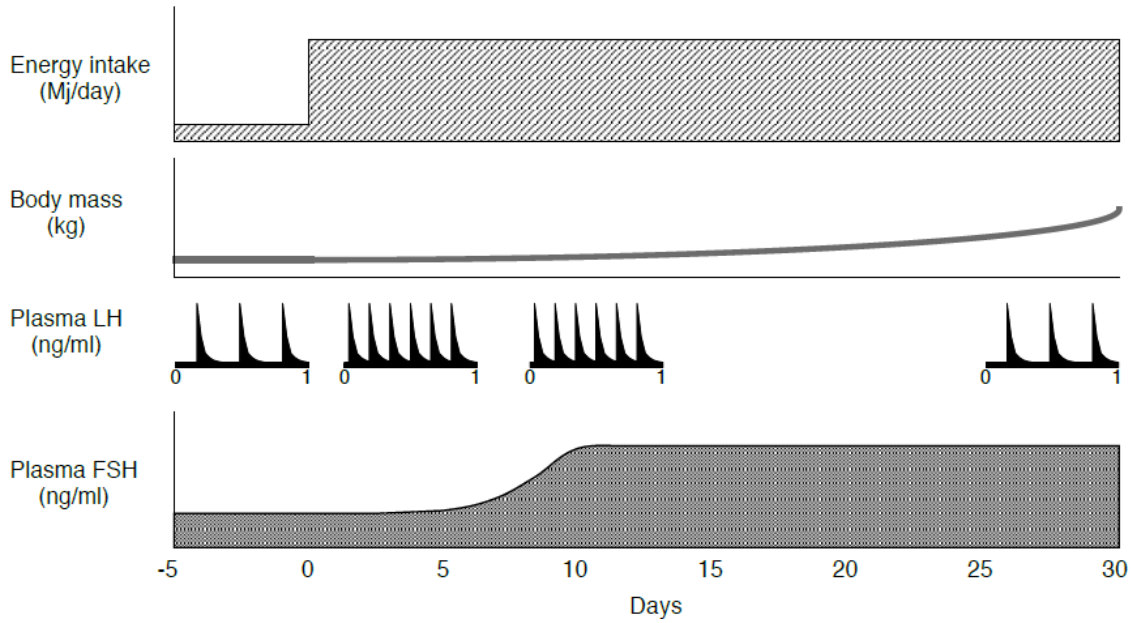


Figure 1.2 Changes in gonadotrophin secretion after the diet was changed from a maintenance diet to a weight gaining diet (Blache *et al.*, 2002)

Braden *et al*. (1974) reported a similar observation, stating that the energy content of the diet affected testosterone output and that energy intake influenced spermatogenesis indirectly by

influencing gonadotropin secretion from the pituitary gland. The composition of the diet influenced semen quality and the ability of spermatozoa to fertilize ova (Adeel *et al.*, 2009). Selvaraju *et al.* (2012) suspected that the differences in semen quality parameters were due to the differences in the energy concentrations of the diets as the crude protein content of the three diets were the same. It seems that the energy component of a diet modified gonadotropin secretion in rams rather than the protein content (Martin & Walkden-Brown, 1995). A change in dietary energy affected sperm motility, membrane integrity, sperm velocity, and the mitochondrial membrane potential. An increase in energy intake improved these semen parameters, but there was a significant reduction in the spermatozoa velocity parameter in the high energy group. Thus, feeding too high energy diets could have adverse effects on semen parameters as well (Selvaraju *et al.*, 2012). It seems that the reproduction axis was not greatly influenced by dietary intake of amino acids or by circulating glucose concentrations, but rather by the energy components of a diet. The fatty acid content of a diet specifically seems to play a key role in how nutrition influences the reproduction response by stimulating the GnRH-dependant pathways which influence changes in testicular function (Blache *et al.*, 2014). Contradictory to Blache *et al.* (2014), it was suggested that part of the effect of nutrition on testicular growth was independent of the changes in GnRH pulses (Martin *et al.*, 1994, Fernandez *et al.*, 2004) for example, the increase in Sertoli cell numbers after puberty.

Hötzel *et al.* (1995) identified two physiological processes through which nutrition influences the male's reproduction function: (a) through a change in GnRH output via metabolic and reproduction centres in the brain and (b) through pathways independent of changes in GnRH secretion. These combined pathways result in changes in primary seminiferous tubules, testicular weight and the efficiency of spermatogenesis. This is known as the brain-gonadal axis. Setchell *et al.* (1965) started to decode these physiological processes when the researchers discovered testicular metabolism's dependency on glucose. It was reported that the underfeeding of males had reduced testosterone production, and the metabolic activity and blood flow through the testes (Setchell *et al.*, 1965; Setchell & Hinks, 1967). This work was supported by the by the work done on pseudohyophysectomised rats which showed that pituitary gonadotropins played a role in nutritional responses.

All reproductive processes, from the expression of certain behaviour (e.g. libido) to the production of morphological elements (e.g. gamete production), require energy. In order to have reasonable reproduction success and, taking energy requirements into consideration, the relationship between the reproductive and metabolic regulatory systems have to be finely tuned. Therefore, there are regulatory processes which link nutrition and reproduction and many of these regulatory processes also control energy homeostasis (Martin *et al.*, 2010). Generally the energy balance, or metabolic status, of an animal refers to the difference

between the amount of energy expended by that animal (for maintenance requirements, movement etc.) and the pool of disposable energy (amount of energy consumed by the animal plus the energy stored in the animal's body tissues – adipose tissue, muscle and liver). The amount of energy that is available to reproduction will depend on the energy balance of the animal (Martin *et al.*, 2010).

Blache *et al.* (2007) and Martin *et al.* (2010) both discussed the relationship between energy balance and pulsatile GnRH secretion as a multi-dimensional control system. This control system is comprised of four interdependent "dimensions", namely genetic, structural, communicational and temporal. In the "genetic dimension" the researchers explained that, in rams, the effects of dietary manipulation and energy balance on the reproduction axis differs between genotypes. Blache *et al.* (2003) described photoperiod as a "filter" on the effect that nutrition has on the reproduction system and thus the extent of the "filtering" depends on the animal's genotype. So, for example, Martin *et al.* (2002) and Hötzel *et al.* (2003) stated that nutrition had a smaller effect on the reproduction endocrine axis in sheep breeds that are very responsive to photoperiod, such as the Suffolk, compared with sheep breeds that are less responsive to photoperiod, such as the Merino (Figure 1.3).

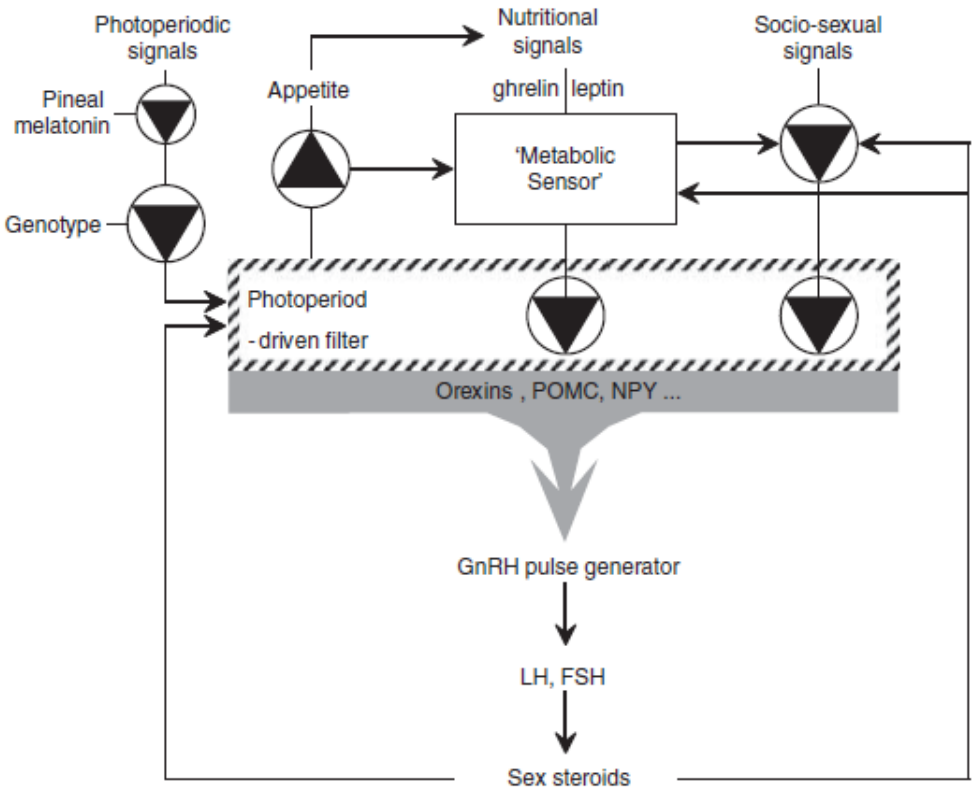


Figure 1.3 Diagrammatic illustration of the relationship between photoperiodic, nutritional, and social cues and the interaction with genotype and steroid feedback under the control of the hypothalamo-pituitary-testicular axis in rams. The "metabolic sensor" is the nutritional input (Blache *et al*., 2003)

The second dimension which Blache *et al.* (2003) and Martin *et al.* (2010) described is the "structural dimension". It has always been accepted that the brain and the gonads were the primary organs which were altered when nutritional inputs changed. However, adipose tissue, the liver, and the pancreas have also been shown to play major roles in the reproduction function (Figure 1.4). This is especially true for adipose tissue which has been promoted from being a simple, passive storage site to being an important endocrine organ. It has also been discovered that the digestive system not only produces direct metabolic information in the form of amino acids and energy substrates, but that it also has an endocrine output and regulates how nutrition affects reproduction. Thus, all the tissues that play a role in the regulation of energy balance are also part of the "communication" dimension (Figure 1.4) which regulates reproduction activity.

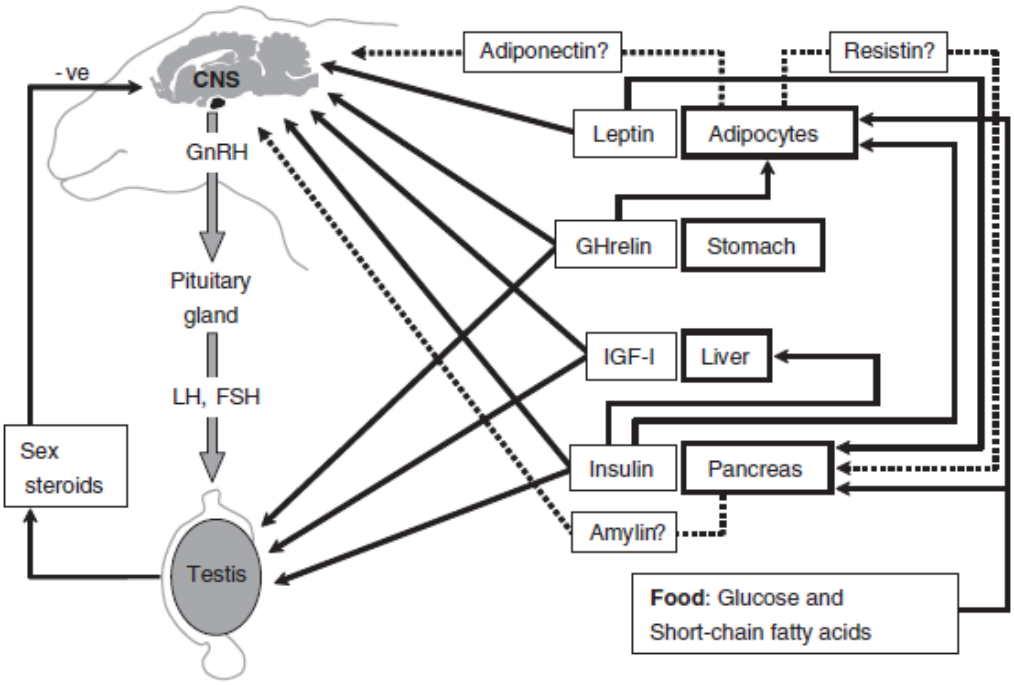


Figure 1.4 Diagrammatic illustration of the relationship between the endocrine and neural inputs which control the reproduction system and mediates the responses to changes in metabolic status. Hormonal systems which do not exert a direct action on GnRH secretion have been omitted (Martin *et al*., 2010)

The "communication dimension" is the third dimension of the system. There are a variety of communication processes – nutrient, neural and endocrine-based – to ensure that the systems accurately regulate the reproductive axis via energy balance. The fundamental and central

controller of the reproduction process is the GnRH neuroendocrine system: the hypothalamus secretes GnRH which stimulates the release of luteinizing hormone (LH) and follicle-stimulating hormone (FSH) from the pituitary gland. The GnRH pulses must first reach a certain threshold frequency before males will start to produce sperm and females will start to ovulate. External factors, such as energy balance, photoperiod and socio-sexual signals (Figure 1.3), influence gonadal activity via the GnRH neuroendocrine pathway (Blache *et al.*, 2003). When the energy and protein intake is drastically increased in mature rams, it results, firstly, in the increase of the frequency of GnRH and LH pulses and then an increase in FSH secretion. The opposite effects will occur if the energy and protein intake is drastically reduced. Tissues, such as the gonads and pituitary gland – which play a pivotal role in reproduction – can respond independently to nutritional inputs. Adipose tissue was once considered to be a passive energy reserve, but recent studies have shown that adipose tissue plays an active role in thermoregulation, immunity, feed intake regulation, metabolism and reproduction (Blache *et al.*, 2003).

Leptin, an endocrine product of adipose tissue, seems to have the greatest influence over the reproduction axis in ruminants (Chilliard *et al.*, 2005). The release and expression of leptin, as well as the sensitivity of the brain and gonadal tissues to leptin, is altered by both short- and long-term changes in metabolic status. Although many studies done on ewes and rams have shown that leptin affects the reproduction neuroendocrine control system, it is widely agreed that the role which leptin plays is a permissive one and not a triggering one. Nutrients from digestion could act as signals and affect the hypothalamic-pituitary-gonadal axis by regulating GnRH secretion or by promoting hormone or gamete production in the gonads. In rams, volatile fatty acids stimulate GnRH secretion, while the effect of glucose remains unclear. In ewes, the ovarian follicles respond strongly to fatty acids, glucose, and other metabolic hormones. Integrated pathways and mechanisms, as well as intra-follicular nutrient sensing, regulate ovulation rate and gonadotropin-stimulated folliculogenesis (Scaramuzzi *et al.*, 2006). This is a concept which has not yet been tested in the testes of rams. The metabolic status of an animal depends on two things: the three compartments of energy balance (intake, expenditure and storage) and the hormonal systems which are affected (Figure 1.4). Leptin is the best example of these interactions as it is influenced by intake, expenditure and storage, while at the same time stimulating three other endocrine systems (pancreatic insulin, pituitary GH, and thyroid hormones) involved in controlling the reproduction axis (Martin *et al.*, 2010). Leptin secretion is also affected by the autonomic neural activity, as well as the products of digestion and absorption (Pénicaud *et al.*, 2000).

The fourth dimension is the “temporal dimension”. Effects such as time (foetal programming and photoperiod) and metabolic memory – where nutritional information is carried beyond the

original metabolic stimulus – are dynamic aspects which influence how reproduction responses respond to nutritional inputs. In the ram, an abrupt change in nutrition causes an initial rapid response in the GnRH neurons which fade over a couple of weeks (Figure 1.2) (Martin *et al.*, 1994; Zhang *et al.*, 2004). While the long-term effect (several weeks) of nutrition on the testis of the ram appears to be independent of GnRH-based changes (Hötzel *et al.*, 1995). The role of nutritional inputs and the responses to these inputs vary significantly throughout the year, especially in genotypes which have seasonal changes in appetite e.g. the temperate breeds (Blache *et al.*, 2002; Rhind *et al.*, 2002). Previous metabolic status (metabolic memory) affects the way in which reproduction responses respond to an increase in energy availability. For example, the adipose stores in mature rams – rams with a low body condition score show a strong and repeatable increase in LH pulse frequency when intake is increased while this is not observed in rams with a high body condition score. In rams with a low body condition, the response to leptin is blunt while the response to insulin is not (Zhang *et al.*, 2004). These findings suggest that leptin secretion is not always in response to an increase in nutrients and that neither leptin nor insulin is needed to increase GnRH pulse frequency due to an increase in nutrient intake. These findings are consistent with the idea of "metabolic memory" and that leptin and insulin are key components in this concept (Chillard *et al.*, 2005). "Metabolic memory" regulates how nutrient intake will influence the stimulatory effect based on the level of energy expenditure and nutrient reserves. Figure 1.5 illustrates that when energy reserves of the animal is low, "nutrient sensing" is turned on which stimulates feed intake. This then causes an increase in GnRH pulses. However, as energy reserves increase, the "nutrient sensing" is turned off, and GnRH pulses decrease.

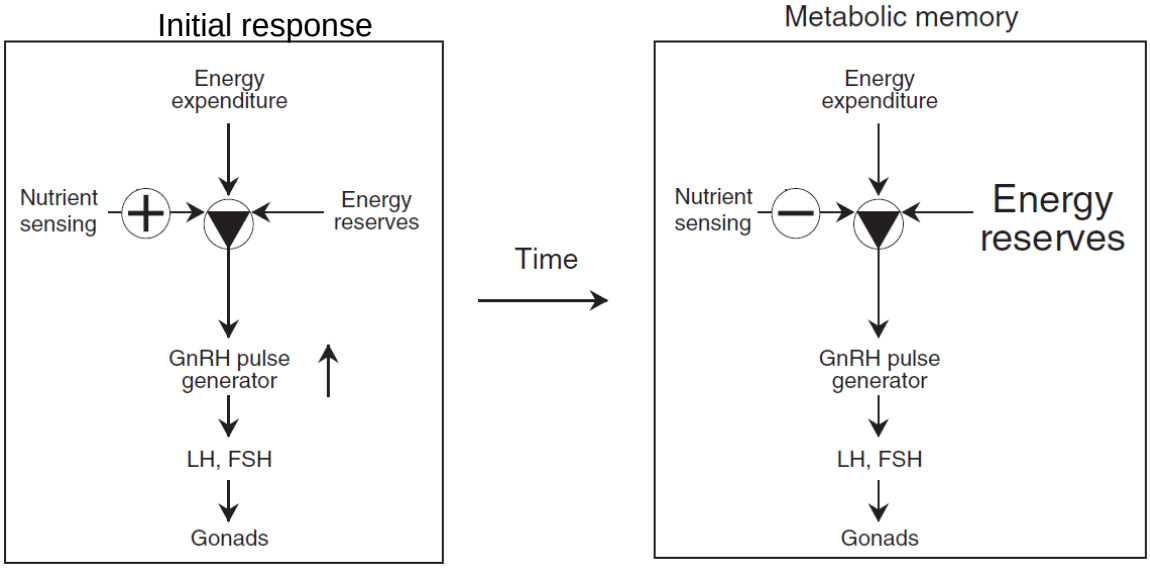


Figure 1.5 Schematic drawing illustrating the potential influence of "metabolic memory" (e.g. energy reserves) on the stimulatory effect of the nutrient influx mediated by "nutrient sensing" (Blache *et al.*, 2002)

It is clear that nutrition influences reproduction endocrinology, but it is still uncertain how undernutrition affects the ram's sexual behaviour. Due to the way and frequency in which libido is observed and assessed, it is difficult to determine the influence of nutrition on libido (Parker & Thwaites, 1972). Parker & Thwaites (1972) stated that if feed restriction was long and severe enough – resulting in a loss of up to 30% of body weight – then normal sexual behaviour was compromised. However, Banks (1964) noted that an intensive amount of motor activity is required for sexual behaviour to be expressed. The lack of libido could thus be due to the ram's general weakness instead of energy restriction (Tilbrook & Cameron, 1990). It appeared that rams with smaller testes had greater motor activity than rams with large testes (Raadsma & Edey, 1985) implying that the toll of reproduction was greater in rams who produced fewer spermatozoa.

Generally, it seemed that undernutrition had a greater effect on libido than on sperm production, but when the plane of nutrition increased, sperm production was stimulated before libido (Martin *et al.*, 2010). On the other side of the spectrum, overfed rams – which led to overweight rams – also had reduced sexual activity as they struggled to mount and express courtship rituals (Okolski, 1975). As energy balance is expressed as energy intake minus energy expenditure, the motor activity (exercise) of rams affects their testes size (Thwaites, 1995). Thus, rams in intensive production systems had better reproduction performance compared with rams in extensive production systems (Fourie *et al.*, 2004). In extensive production systems, where the rams mate under field conditions, rams had higher motor activity and thus higher energy expenditure than rams in intensive production systems. The higher energy expenditure in extensively kept rams resulted in the loss of testicular weight, reduced sperm production, increased the proportion of intertubular tissue, decreased the proportion of round spermatids, spermatocytes and decreased the number of spermatozoa in the epididymis (Knight *et al.*, 1987).

1.5 Overview of ovine growth

During growth two events occur sequentially and overlap at a certain time. Firstly, there is an increase in body weight, also defined as true growth, and secondly, there is a change in the animal's body proportion. These events can be described as quantitative and qualitative changes that occur during animal growth. Quantitative changes are changes that can be measured such as height and length and represent the linear growth in animals. The increase in body size, and the change of body proportions that go with it, is known as allometric growth

and defines qualitative changes. Quantitative and qualitative measures are used to determine whole animal growth (Echols, 2011).

Organs, body regions and tissues do not mature at the same rate nor at the same time. During embryonic growth, sequential growth occurs in the body proceeding from the anterior to posterior regions and from the core to the extremities (Hossner, 2005) – as can be seen in Figure 1.6. Adipose tissue is the last tissue to develop and develops mainly postnatally as it is a tissue which is associated with maturity. When comparing graph (a) with graph (b) in Figure 1.6, the shape and the order of all the growth curves, representing different areas, are similar. It is the slope of the curves that change indicating different rates of growth. In graph (a) the steep slopes show that growth rate was rapid, while the flatter slopes in graph (b) imply that growth rate was slower (Batt,1980; Hossner, 2005).

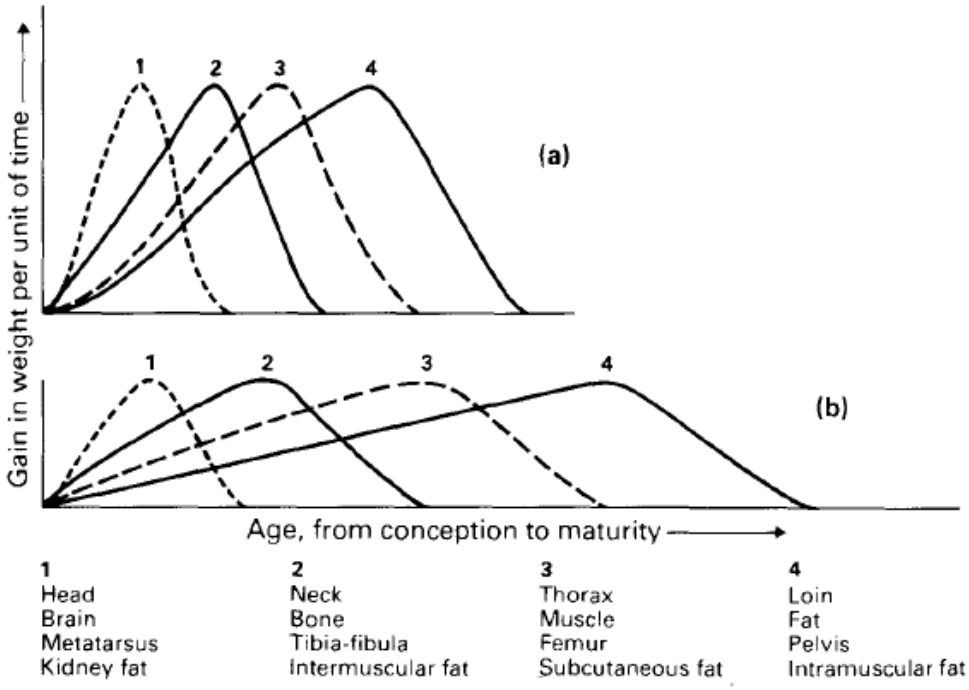


Figure 1.6 Growth rates of various tissues and various sites in animals fed for a) rapid or b) slow growth rates (Hammond, 1955)

Postnatal growth follows a sigmoidal growth curve and is a characteristic of all organs and all living organisms. The sigmoidal curve is constructed by plotting the animal's height or weight on the y-axis and time on the x-axis, as illustrated in Figure 1.7. This curve illustrates how the growth rate of an animal changes as the animal ages. When the animal has reached maturity, the curve will flatten and reach a plateau. It is characterised by a prepubertal, self-accelerating

growth phase (point c) where the slope of the curve is at its maximum indicating rapid growth. An inflexion point (point d) occurs where the shape of the curve starts to change. The slope starts to decrease indicating that the animal is growing at a slower rate. The last component of the curve is the post pubertal, self-inhibiting phase (point e) where the slope starts to flatten and reach a plateau. The animal reaches maturity (point f) when the maximum protein weight has been achieved. All the nutrients consumed after maximum protein weight has been achieved, will be deposited as fat. (Hossner, 2005; Echols, 2011).

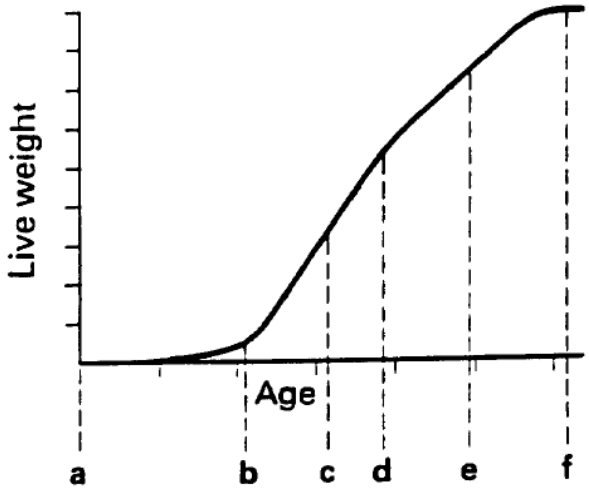


Figure 1.7 A sigmoidal growth curve where live weight is plotted against age. The points represent a) conception, b) birth, c) self-accelerating phase, d) inflexion point, e) self-retarding phase and f) maturity (Batt, 1980)

There is only one definition for frame size in sheep. In cattle, frame size and frame score, and how these factors explain and predict growth in cattle, is better described and explained. In order to better understand growth and maturing rate, it is useful to first consider how it is described in cattle and use that knowledge when analysing sheep growth, before the definition of frame size in sheep is considered.

There are numerous measures to describe the size and conformation of cattle. These include frame score, body weight, and frame size. Frame score and body weight are the two measures used most frequently to describe the size of cattle and there is a direct relationship between these two measures (Echols, 2011).

- Frame score is a numerical description (1 to 9) of skeletal size based on hip height at a certain age and should stay constant throughout the animal's life. Frame scores reflect the growth pattern of an animal and can also be used to project the mature size

and performance potential of the animal. Low frame scores generally indicate early maturing animals which are small in stature and which will achieve maturity at lighter body weights. By contrast high frame scores indicate late maturing animals that are larger and heavier at maturity (Dhuyvetter, 1995; Echols, 2011).

- Frame size is another measure to describe size and maturing rate. Frame size projects the weight of the animal after finishing when there is a 1.3cm fat covering over the twelfth rib. There are three categories: small, medium and large (Dhuyvetter, 1995). It is used to reflect the size which an immature animal would reach once it is mature (Brown *et al.,* 1983) and indicates an animal's live weight at a certain degree of carcass fatness (Tatum *et al.,* 1986). In South Africa the medium class animal should finish at a weight between 380-420kg, a small class will finish below 380kg and a large class above 420kg. The small class animals are thus early maturing and large class animals are late maturing. There is a favourable correlation between growth rate and frame size in beef cattle (Du Plessis *et al.*, 2006).

According to Meat and Livestock Australia (2017), frame size in sheep is determined by measuring the height from the ground to the highest point of the withers minus the length of wool. Frame size could specify the likely mature size, as well as the fattening pattern of the animal. It is used to assess stock at store markets. Frame sizes can be small (55cm and less), medium (56-65cm) and large (70cm and higher). Tatum *et al.* (1998) found that lambs of larger frame sizes had accelerated weight gains during finishing. Both Tatum *et al.* (1998) and Souza Júnior *et al.* (2013) found no significant influence of frame size on ADG. When comparing the lambs at a constant slaughter weight, lambs of larger frame sizes had lower values for yield grade, fat thickness, body wall thickness and quality grade. Tatum *et al.* (1998) projected final weights which sheep of different frame sizes had to achieve to be classed as grade 2 carcasses. The final weights of small-framed lambs were 50kg, 50-55kg for medium frame size lambs, and greater than 55kg for large-framed lambs. Souza Júnior *et al.* (2013) found that frame size of sheep influenced carcass tissue composition and performance. Lambs of large frame size had better carcass composition and had higher carcass compactness.

1.5.1 Factors affecting general animal growth

To achieve optimal production and reproduction of sheep, it is essential to be able to control and manipulate whole animal growth. There are three factors that have obvious effects on growth, and which can be easily used and manipulated, namely: genetics, nutrition, and environmental effects.

Genetics: The growth of an individual is influenced by additive and non-additive gene actions. Additive gene action, or quantitative genes, is the combined effect of many genes working together. Economic important traits such as weaning weight and average daily gain, are quantitative traits. Non-additive gene actions are single gene-mediated traits. The genetic background determines the animal's growth potential, growth rate, body composition and mature size. Growth traits are heritable and cause variations in body size and growth rates within and between breeds (Hossner, 2005; Echols, 2011). The genetic background will also determine at what age and at what weight the animal will reach puberty. The variation of genes can be seen when comparing the ages at which different cattle breeds reach puberty (Bearden *et al.*, 2004).

Nutrition: For an animal to reach its full genetic potential, it has to be fed the optimal amount of nutrients to meet the animal's nutritional requirements. When the animal's nutritional requirements are met, the animal will be healthy and have good production characteristics. Growth rate can be regulated by the amount and quality of feed fed to the animal. If feed is limited, the growth rate will slow down. Compensatory growth will occur if the individual wasn't starved for too long and once enough feed is provided again (Hossner, 2005). Energy is required for maintenance and growth. The level of energy in a diet will determine at what rate the individual will grow. More energy in the diet means a smaller proportion of the energy is needed for maintenance requirements, leaving a larger proportion of energy available for growth and production. However, energy intake is the first limiting factor in a diet and can cause stunting if not enough is consumed by the animal. The level of nutrition will also determine at what age the animal reaches puberty. Puberty occurs once the animal has reached a percentage of its mature weight, for example, most sheep breeds should reach puberty at 40-50% of their mature weight (Bearden *et al.*, 2004). Thus, when feeding a higher recommended plane of nutrition, the animal will grow faster and reach puberty at an earlier age, but when the plane of nutrition is lower than the animal's requirements, it will take longer to reach the required body weight for the onset of puberty and the animal will be at puberty. Puberty and sexual maturity are not the same concepts. Just because an animal has reached puberty does not mean it is ready to breed. Thus, the longer it takes an animal to reach puberty, the older it will be when used to breed for the first time (Bearden *et al.*, 2004).

Environment: Photoperiod effects and temperature extremes are the primary environmental factors that affect animal growth and reproduction (Senger, 2003; Bearden *et al.*, 2004). Photoperiod indicates the change of season due to the change in day-length. This will cause seasonal breeders, such as sheep, to enter the natural breeding season in order to ensure that lambing occurs during the time of year most favourable for the lamb's survival. When lambs are born during the spring, forage quality and quantity starts to increase. Usually, longer

day-lengths result in higher feed intake and enhance growth rate. Increased growth rates and higher weaning weights thus cause lambs to reach puberty at an earlier age.

The environmental temperature has a considerable influence on the animal's nutritional requirements. When the animal is stressed due to uncomfortable temperatures or living environment, its maintenance requirements increase resulting in a larger proportion of nutrients being used to meet maintenance requirements and a smaller proportion being available for production, growth and reproduction. Each type of breed has an environment to which it is best suited and where it will produce at its optimum. High temperatures also cause a decline in sperm quality (Senger, 2003; Bearden *et al.*, 2004).

1.6 The South African sheep industry

South Africa is considered, on the whole, as an arid country (AGIS, 2007a). A large part of the Northern Cape is classified as a hyper-arid to arid region, while certain areas of Limpopo, North West, Eastern Cape and Western Cape are arid regions. Great parts of South Africa are also classified as semi-arid and include summer rainfall cropping areas of the North West and Free State, summer rainfall Bushveld areas of Limpopo and Gauteng, and the cropping-pasture areas with winter rainfall of the Western Cape (AGIS, 2007b). Due to these large arid areas and the limitations in soil fertility and texture (AGIS, 2007a), crop production is hampered, making pastoral use the more viable option. The drier western and north-western parts of South Africa, which have lower average precipitation values than the eastern areas, have a grazing capacity of less than 12 ha per large stock unit (Cloete & Olivier, 2010), making extensive small stock production the most suitable form of livestock production in these regions.

1.6.1 Sheep production in South Africa

Sheep farming is practiced throughout South Africa, but is particularly concentrated in the more arid areas. Sheep farming in South Africa is for wool, mutton and lamb production. Eighty-five percent of the country's sheep is farmed in the Eastern Cape, Northern Cape, Free State and Western Cape (30%, 24%, 20% and 12% respectively) (Figure 1.8). In 2016 it was calculated that there were approximately 8000 commercial sheep farms, 5800 communal farmers, and 23.2 million sheep in South Africa (DAFF, 2017). One of the most crucial factors that determine the profitability of sheep farming, is the efficiency with which sheep can convert feed into wool or mutton (Coetzee, 2005).

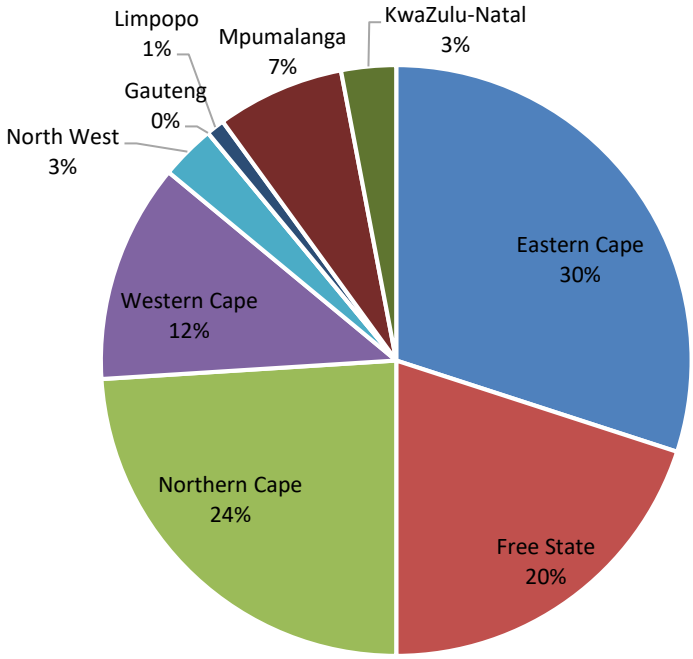


Figure 1.8 Pie chart showing the distribution of sheep over the provinces in South Africa in 2018 (DAFF, 2019)

1.6.2 Mutton production in South Africa

The Dorper breed is the most successful South African-bred mutton breed. It was specifically bred for the more arid areas of South Africa. Figure 1.9 illustrates the different market supply chains for mutton production in South Africa. The channel starts at the farmer who produces the sheep or lambs. A farmer, who keeps his/her sheep for wool production, will keep the sheep for a period of five to six years after which the sheep will either be sold directly to an abattoir or via an auction. From the abattoir, the meat is distributed through retailers, wholesalers and butcheries or exported. Exports are done by abattoirs, while imports are done by processors, retailers and wholesalers (DAFF, 2017).

The price and the quantity of meat produced are the major determinants of the gross value of mutton production. Over the past ten years, there has been a continuous increase in the gross value of mutton production, with an average gross production value of R 4.1 billion per annum. This totals a gross value of R41.6 billion over the past ten years (DAFF, 2017).

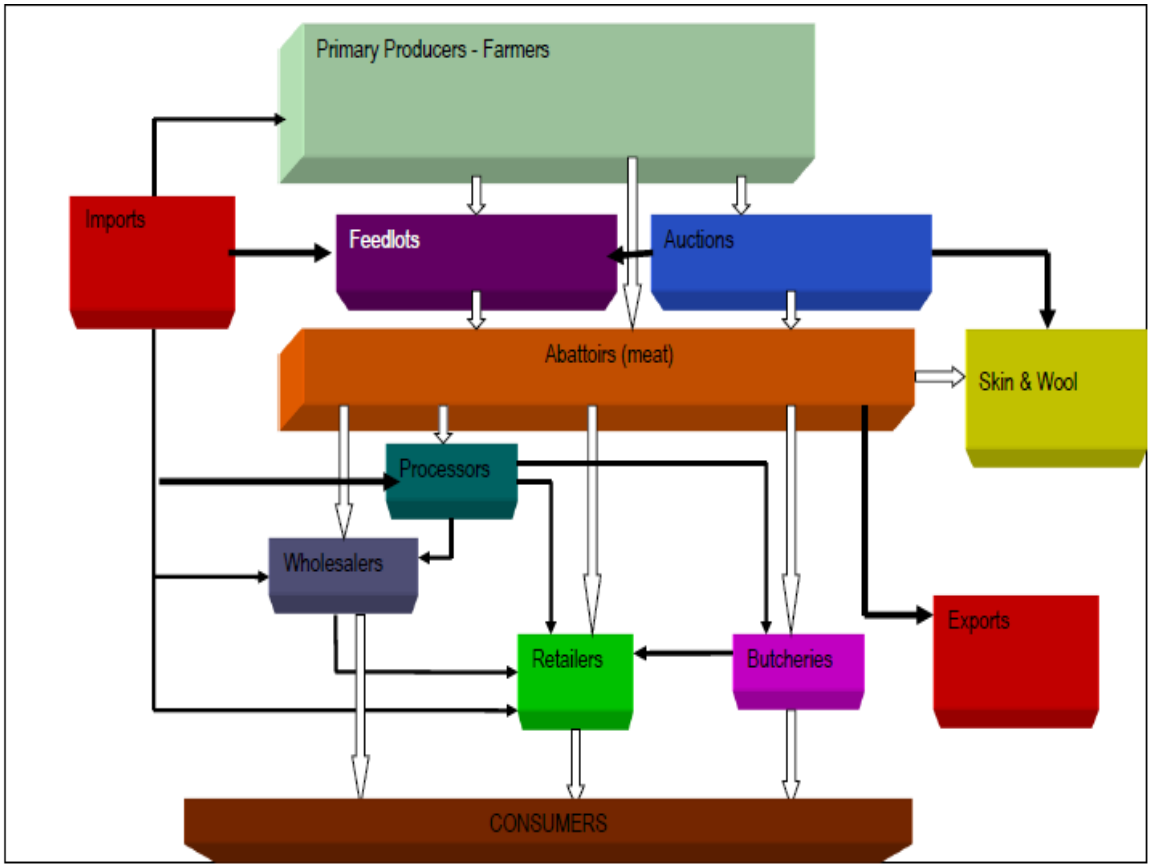


Figure 1.9 Diagram illustrating of the market supply chain of mutton production in South Africa (DAFF, 2017)

Due to livestock theft and predation, sheep numbers in South Africa are declining. With South Africa's rapid population growth and the decline in sheep numbers, there is a resultant shortage of mutton in South Africa. South Africa has been a net importer of mutton over the period 2006 to 2018 as mutton consumption exceeded mutton production. However, the gap between consumption and production is narrowing, which implies that South Africa is heading towards self-sufficiency when it comes to mutton production. Mutton consumption reached its peak of 203 000 tons during 2006/2007, while mutton production peaked in 2014/2015 at 184 600 (DAFF, 2017). The increase in total gross value of agricultural production and the increase in gross producer income can be attributed mainly to the increase in the value of animal products (contributed 50.6% to total gross value of agricultural production) (DAFF, 2019). In 2016/2017 the gross income from animal products was R126 159 million and increased to R142 964 million in 2017/2018, an increase of 13.3%. Income from mutton production increased by 5.6% (DAFF, 2019). The number of sheep slaughtered, decreased by 12.1% from 2016/2017 to 2017/2018 (DAFF, 2019). Due to insufficient supply, the improvement in customers' lifestyles and inflation, the price of mutton increased continuously

from 2006/2007 until 2015/2016 (with a significant decrease in 2012/2013). Over the past ten years, the average price of mutton increased by R23.79/kg, from R29.41/kg in 2006/2007 to R53.21/kg in 2015/2016 (DAFF, 2017). In 2016/2017 mutton price was R61.67/kg and increased by 17.4% to R72.39/kg in 2017/2018 (DAFF, 2019). International trade had a strong influence on local mutton production and thus price patterns were influenced by imports.

South Africa exports meat of sheep or goats as fresh, chilled or frozen, and this represented 0.1% of the world's meat exports of sheep or goat meat – South Africa is ranked 36 in the world in this regard. In 2016, the greatest share of South Africa's exports was to Lesotho (21.1%), Botswana (17.8%), Kuwait (10.1%) and Swaziland (9.8%). A decrease of 15% was noted in South Africa's export value to the rest of the world during 2015 – 2016 (DAFF, 2017). Over the past decade, South Africa has imported an average of 16000 tons of mutton per annum. Mutton imports amounted to 2436 tons in 2016/2017, a 50.8% decrease from the previous year (2015/2016) and 35.8% lower than the last five years' average of 3753 tons (DAFF, 2018).

1.6.3 Wool production in South Africa

Sheep are shorn during the production season which occurs between August and June of the following year. The production and marketing of coarse and coloured clips are limited because these clips fetch a weaker price, are more difficult to dye and to work with, and will be used to manufacture less valuable products such as carpets. The wool produced in South Africa is mainly for apparel (DAFF, 2016). As the country where the largest volumes of wool are traded, Australia determines the global price for apparel wool. This means South Africa is a price-taker (DAFF, 2019). An advantageous asset of the wool industry in South Africa is the high standard of the on-farm classing and clip preparation of greasy wool. This assists continuous production of high-quality wool that not only meets the textile industry's requirements, but is also environmentally friendly, has a reputation for uniformity and softness, as well as other quality features. When wool is sent to be processed, it is classified as Karakul, Merino or other. After it has been processed, it is classified as scoured, carbonising, noil (knots and short strands combed out of the wool before spinning), top or waste (DAFF, 2018).

Most farmers start to shear their flocks from August as temperatures start to rise, making it possible to have weekly auctions from August to June. More than 90% of South Africa's greasy wool is sold during this period. The wool industry's prices are ever-fluctuating and the price of wool at and during these auctions is influenced by variables such as the Australian wool market on that day, exchange rate, quantities of different wool types available at the auction,

demand for specific wool types, contract commitments, and the economic conditions of wool-consuming countries (DAFF, 2019). The main wool sheep breeds in South Africa are Merino sheep and their derivatives, with Merino sheep making up *ca.* 74% of total wool sheep in South Africa. (DAFF, 2016). In South Africa, more than 80% of the lots offered for sale comprise of a Merino clip (DAFF, 2019). The mean fibre diameter of Merino wool is a strong price determinant, with finer micron wool (<20µm) commanding a premium over medium (20.1 - 22µm) and strong (>22.1µm) wool (DAFF, 2018). Exchange rates, global economic conditions and the availability of apparel wool will determine prices and sales for domestic producers. Prices are also underpinned by the strong demand for wool from China (DAFF, 2018).

South African wool marketing is free from statutory intervention. The South African wool industry has not established other selling structures such as contract growing, forward deliveries and futures. Wool is traded by two means: private treaty or auctions. Open-cry auction is the primary wool trading operation in South Africa. These auctions are centralised in Port Elizabeth and are coordinated by the South African Wool Exchange. During the wool selling season, which runs from August to June of the following year, weekly auctions are held (DAFF, 2019). In South Africa, there are three primary ports – Durban, Port Elizabeth, and Cape Town – to which wool producers can send their wool (DAFF, 2016). At these auctions, there are more sellers than buyers. There are certain specifications (in terms of quantity, price, and delivery date) in the contracts between the buyers and their clients and in order to meet these specifications, buyers have to compete for wool over a few auctions to make up processing batches (DAFF, 2019). Wool brokers, such as Cape Mohair and Wool (CMW) and BKB Pty Ltd, are present at the auctions to facilitate sales. In South Africa, the following companies are foremost wool buyers: New England wool SA, Lempriere SA, G. Modiano SA, Stucken & Co., H. Dawson Sons and Co., Segard Masurel SA, Standard Wool SA, Chargeurs Wool SA and CMW Operations. All these companies – except G. Modiano who only exports greasy wool – export greasy wool and semi-processed wool (DAFF, 2016). Alternatively, small wool buyers buy directly from wool producers and will then either export the wool directly or organise smaller wool auctions. These smaller wool auctions are organised separately but are usually held at the same venue on the same day as the auction organised by Cape Wools. Smaller wool traders include Van Lill Wool Buyers, Lantana, and Saunders. In order to bid at auctions supported by the South African Wool Exchange and to market to overseas buyers, sellers must be registered members of the South African Wool and Mohair Buyers Association (SAWAMBA) (DAFF, 2016). Figure 1.10 demonstrates the wool value chain in South Africa.

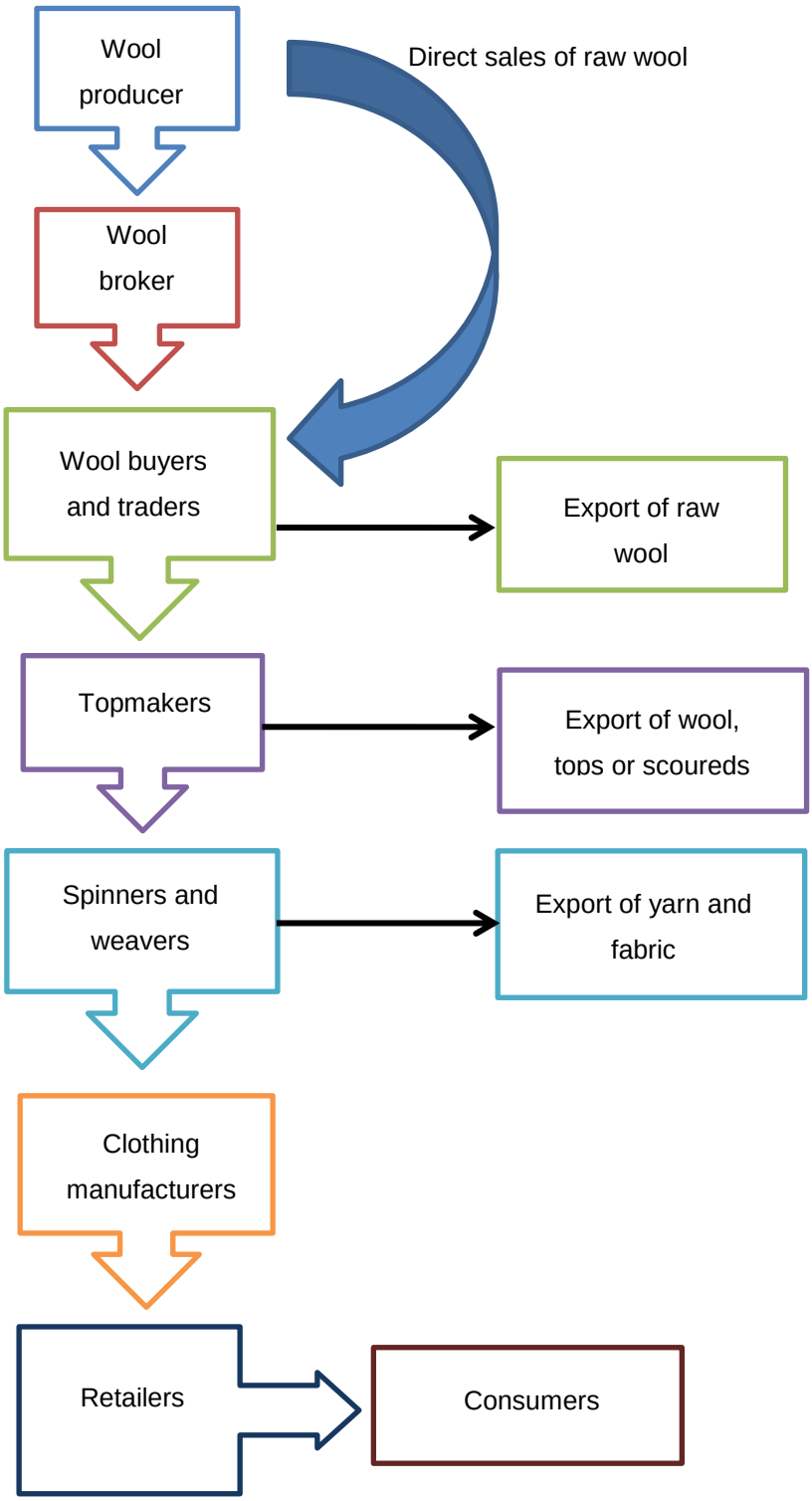


Figure 1.10 Diagram depicting the wool Value Market Chain of South Africa (DAFF, 2016)

A non-profit company, Cape Wools, was established on 1 September 1997 and promotes the interest of the South African wool industry. It is comprised of farmers and other industry groups who are directly affected, all of whom are registered with the Wool Forum. Cape Wools, with

the approval of the Minister of Agriculture, Forestry and Fisheries, intend to start a wool statistics databank from which information about the industry and the national market will be available to all, locally as well as internationally. The service portfolio of Cape Wools encompasses research and development, statistics and market information, the promotion of wool, and transfer of wool. Wool Trust funds Cape Wools by transferring funds from the previous Wool Board (DAFF, 2019).

For the period 2017/2018, the Eastern Cape was the highest wool producing province with 12 900 tons. The Free State followed with 6 900 tons, then Western Cape with 6 200 tons, 4 400 tons for the Northern Cape, 1 700 tons for Mpumalanga and 1 200 tons for the rest of the country (DAFF, 2019). These farmers either produce wool under extensive, semi-intensive or intensive production systems. South Africa's neighbouring countries, Lesotho and Namibia, have always sold their wool in South Africa and have always been considered part of South Africa's wool production chain (DAFF, 2018). Lesotho produced 6 100 tons of wool in 2017/2018. South Africa, Namibia and Lesotho's wool production has decreased by 1.1% from 61 600 tons in 2016/2017 to 60 900 tons in 2017/2018 (DAFF, 2019). The gross income from wool production increased by 17.4% (up to R4 380 million) from 2016/2017 to 2017/2018 in South Africa (DAFF, 2019).

It is estimated that 94% of total wool production is exported overseas as either greasy or semi-processed form. For 2017/2018 the main export destinations were China, Czech Republic and Italy. Italy buys wool tops and greasy wool, while China and Czech Republic import greasy wool. South Africa imported an average of 1047 tons of wool during 2015's marketing season (DAFF, 2019). The imported wool is processed and again exported with locally produced wool. The biggest supplier of imported shorn wool, from the world to South Africa, was Africa. Minimal imports were recorded from the Americas, Oceania and Europe (DAFF, 2016).

1.6.4 The purpose of veld ram clubs in South Africa

The majority of South African sheep farmers farm extensively on rangeland. Many of these farmers send their potential breeding rams to a central station, in other words, to a "Veld ram club" (Fourie *et al.*, 2004). Veld ram clubs, or forage raised sheep, play a major role in the breeding, selection and supply of rangeland adapted and performance-tested rams to the local sheep industry. The aim of these clubs is to accurately evaluate potential breeding rams under uniform, commercial-farming conditions and production systems (SA Stud Book, 2015).

These clubs are used to identify which rams are the top-performing rams. A top-performing ram has superior genetic potential, as well as being more adapted to that environment. Rams

should be evaluated under the same conditions in which its offspring will be expected to perform. Rams must be divided into contemporary groups and be tested within their groups. Rams can be sent to veld ram clubs rather than small stock test centres (SA Stud Book, 2015).

There are a few test procedures from which farmers can choose. There are extensive tests, intensive tests and feed conversion tests. The physiological age of a ram influences its performance, so rams should be of similar age when they enter the veld ram club to make comparisons meaningful. A good rule of thumb is that rams should not be older than six-months and the difference in age between rams should not be more than two months. The ideal age for extensive tests is between four and six months, for intensive tests is between three and five months, and for feed conversion tests is between two and five months of age. To minimise the effects of different rearing conditions, body weight needs to be as uniform as possible (SA Stud Book, 2015).

The admission weight range (before the adaptation period and before rams are accepted to participate in the veld ram club) should not be more than 15kg. This means there should not be more than a 15kg difference between the heaviest and the lightest rams. The recommended weight for Dorper rams is between 35 – 48kg, Merino rams should be between 35 – 50kg and Meatmaster rams should weigh between 30 – 45kg. Rams that are heavier than the top range will not be offloaded at the farm of the veld ram club, and rams lighter than bottom range run the risk of not falling in the 20kg entry weight range after the adaptation period. Rams that comply with the admission weight range, are shorn as soon as possible and are put on similar feeding and environmental conditions for an adaptation period (minimum of 14 days and maximum of 28 days) (SA Stud Book, 2015).

After the adaptation period, the rams are weighed after a 12-hour fasting period, which is used as the starting weight. The starting weight range is now set at 20kg. The heaviest rams are weighed and used to set the higher range mark. Twenty kilograms is usually subtracted from the heaviest ram's weight to determine the lower range mark. The lightest rams, that do not fall within this 20kg range, are retained for hand-and-eye evaluation for final admission. These rams may be sold at an auction, but performance figures will not be analysed nor be published (SA Stud Book, 2015).

There are two performance testing periods namely (1) the wool test period and (2) the body weight test period. The duration of the wool test period is 180 days and starts on the day when the rams are sheared, just after admission. The body weight testing period is used to determine average daily gain (ADG) and must be done over a minimum period of 150 days. The 150-day duration starts on the day that the starting weight is recorded. Rams need to be weighed on a regular basis (SA Stud Book, 2015).

Veld ram clubs are required to have records of the initial weight, final weight, and three additional interim weights. After the 150-day period, the rams are weighed after a 12-hour fast and a minimum ADG of 90g/day is required. If the rams grew less than 50g/day, their data will not be analysed, and their entire test will be rejected. Rams need to stay in the same group for the whole duration of the testing periods (SA Stud Book, 2015). Only the top performing rams pass the tests and are sold at auctions under the auspices of their respective breed societies (Fourie *et al.*, 2004). During the last phase, Phase C, which is about 50 days before auction, rams are often fed high energy diets to improve their body condition before auction (Bester *et al.*, 2004). Well-conditioned rams are more "appealing" to the eye and realise better prices at auctions (Fourie *et al.*, 2004).

Veld ram clubs often work in conjunction with other research and data analysing facilities such as Stud Book, Wool Testing Bureau SA, and the ARC. This is to ensure that all data is available on the same system if members wish to do a BLUP analysis.

1.7 Characteristics of the three sheep breeds used in this trial

Three breeds of different maturing types were used in this study – the Merino which is an earlier maturing breed, the Döhne Merino which is a medium maturing type and the South African Mutton Merino which is a later maturing breed.

1.7.1 Merino

The Merino breed originated in Spain, the country that first specialised in breeding fine-wool sheep. It was a highly desired sheep, belonging to kings, nobility and the church. There was a strict export ban on the breed. There were four fine-wool breeds and, of these four, the Escurial Merino breed was considered the best. Two rams and four ewes of the Escurial Merino breed were sent to the Cape of Good Hope in 1789 as a gift to the House of Orange from the Spanish king. The sheep were kept on a state-owned farm, Groenkloof, close to Darling. These six sheep had to be sent back, as they were meant exclusively for the royal household of Holland. Colonel Gordon – the commander of the garrison in whose care the sheep were - sent the sheep back, never revealing the fact that they used the sheep for breeding (Terblanche, 1979).

The English invaded the Cape in 1795 and defeated Colonel Gordon's garrison. Due to the amount of criticism and rumours of treason, Colonel Gordon committed suicide. His wife decided to sell all his belongings and leave the country. A British ship in Table Bay transported

all of Colonel Gordon's sheep to Australia, where a Captain MacArthur continued to breed with these Merinos and established the Merino fine wool market. Before the Colonel's death, he had sold a few of his sheep to local Cape farmers, thus ensuring that the Spanish, fine-woolled Merino would not be lost to South Africa. Michiel van Breda, J.F. Reitz, and the Van Reenen brothers were all responsible for establishing the Merino breed in South Africa (Terblanche, 1979). The Association of South African Merino Breeders was established in Bloemfontein in 1937 and had 130 members within the first year (Terblanche, 1979; Venter, 2017).

The Merino is a white wool sheep farmed primarily (and intensely selected) for high-quality fine wool. The breed has an acceptable body conformation for mutton production (Terblanche, 1979). Rams generally exhibit well developed, amber-coloured, heavy horns that turn back, or be polled. Ewes are usually polled (Snyman, 2014b). Merinos used to possess characteristic neck and body skin folds. These folds ranged between practically no neck folds – smooth-bodied animals – to animals with excessive skin folds – large and many skin folds around the neck, down the length of the body and around the tail (Terblanche, 1979). Over the past few decades, there have been back and forth shifts between selecting for skin folds or not. This was largely dependent on the demand for wool (Venter, 2017). The breed is of medium frame size and genotypes differ mainly in terms of fibre diameter and skin pleats (Snyman, 2014b). Emphasis has also been placed on improving the breed's efficiency and profitability (Coetzee, 2005).

The Merino is a fertile breed. The Merino ram is a sheep breed which shows rapid and repeatable testicular responses to changes in diet all year round (Martin *et al.*, 2010). Rams can reach a live weight of 85kg and ewes 55kg. The average lambing percentage is 80% (due to poor mothering abilities – there is a high incidence of abandonment (Coetzee, 2005)), but management and feeding can alter this value (Terblanche, 1979). The Merino breed has an intermediate breeding season and is polyestrous in favourable environments (Bearden *et al.*, 2004). It has a cyclic period of 200-260 days (Senger, 2003).

South African produced Merino wool is known worldwide for its fine wool fibres and high quality. It has fine to medium wool which grows quickly (Venter, 2017). Wool quality is determined by its fibre diameter, staple length, crimp, yield, and colour – fibre diameter is the most important characteristic. Mature ewes produce, on average, 4kg of clean fleece weight, while mature rams produce 5kg (Snyman, 2014b). The South African Fleece Testing Center has shown that over the past twenty years the average fibre diameter of the National Merino flock has decreased from 20.6 microns to 18.2 microns (Swart *et al.*, 2009). Wool length is important as it determines the weight of the wool and thus the price for the wool. It is best when the length of the wool stays quite even over the entire coat. After a year's growth, the

wool fibres should be 90mm – 115mm long. The wool should be light, cream coloured, soft to the touch, and possess a prominent crimp. It should be free of kemp, hair, and coloured fibres. Wool density is important as it not only determines the amount of wool produced but also protects the sheep from wind and rain. Wool oil protects the wool fibres and fibre point from the elements. This wool oil should be white to cream coloured (Terblanche, 1979).

The marketing of old ewes and adult wethers contribute to meat production. Old ewes and wethers can reach weights of 55kg and 58kg respectively and can produce prime, first class carcasses of 18kg and 20kg respectively. Crossbred lambs, from secondary stud ewes or rejected Merino ewe mothers, further contribute to meat production. The crossbred lambs (Merino ewe with a meat breed ram) can be marketed at five to six months of age and can produce a high-quality carcass of 15kg (under good management and feeding) (Terblanche, 1979). During the 2002/2003 period, 60.92% of a farmer's income was from wool, while the other 39.08% was from meat. From 2009/2010 – 2011/2012 period the situation was completely the opposite; 32% of a farmer's income was from wool and 68% from meat. Although meat is now the larger contributor of income, it is important to maintain high-quality wool as there is still a demand for it. The income from wool production has an added benefit as it generates enough funds to help cover non-wool related costs, for example, costs needed for meat production, making it one of the most profitable sheep breeds in South Africa (Coetzee, 2005; Geyer, 2013; Snyman, 2014b).

The Merino has contributed greatly and served as foundation stock for the development of new sheep breeds through crossbreeding and selective mating. Such breeds include the Döhne Merino, Afrino, Walrich and Kaffrarian Polled Merino. The wool component in dual-purpose breeds is an attribute of the Merino breed (Terblanche, 1979).

1.7.2 Döhne Merino

Merino farmers struggled to establish and maintain economically strong Merino sheep farming in the sourveld areas of the Eastern Cape. Reproduction rates were low and mortalities high. At that time, Merino sheep had excessive skin folds which, although increasing the amount of wool produced, made the sheep more susceptible to blowfly strike and fleece rot. Merino sheep are selective grazers. This, and the fact that the area was sourveld, necessitated more intensive farming systems with higher input costs in order to maintain sustainable wool production, thus profitability was compromised. This created the need for a breed of sheep which would be more adapted to the climate and pasture quality – thus facilitating a return to extensive farming systems - while improving reproduction rates and mutton production and maintaining high-quality wool production. The initiative was taken in 1939 at the Döhne

Agricultural Research Station at Stutterheim in the Eastern Cape to start selecting and breeding a dual-purpose breed which would meet all of these requirements (Terblanche, 1979; Swanepoel, 2006).

The head of this breeding program, also known as the “father” of the Döhne Merino, was J.J.J. Kotzé the director of the Döhne Agricultural Research Station. South African Mutton Merino rams (still called German Merinos at that time) were crossbred with Merino ewes. It soon became evident that the crossbred generation adapted well and was highly productive in the sour grassland Döhne area. To fix the outstanding traits and develop a dual-purpose breed with fine wool and high meat and lamb production, an inter-breeding and selection program was initiated. By the 1950s a clear type had been developed. Farmers, living in the same area as the Döhne Agricultural Research Station, started Döhne Merino studs and played a pivotal role in commercially establishing the Döhne Merino and supplying breeding stock across the whole of the Republic. In 1966 the Döhne Merino Breed Society was established in South Africa (Terblanche, 1979; Swanepoel, 2006; Snyman, 2014a). Performance testing has aided in selection processes since 1974 and the Döhne Merino Breed Society became affiliated with the South Africa Studbook in 1976. The production records of all the recorded animals are stored on a computerised flock recording scheme which came into use in 1985. Breeders collected raw on-farm data (wool and weights), while the Breed Society collected and handled weaning information and birth registration. These days the Agricultural Research Council (ARC) does routine testing and data analysis to evaluate performance. Final selection and the registration of breeding stock is still done by the Döhne Merino Breed Society (Swanepoel, 2006).

The Döhne Merino is a composite dual purpose, smooth bodied, medium to large frame sheep with good body conformation for high meat production. High-quality fine to medium white wool is also produced. The face should be covered with soft, cream coloured hair with no kemp or jowl pleats. Rams and ewes are polled (Terblanche, 1979; Snyman, 2014a).

Mature rams can average a weight of 100kg, while ewes have an average weight of 70kg. The Döhne Merino is a fertile breed with an intermediate breeding season. The ewes have great mothering traits and can maintain lambing percentages between 100% - 150%. The lambs are fast growers. In an extensive production system, the lambs can reach live weights of 28kg by the age of three and a half months. This will increase to 40kg by the age of four to six months. As the lambs do not put on weight in the form of fat at an early age, they can be marketed and sold at an older age and heavier weight (Snyman, 2014a).

Döhne Merino rams can be mated to Merino ewes and their rams marketed as slaughter lambs at five to six months of age. Many farmers keep the crossbred ewes to mate with them again

as they will be able to give a “boost” to the next generation’s growth potential. There is, approximately, a 2% decline in wool weight – compared with pure Merino ewes – but meat traits of lambs improve by 20% (Terblanche, 1979). After a year’s growth, the Döhne Merino’s wool can reach lengths of 75mm – 90mm; mature rams can produce 3kg clean fleece weight and mature ewes 2.5kg. The quality, in terms of diameter, can range from strong to fine (17µm) and is accepted in the industry as Merino wool. The wool should have a soft handle with well-defined and prominent crimp. No hairy, coloured fibres or kemp should be present in the wool. The wool should be white to cream coloured (Snyman, 2014a). It has great draping capabilities and has a low felting occurrence, all of which makes it desirable for textile use (Terblanche, 1979). Of all the South African wools, Döhne Merino wool – due to its crimp frequency – is closest to the Duerden standard (Snyman, 2014a).

At four and 18 months old, Döhne Merinos are judged for selection purposes. These records are kept and used to assess the sheep’s breeding value. At four months , the sheep are selected for size, build, and noticeable wool faults. The classes of grading are as follows: “aa” is a special stud animal that has an ideal body build, has no noticeable wool faults and is above average in size, “a” is a stud animal, “b” indicates a commercial herd animal, and “c” a cull. Before the sheep are added to the breeding group, at the age of 18 months, they are selected one last time. This time they are selected for outstanding wool and body capacity (they must have grown their wool for six months by this time). The grading is the same as at four months, but this time the symbols are in capital letters, for example, a special stud animal will be graded “AA”. Production records are used as an aid during grading, thus the symbol is an indication of production potential. The Döhne Agricultural Research Station has a simple and effective breeding register which is compulsory for all ram breeders (Terblanche, 1979). Dual purpose breeds face increasing economic pressure to produce finer wool, as well as more meat, creating further challenges for the Döhne Merino (Adams & Cronje, 2003).

Döhne Merino is mainly farmed in the Free State, Eastern Cape and Western Cape provinces of South Africa. The Döhne Merino Breeders’ Society currently has 31 000 registered ewes, but the total number of Döhne Merinos in South Africa is unknown (Snyman, 2014a).

1.7.3 South African Mutton Merino

The German Mutton Merino breed originated in Germany when the Merino Precoce (from France) was bred with the Mele breed to produce a dual-purpose sheep breed. The Merino played a prominent role as the Mele sheep which, in turn, was a cross between the Merino and the Leicester breed. The Elsenburg Agricultural College in Stellenbosch, South Africa, was home to the first German Merino when one ram and ten ewes were imported by the

Department of Agriculture in 1932 (Terblanche, 1979; Swanepoel, 2006; Snyman, 2014c). Due to the limits on importing sheep, new “blood” could not be imported from Germany for a time. The farmers started using indigenous stock and so the breeding continued in a closed South Africa. This gave rise to the change of name from German Mutton Merino to South African Mutton Merino. In 1946 the first breeding organisation was established which subsequently became affiliated with the South African Studbook in 1951 (Terblanche, 1979; Snyman, 2014c).

The South African Mutton Merino is a large frame, polled, dual-purpose sheep breed (Snyman, 2014c), with good body conformation, meat traits, and a fair amount of good quality white wool. The South African Mutton Merino is also a late maturing breed (Burger *et al.*, 2013). The size of this breed, combined with its excellent body conformation for meat production, results in the production of rams with live weights of 125kg and ewes of 70kg (Snyman, 2014c). This breed is active, and adapts well to different climate and grazing conditions. The outstanding traits of this breed are carried over and expressed in its crossbred progeny (Terblanche, 1979).

The South African Mutton Merino has outstanding reproduction traits due to years of selection against infertility and intense selection for high lambing percentages. The South African Mutton Merino is classified as a fertile breed with an intermediate breeding season. Thus, under good management, it is possible to have three lambing seasons in two years. Lambing percentages of 150% can be expected, as well as high occurrences of twins in older ewes. The ewes also have high milk production abilities and can produce up to 4.8 litres of milk per day shortly after lambing. High milk production from the ewe along with inherent growth potential, ensures that lambs have fast growth rates. These lambs can attain an average daily gain of up to 0.4kg per day (Terblanche, 1979), reaching body weights of 34kg at three months of age (Snyman, 2014c). Vigorous lambs that are quick to stand and mothers with good mothering traits (ewes very rarely abandon their lambs) ensure high lamb production. Lamb carcasses can reach weights of 23-28kg with little to moderate body fat which is evenly distributed (Terblanche, 1979; Snyman, 2014c).

This is a smooth bodied breed with no neck folds. Due to the South African Mutton Merino breeders’ breeding policy, the wool of this breed has been much improved when compared with its German counterpart (Terblanche, 1979). The South African Mutton Merino has white to cream coloured wool, and with a year’s growth a ram can produce 4.5kg wool and a ewe 3.4kg. The average length of the wool is 75mm and the average fibre diameter is 21-23 micron (Snyman, 2014c). In effect, the wool is overly crimped which gives the wool good physical fibre characteristics. This, in turn, makes the wool ideal for yarn, carpets and upholstery. The coat has to be soft to the touch and should also be free of hair and kemp (Terblanche, 1979).

The South African Mutton Merino has also played a significant role in the development of new breeds. It has been used in the breeding programs of the Dormer, the Vandor, the Afrino and the Döhne Merino (Snyman, 2014c). The Mutton Merino has also been used in crossbreeding programs, either through mating Mutton Merino rams with Merino ewes to produce crossbred lambs that will be sold nationwide, or by using the ewe lambs as mothers for a third cross mating. The benefit of using Merino ewes to produce slaughter lambs is that these lambs develop quickly on good quality nutrition and will produce high-quality carcasses of 15-16kg at four months of age.

CHAPTER 2

MATERIALS AND METHODS

2.1 Experimental location and period

The study was conducted in the farming district of Vrede which is located in the Thabo Mofutsanyana region of South Africa's Free State province. Vrede, where the study took place, is located at a latitude of 27.45˚ South and longitude of 29.15˚ East, in the hub of the region's agriculture industry, which also serves as an important producer of wheat, maize, poultry, wool, mutton, beef and dairy products. Vrede is at an altitude of 1675m above sea level and has an average annual rainfall of 524mm per year.

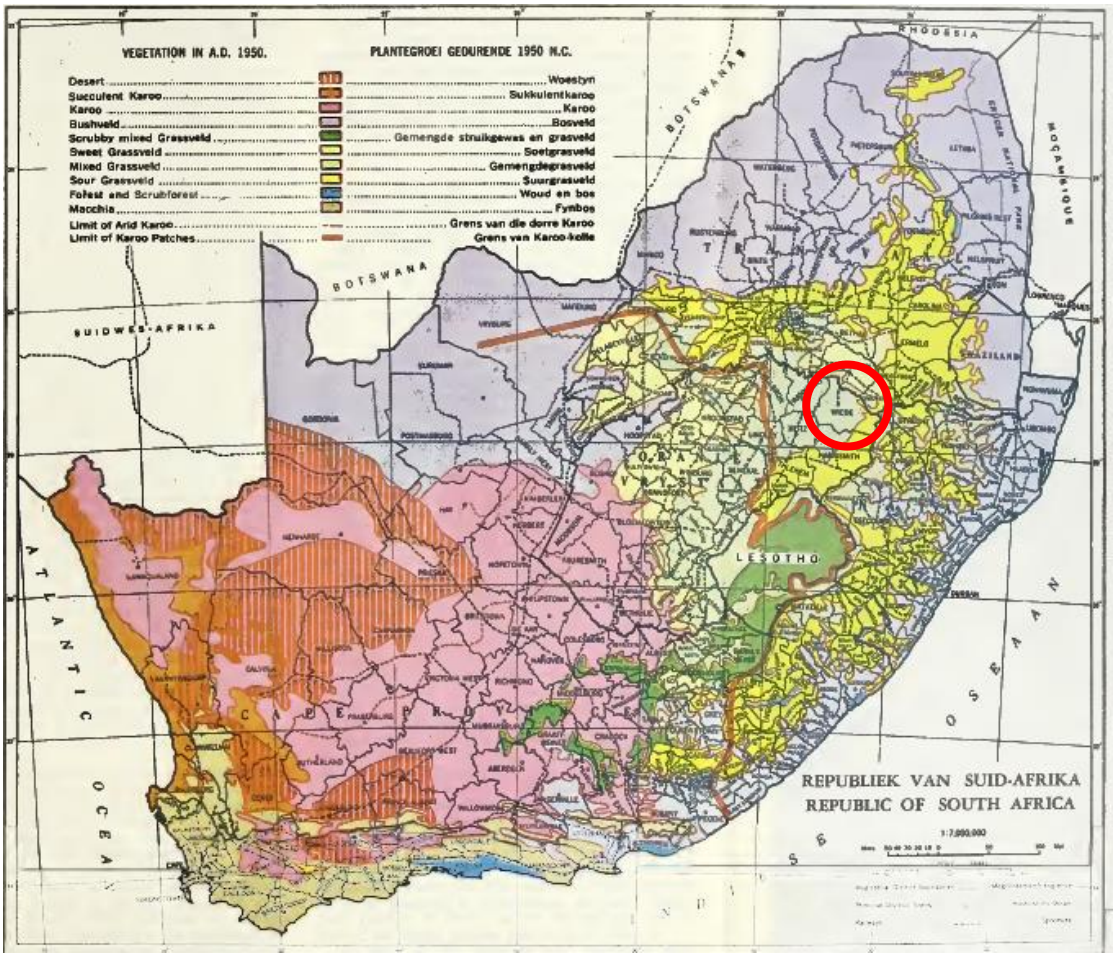


Figure 2.1 The South African map showing the vegetation growth of the various districts in South Africa. Vrede district has been circled in red (Acocks, 1975).

The biome type in the Free State is classified as Grassland and Vrede is classified as a mixed Grassland biome (Acocks, 1975; Van Oudtshoorn, 1992). The Grassland biome stretches from the high central plateau of South Africa to the inland areas of the Eastern Cape and KwaZulu-Natal (Mucina & Rutherford, 2006). The topography is flat and rolling. A single layer of grasses dominates the Grassland, and rainfall and grazing will determine the amount of cover. Except for a few localised areas, trees are absent due to frosts, fire, and grazing which prevents the establishment of trees but maintains grass dominance. Sweet grasses and sour grasses are both prevalent in this biome. Sweet grasses have a lower fibre content compared to sour grasses and store their nutrients in their leaves during the winter, making them more palatable to livestock. Sour grasses lose the nutrients in their leaves during the winter making them less palatable to livestock and lower in nutritional value. Sour grasses predominate in more acidic soils and higher rainfall areas (625mm per year). Throughout the biome C_4 grasses dominate, but at higher altitudes C_3 grasses prevail (Mucina & Rutherford, 2006). Overgrazing causes an increase in annual, pioneer, and creeping grasses. *Themeda trianda* is the most prevalent grass type in this region. It is considered one of the best rangeland grasses, especially in the Highveld.

The study was carried out from 26 September 2008 to 14 April 2009 (from the start of Spring to the onset of Autumn). Three treatments were included in the study, namely a control treatment with a duration of 200 days from 21 September 2008 to 16 April 2009, the finishing treatment 1 for a duration of 133 days (21 September 2008 – 9 February 2009), and the finishing treatment 2 which was for 70 days from 21 September to 28 November 2008.

This research was approved by the Animal Ethics committee of the UP, reference number EC027-08.

2.2 Experimental design

The rams of each breed were stratified according to weight and randomly divided into three finishing treatments. Each finishing treatment was a replication of a different feeding practice commonly used in South Africa. These feeding practices have different combinations of dietary energy and protein concentrations, and are of different durations. The different South African feeding practises feed rams to reach target auction weights of 50-70kg.

The three finishing treatments were as follows: Control treatment, finishing treatment 1 and finishing treatment 2. The three treatments differed in duration (and the Control treatment continued into a different season), but the aim of the experimental design was to replicate

what happens in industry. A schematic representation of the experimental design is presented in Figure 2.2.

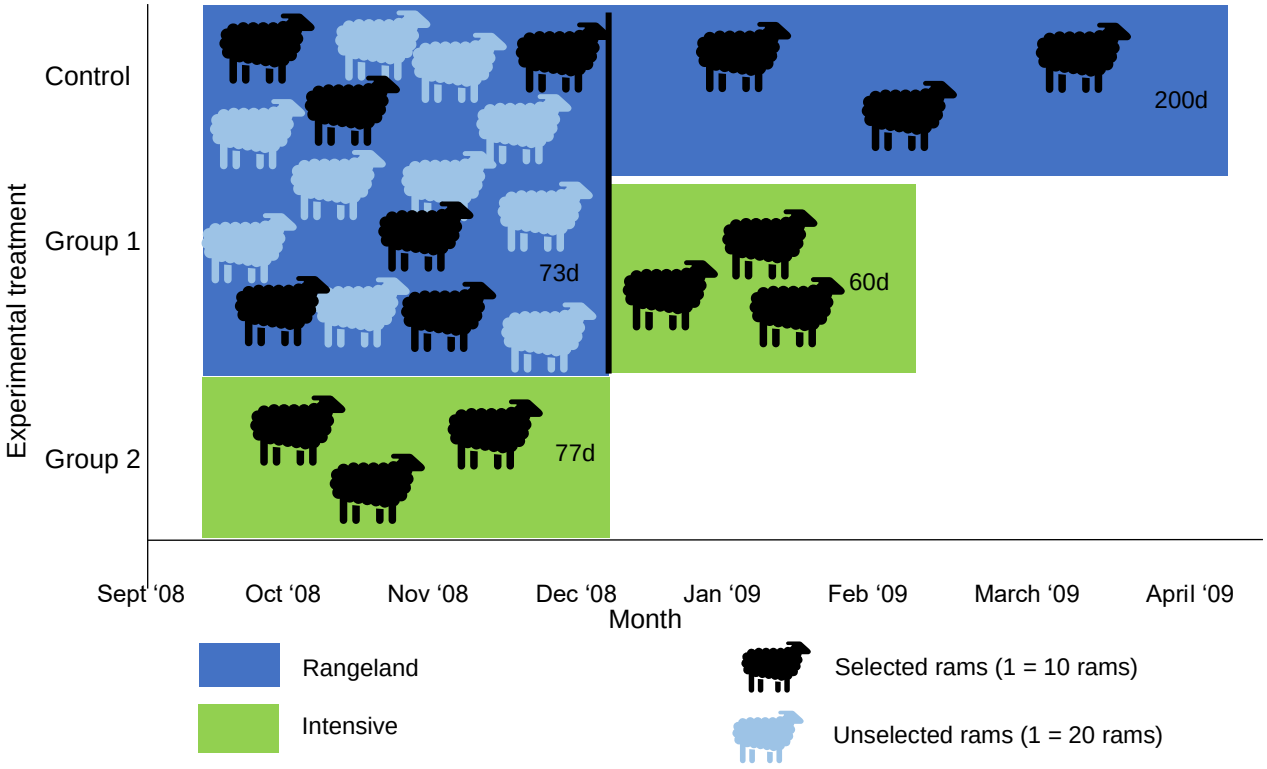


Figure 2.2 Schematic representation of the three different experimental treatments in this study.

2.2.1 Control treatment

This treatment was based on the most commonly used feeding practice used by South African sheep farmers: an extensive feeding system (or rangeland system). The weaned five-month-old rams were placed on *Themeda trianda* pastures and received an additional production lick for the entirety of the trial (200 days).

This treatment took place at the Vrede Veld Ram Club and because of this there were 250 rams at the start of this treatment. Not all of the 250 rams passed the performance tests and went on to the finishing phase of the Vrede Veld Ram Club. Sixty of the rams, that failed the performance test, were randomly chosen and were stratified according to weight. These 60 rams were then randomly divided into the Control treatment and Phase 2 of Finishing treatment 1. The 30 randomly selected rams to continue with the Control treatment were 11 Merino rams, 10 Döhne Merino rams and nine South African Mutton Merino rams. In this dissertation, this treatment will be referred to as the "Extensive treatment".

At the onset of this treatment (26 September 2008), body weight, anthropometric measurements and scrotal circumferences were measured (Table 2.1). These measurements were further recorded on a monthly basis and at the end of the trial. Blood samples were also taken at the start of the treatment. A week before slaughter (7 April 2009), blood samples, semen samples and ultrasonic scans of the scrotum were also taken.

The 29 rams (10 Döhne Merino, 11 Merino and eight South African Mutton Merino) were transported to and slaughtered on 16 April 2009 at the Vrede Abattoir. One SAM ram was expelled due to poor health. Carcass weight, subcutaneous fat, and carcass classification score were determined and recorded. The scrota were dissected into testis and scrotal fat. Pathology was performed on the testes, scrotal weight and scrotal fat weight determined. The testes were weighed, and the widths, lengths and circumferences were measured.

2.2.2 Finishing treatment 1

This group was a combination of an extensive and intensive production system and was based on the system used by Veld Ram Clubs. Thus, this treatment had two phases: Phase 1 the rams were kept on rangeland and Phase 2 the rams were kept intensively and were finished off. The total duration of this treatment was 133 days. The first phase of the treatment took place at the Vrede Veld Ram Club and lasted for 73 days. As explained in Section 2.2.1, there were 250 rams at the start of Phase 1, and 60 of those rams – which failed the performance test – were randomly chosen. Thirty rams (Section 2.2.1 explains how these 30 rams were randomly assigned to this treatment) entered Phase 2 of the treatment – the finishing off phase which lasted for 60 days – and were then slaughtered. Each breed was fed separately and were fed a high energy and high protein, growth-fattening diet provided by Vrede Saamstaan Veeboere. The 30 rams were 10 Döhne Merino, 10 Merino and 10 South African Mutton Merino rams. In this dissertation, this treatment will be referred to as the “Extensive-intensive treatment”.

At the beginning of the treatment (26 September 2008), body weight, anthropometric measurements and scrotal circumferences were measured (Table 2.1). These measurements were further recorded on a monthly basis and at the end of the trial. Blood samples were taken at the start of the treatment, at the start of the 60-day finishing phase (5 December 2008), at 30 days of intensive feeding (9 January 2009) and a week before slaughter (30 January 2009). A week before slaughter (30 January 2009), semen samples and ultrasonic scans of the scrotum were taken.

Thirty rams (10 Merino rams, 10 Döhne Merino rams and 10 South African Mutton Merino rams) were transported to and slaughtered at the Vrede Abattoir on 6 February 2009. Carcass weight, subcutaneous fat, and carcass classification score were determined and recorded. The scrota were dissected into testis and scrotal fat. Pathology was performed on the testes. Scrotal weight and scrotal fat weight were determined. The testes were weighed, and the widths, lengths and circumferences were measured.

2.2.3 Finishing treatment 2

These rams, from the same cohort as the rams in the other two treatments, entered a feedlot environment immediately after weaning (from 26 September 2008) and had a 21-day adaptation period. The Merino rams were reared for 70 days, and the Döhne Merino and SAM rams for 77days. Each breed was fed separately and were fed an identical high energy and high protein, growth-fattening diet provided by Vrede Saamstaan Veeboere, as the Group 1 rams. In this dissertation, this treatment will be referred to as the “Intensive treatment”.

At the beginning of the treatment (26 September 2008) weight, anthropometric measurements and scrotal circumferences were measured (Table 2.1). These measurements were further recorded on a monthly basis and at the end of the trial. Blood samples were also taken at the start of the treatment. A week before slaughter (28 November 2008), blood samples, semen samples and ultrasonic scans of the scrotum were taken.

The 30 rams (10 Döhne Merino, 10 Merino and 10 South African Mutton Merino) were transported to and slaughtered on 5 December 2008 at the Vrede Abattoir. Carcass weight, subcutaneous fat, and carcass classification score were determined and recorded. The scrota were dissected into testis and scrotal fat. Pathology was done on the testes. Scrotal weight and scrotal fat weight were determined. The testes were weighed, and the widths, lengths and circumferences were measured.

2.3 Experimental animals

This study consisted of three different treatments (see 2.2 Experimental design). The extensive treatment and extensive-intensive treatment were done at the Vrede Veld Ram Club. These trials commenced with a total of 250 rams, but not all the 250 rams passed the performance tests and went on to the finishing phase of the Veld Ram Club. A total of 30 of these rams (10 wool-mutton type Döhne Merino rams, 11 wool type Merino rams and nine mutton-wool type South African Mutton Merino (SAM) were randomly selected to continue with

the extensive treatment, while another 30 rams (10 Merino, 10 Döhne Merino and 10 SAM) were randomly chosen to continue with the finishing off phase of the extensive-intensive treatment. From the beginning of the intensive treatment, only 30 rams were randomly selected to enter this treatment. These 30 rams consisted of 10 Döhne Merino rams, 10 Merino rams and 10 SAM rams. Thus, in total, 90 rams were included in this study and 89 were slaughtered at the end of the trial. These rams were weaned and entered the treatments at five-months of age. The rams were all kept on rangeland before weaning and were all from farmers in the Vrede district. Some rams came from the same farmers which made them genetically more similar.

As the rams came from different farmers, the pre-weaning vaccination program of each ram was unknown. All the rams were bred by stud farmers and it could be assumed that they were at least vaccinated with Rev1. The animals were then vaccinated for bluetongue, botulism, Pasteurella, pulpy kidney, malignant oedema, necrotic hepatitis, red gut, dysentery, quarter evil and tetanus before the start of the trials. The rams were dosed for wireworm and tapeworm (using Dectomax and Ivomec Super) and regular FAMACHA checks and faecal egg counts were done. The animals were checked daily for disease symptoms and treated accordingly. Before the onset of the trial, all the rams were weighed, aged and ear tagged. The rams were evaluated for structural soundness by a veterinarian and sheared by a team from BKB Pty Ltd. Only animals with no anatomical deformities, and with two symmetrical, well-developed testes of normal consistency, were selected.

2.4 General husbandry

2.4.1 Extensive treatment and extensive-intensive treatment

These two treatments took place on Mr Potgieter's farm and were managed by the owners. The pastures on the farm were divided into camps. The size of each camp was determined by the carrying capacity of the grazing. The carrying capacity was calculated by determining the dry matter of the area using a disc pasture meter. Shade and shelter were offered to protect the rams from harsh weather conditions. Water and lick troughs were large in order to provide adequate feeding and drinking space and to decrease fighting and competition between rams. The lick troughs were placed under shelter to protect it from rain. Water was provided *ad libitum*.

2.4.2 Extensive-intensive treatment and intensive treatment

After 73 days on rangeland, the rams from extensive-intensive treatment, entered the finishing off phase and were moved and placed into pens. The rams of intensive treatment were also housed in pens. The rams were divided into the three breeds and the breeds were housed and fed separately from each other. The pens had large water and feed troughs to ensure sufficient drinking and eating space. The pens had shade and shelter to protect the rams from the elements. The feed, water and lick troughs were cleaned on a regular basis and were placed under shelter to protect them from rain. Water was provided *ad libitum*.

2.5 Experimental diets

The extensive treatment and first phase of the extensive-intensive treatment grazed typical *Themeda trianda* grazing on the mixed sourveld of the Highveld. The extensive treatment grazed for 200 days, while the extensive-intensive treatment grazed for 73 days. The rams received a production lick supplement, containing *ca.* 8 MJ ME/kg DM and *ca.* 250g/kg crude protein, provided by and similar to the production lick used by the Vrede Veld Ram Club. The ingredients used in this lick were salt (17%), Molatek Meester 20 (21%), ground maize (31%), urea (2%), cottonseed oilcake (22%), fishmeal (2%), ammonium sulphate (2%), feed lime (2%) and BASF vitamins and minerals (1%). Fresh lick was offered every other day. Grab samples were taken and analysed on a regular basis to make sure the lick had been properly mixed. Water was given *ad libitum*.

The second phase of the extensive-intensive treatment, and the intensive treatment received the same commercial concentrate veld ram diet. This commercial concentrate diet had an energy value of 11.4 MJ ME/kg DM, a crude protein and crude fibre content of 13.5% and 12% respectively, as well as 0.8% calcium, 0.35% phosphate, and 0.8% urea. The ingredients used in this diet were maize, hominy chop, lucern, cottonseed oilcake, molasses meal, feed lime, grade 1 salt, urea, vitamins, trace minerals, and lasalocid sodium. It was provided by Vrede Saamstaan Veevoere (Church street, Industrial, Vrede) and was similar to the diet used by the Vrede Veld Ram Clubs during their finishing off phase. The extensive-intensive treatment had an adaptation period of 10-14 days and were fed for a total of 60 days. The rams of the intensive treatment entered this treatment after weaning and had an adaptation period of 21 days. The Merino rams of the intensive treatment were fed for 70 days, while the Döhne Merino and SAM rams were fed for 77 days. The rams were fed twice daily in order to stimulate intake. Feed grab samples were collected and analysed on a regular basis to ensure the feed had been properly mixed. Water was given *ad libitum*.

2.6 Experimental factors and variables

Table 2.1 Summary of fixed factors, random factors, and variable factors recorded during each treatment

<table>
<tr><th>Fixed factors</th><th>Growth variables</th><th>Anthropometric variables</th><th>Scrotal variables</th></tr>
<tr><td>• Experimental treatment
• Breed</td><td>• Body condition score
○ Beginning
○ Final
○ Difference
• Body weight
○ Beginning
○ Final
○ Difference
• Average daily gain
• Metabolic weight
• Kleiber index</td><td>• Heart girth
○ Beginning
○ Final
○ Difference
• Body length
○ Beginning
○ Final
○ Difference
• Shoulder height
○ Beginning
○ Final
○ Difference
• Hip height
○ Beginning
○ Final
○ Difference
• Subcutaneous fat
• Carcass weight
• Carcass compactness
• Carcass classification score</td><td rowspan="3">• Scrotal circumference
○ Beginning
○ Final
○ Difference
• Scanned scrotal neck fat
• Scrotal weight
• Scrotal fat weight
• Pampiniform venous plexus circumference
• Pampiniform venous plexus circumference to scanned scrotal neck fat ratio
• Pampiniform venous plexus circumference to scrotal fat weight ratio
• Pampiniform venous plexus circumference to testes weight ratio
• Effective Pampiniform venous plexus circumference to testes weight ratio
• Testes weight
• Testes length
• Testes width
• Testes circumference
• Testes volume
• Scrotal fat weight as a percentage of testes volume</td></tr>
<tr><th>Random factor</th><th>Semen variables</th><th>Blood analysis variables</th></tr>
<tr><td>• Season</td><td>• Semen volume
• Semen colour
• Mass motility
• Progressive motility
• Percentage aberrant motile spermatozoa
• Percentage immotile/dead spermatozoa
• Percentage normal spermatozoa</td><td>• Plasma triiodothryonine concentration
• Serum testosterone concentration
• Plasma calcitonin concentration</td></tr>
</table>

2.7 Data collection

In this study, data were collected over a two to six-month period from 90 rams.

2.7.1 Growth measurements

At the beginning of the study, after the rams were sheared, body weight was recorded using a scale, and body condition scores (BCS) of all the rams were assessed. Body condition scoring was based on the principles described by Keinprecht *et al.* (2016) on a modified 9 point scale. This was done to simplify the 0.5 scoring on the 5 point scale. One represented an emaciated ram and 9 represented an extremely fat ram. Body weight, BCS and average daily gain were recorded on a monthly basis (at the same time of day) as well as at the end of every treatment (after the rams had been sheared).

2.7.2 Anthropometric measurements

Anthropometric measurements (body length, hip height, heart girth, and shoulder height) were also measured (using a measuring tape), and recorded at the beginning of the study. Body length was measured from the acromion of the shoulder to the pin bone; hip height was measured at the hindquarters from the ground up to the pin bone; shoulder height was measured at the front limbs, from the ground up to the most dorsal point of the shoulder; heart girth was measured just behind the front limbs. These measurements were further recorded on a monthly basis (at the same time of day) and at the end of every treatment (after the rams had been sheared).

Once the rams were slaughtered, carcass weight, subcutaneous fat thickness (measured at the 13^{th} rib), and carcass classification score were weighed, measured and determined. This was used to compare the physiological age of the rams. It was also used to estimate how the serum and plasma concentrations of testosterone, calcitonin and T_3 concentrations influenced the underlying physiological effects.

2.7.3 Scrotal measurements

At the beginning of the study, scrotal circumferences were measured using a flexible measuring tape (scrotum was wool-free). Scrotal circumference was measured while the rams were in a standing position. The testes were palpated to the distal part of the scrotum and the measurement was taken at the widest part. The scrotum and testes were palpated to ensure

symmetry and normal consistency. The epididymis was also palpated to ensure that there were no abnormalities. At the end of every treatment, scrotal circumference was measured again (any wool was sheared off). Ultrasound scans of the neck of the scrotum of each ram were taken a week before a treatment's slaughter date. The ultrasound showed the fat accumulation in the neck of the scrota, around the *Pampiniform venous plexus*, which was used to determine the correlation between subcutaneous fat thickness and the fat accumulation in the scrotal neck, as well as the correlation between scrotal neck fat thickness and semen quality. To determine how effectively thermoregulation was maintained, a new ratio was formulated to estimate the "Effective *Pampiniform venous plexus* " which is *Pampiniform venous plexus* circumference (PPC) to scanned scrotal neck fat (SSNF) (PPC:SSNF). Other ratios were also formulated and included PPC to scrotal fat weight, PPC to testes weight, and Effective PPC to testes weight.

Once the rams were slaughtered, the total scrota were weighed. The scrota were then dissected into testes and scrotal fat. The testes were weighed, and the volume, width, length, and circumference were measured. All these measurements were correlated with the results from the semen and sperm analyses. Pathology was done on the scrotum and testes of the slaughtered rams. Scrotal fat weight was recorded.

2.7.4 Semen analyses

Semen samples were collected and analysed by Prof Henry Annandale, from the Faculty of Veterinary Science at Onderstepoort, by means of an electro-ejaculator. Semen samples were collected a week before every treatment's scheduled slaughter date. This was a harmless procedure which yielded sperm of acceptable quality. These semen samples were evaluated using standard procedures for semen volume, colour, mass motility, forward progressive motility, percentage aberrantly motile spermatozoa, percentage immotile/dead spermatozoa, and percentage normal spermatozoa (Bester *et al.*, 2004; Fourie *et al.*, 2004; Elmaz *et al.*, 2007; Swanepoel *et al.*, 2008).

A calibrated test tube was used to measure the total volume of the ejaculate (Bester *et al.*, 2004; Fourie *et al.*, 2004; Swanepoel *et al.*, 2008). The colour of the semen, which provides an indirect indication of sperm concentration, was determined on a scale of 0 to 5 where zero represented a clear or cloudy appearance (low sperm concentration) and five represented a thick creamy appearance (high sperm concentration). Semen samples were then diluted (1:100) in a TL-Hepes solution and sperm motility microscopically examined (Bester *et al.*, 2004; Fourie *et al.*, 2004). A drop of diluted semen was placed on a pre-warmed microscope

slide and covered with a cover-slide. Mass motility, or gross motility of the spermatozoa, and progressive motility was evaluated. Mass motility was scored on a scale from 0 to 5 where zero represented no swirl with only sporadic oscillation and five was a rapid and vigorous swirl. This was done using a phase contrast microscope at 40x magnification (Bester *et al.*, 2004; Swanepoel *et al.*, 2008). Progressive sperm motility was assessed by counting 100 sperm cells for each sample. Each sperm cell's progression was determined by using a scale of 0 to 5 where zero indicated no movement and five indicated rapid and vigorous forward sperm movement. These values were added up and provided the mean score for each sample for progressive motility (Tufarelli *et al.*, 2011).

In order to determine the percentage normal spermatozoa in each sample, the morphology of the spermatozoa (normal vs abnormal) were evaluated using a phase contrast microscope at 1000x magnification. Thin smears were made using 5µl of dye (Eosin-nigrosin and eosin B-fast green stains) and *ca.* 10µL of semen (Tufarelli *et al.*, 2011). This time two counts of 100 spermatozoa were evaluated, and the results were presented as percentages. Abnormal sperm cells were divided into major defects (knobbed acrosomes, abnormal loose heads, pyriforms, dag defects, mid-piece reflexes, degenerative heads) and minor defects (distal droplets, normal loose heads, loose acrosomes and curled end-piece) (Vilakazi & Webb, 2004; Palmer *et al*., 2005; Swanepoel *et al.*, 2008).

2.7.5 Hormone assays

Blood samples were collected at the start of the study and analysed for serum testosterone, plasma calcitonin and plasma triiodothyronine (T_3) concentrations. A week before each predetermined treatment slaughter date, blood samples were collected and analysed for the same hormones. Vaccutubes (10mL) were used to collect the blood (serum and plasma) samples from the *vena jugularis*. These samples (7 – 10mL) were centrifuged at 3000 x g for 15 minutes. Until the plasma aliquots (500µL) could be assayed, which were stored at -20°C. Following the Novum Testosterone Eliza method, radioimmunoassay was done to determine serum testosterone concentrations (Fourie *et al.,* 2005). The assay sensitivity was 0.12ng/mL serum with a coefficient of variation of <10% (Elmaz *et al.*, 2007). The effect of the concentrations of serum testosterone, plasma calcitonin and plasma T_3 on sperm quality was determined in subsequent analyses. Serum testosterone and T_3 assays were performed at Onderstepoort.

2.8 Statistical analyses

Statistical analyses were done using General Linear Model (GLM) procedure of the IBM SPSS Statistics v. 23.0 software (IBM Corp, 2015). Addendum A provides an example of the GLM analysis of variance done for each group of variables which were divided into the following categories: growth measurements, anthropometric measurements, scrotal measurements, semen quality and blood-hormone concentrations. The Bonferroni multiple test was used to determine significant differences between the Least Squares means of the three treatments, the differences between the means of the three breeds, and significant treatment x breed interactions (IBM Corp, 2015). Differences were tested at the $P < 0.05$ level of confidence. Regression analyses (S curve, compound, logarithmic, cubic and quadratic mathematical functions) and partial correlations (Pearson's product moment partial correlation coefficients) were calculated by controlling for initial weight (IBM Corp, 2015).

The purpose of this study was to simulate finishing off feeding systems commonly used in the rearing of breeding rams in South Africa e.g. that typically used by South African Veld Ram Clubs. This resulted in treatments with different durations and, consequently, confounding effects between treatment and age. Although there were some confounding between finishing treatment and age, it was still necessary to assess the effects of current finishing treatments due to the concerns of sheep breeders.

CHAPTER 3

RESULTS AND DISCUSSIONS

The results of the treatment effects on the different variables were grouped into the following categories: growth measurements, anthropometric measurements, scrotal measurements, semen analyses, and hormone assays. The results of treatment effects will be presented first, followed by breed effects, and discussed for each variable category. A more in-depth discussion (e.g. treatment x breed interaction effects) will then ensue.

3.1 Growth measurements

Variables grouped in this category were: initial body condition score (BCS_I), final body condition score (BCS_F), initial body weight, final body weight, weight gained, average daily gain (ADG), metabolic weight, and Kleiber index.

Randomisation of experimental animals at the start of the trial included stratification of rams according to weight, followed by random allocation to finishing treatments for each breed. This ensured that initial body weight and body condition scores of the three finishing treatments did not differ ($P > 0.05$), as shown in Table 3.1. The rams were sheared at the beginning of the trial as well as at the end of each treatment – before final measurements were taken.

Overall finishing treatment effects: Final body weight, body condition scores and weight gained by rams in the intensive group had the lowest values while those in the extensive group had the highest values ($P < 0.001$; Table 3.1). These results may seem inconsistent when compared to the well documented effects of improved nutrition on growth, body weight and condition (Batt, 1980; Bester *et al*., 2004; Fourie *et al.*, 2004; Hossner, 2005; Tufarelli *et al.*, 2011). However, the differences in the present study were due to differences in the duration of the treatment periods. Although the rams in the intensive treatment received a concentrate diet, the feeding period of this treatment was (1) shorter than the other two treatments and (2) these rams were younger than the rams of the other two treatments (*ca.*140 days younger than the extensive rams and *ca.* 67 days younger than the extensive-intensive rams) and did not get the chance to reach their full growth potential.

The rams in the extensive-intensive treatment were also lighter ($P < 0.001$) and gained less weight ($P < 0.001$) than the extensively kept rams. Although the extensive-intensive treatment rams received a concentrate diet for two months, fewer days were required for this treatment, so the rams were younger when they were weighed for the last time. However, Table 3.1 does

show that ADG differed between the three treatments (P < 0.001) and that the intensive treatment had the highest growth rates (0.304 ± 0.035kg), while the extensive treatment had the lowest growth rates (0.232 ± 0.022kg).

Table 3.1 Effects of finishing treatment on growth results ($\bar{X} \pm SD$) of Döhne Merino, Merino, and South African Mutton Merino (SAM) rams following either an extensive, extensive-intensive, or intensive treatment

Variables ($\bar{X}$ ± SD)	**Finishing treatment**		
	Intensive (n = 29)	**Extensive- Intensive** (n = 30)	**Extensive** (n = 30)
BCS_I	3 ± 0.7	3 ± 0.7	4 ± 0.7
BCS_F	5 ± 0.5[a]	5 ± 1.6[b]	7 ± 0.8[c]
$Weight_I$ (kg)	31.0 ± 4.68	30.2 ± 6.28	29.4 ± 5.07
$Weight_F$ (kg)	53.7 ± 6.01[a]	66.5 ± 7.61[b]	75.8 ± 5.71[c]
$Weight_G$ (kg)	22.7 ± 2.77[a]	36.3 ± 5.18[b]	46.4 ± 4.48[c]
ADG (kg)	0.304 ± 0.035[a]	0.273 ± 0.039[b]	0.232 ± 0.022[c]
MetWeight ($W^{0.75}$)	19.8 ± 1.66[a]	23.3 ± 2.01[b]	25.7 ± 1.45[c]
Kleiber index	127.2 ± 12.65[a]	97.2 ± 11.59[b]	74.8 ± 6.05[c]

[a, b, c] Means with different superscripts, within a row, differ significantly (P < 0.05)

$\bar{X}$ ± SD – Mean ± Standard deviation

BCS_I – Initial body condition score (on a scale from 1 to 9); BCS_F – Final body condition score (on a scale from 1 to 9); $Weight_I$ – Initial weight; $Weight_F$ – Final weight; $Weight_G$ – Weight gained; ADG – Average daily gain; MetWeight – Metabolic weight

Metabolic weights of rams were significantly affected by dietary treatments in the present study. Metabolic weight is the amount of metabolically active tissue in the body which determines the animal's basal metabolic rate (Souza Júnior *et al.*, 2013). Basal metabolic rate, which is influenced by the concentration of thyroid hormones, is the rate at which the body uses energy just to meet maintenance requirements. Higher concentrations of thyroid hormones result in higher basal metabolic rates as lipolysis and glycolysis rates are increased in the cells. Thyroid hormones also affect the secretion of Growth Hormone (GH) as young

animals with hypothyroidism often suffer dwarfism (Reece, 2015). Thus, as an animal passes the self-accelerating phase, of the sigmoidal growth curve, and reaches the self-retarding phase and maturity portion of the curve, growth requirements decrease, and thyroid hormones reach a plateau. Metabolic weight can thus be used as an indicator of maturity as it will start to plateau once the animal has reached maturity due to the plateaued basal metabolic rate (Batt, 1980). Intensively kept rams had the lowest final body weight (as previously explained) and consequently had the lowest metabolic weight values (19.8 ± 1.66 $W^{0.75}$, $P < 0.001$), while the heavier, older, extensively fed rams had the highest values (25.7 ± 1.45 $W^{0.75}$, $P < 0.001$). The extensive-intensive treatment rams were intermediate with an average metabolic weight value of 23.3 ± 2.01 $W^{0.75}$. The data is thus correct as it would be expected that the older rams (the extensive treatment rams) would have higher metabolic weight values than the younger rams (the intensive treatment rams) (Batt, 1980). The intensive treatment rams also required less energy to meet daily maintenance requirements, while the extensively kept rams needed more energy.

Kleiber index is a measurement of growth efficiency, independent of body size (Kleiber, 1961), and is highly correlated with feed conversion rate (Talebi, 2012), and can be used as an indirect selection parameter for feed conversion efficiency (Scholtz *et al.*, 1990). This variable differed between all three treatments ($P < 0.001$). The present results confirm that rams in the extensive treatment had the lowest Kleiber values (least efficient), while the intensive treatment had the highest values (most efficient). This was not surprising as rams in the extensive treatment had the longest feeding period (200 days), did not receive a concentrate diet, had the lowest ADG and were the oldest when slaughtered. By contrast, rams in the intensive treatment had the shortest feeding period (70-77 days), were fed a concentrate diet for the total period, had the highest ADG and were the youngest when slaughtered.

In the reviews by Vermorel & Bickel (1980) and that of Meissner (1983) it was confirmed that growth efficiency increased as the level of concentrate and metabolisable energy intake increased. Although the current study did not test for feed efficiency, Talebi (2012) stated that Kleiber index is highly correlated with feed efficiency, and it may be assumed that the rams in the intensive treatment had a better feed conversion rate than the rams in the extensive treatment. Overall, the intensive treatment was the most efficient treatment of the three treatments in terms of growth and possibly feed efficiency, while the extensive treatment was the least efficient.

Overall breed effects: The initial BCS did not differ ($P > 0.05$) between the three breeds (Table 3.2), but there were differences in initial weight between the breeds. The Döhne Merino rams differed from the SAM rams (28.5 ± 2.77kg and 35.7 ± 4.08kg respectively, $P < 0.001$),

and Merino rams differed from the SAM rams (26.9 ± 4.47kg and 35.7 ± 4.08kg, P < 0.001). The SAM breed is a large framed breed (Burger *et al.*, 2013) and will thus be heavier than the medium to large framed Döhne Merino breed (Snyman, 2014a), and the medium framed Merino breed (Snyman, 2014b). At the end of the trial, the SAM rams were still heavier (P < 0.05) than both the Döhne Merino rams and the Merino rams. Although the SAM rams were heavier (P < 0.05) at the beginning and at the end of the trial, the breeds did not differ (P > 0.05) in terms of gained weight nor in ADG, implying that over all three finishing treatments the weight gained by the three breeds was similar. All the rams were in an active growth phase which explains the negligible differences in ADGs between the different breeds.

Table 3.2 Effects of breed on growth results ($\overline{X} \pm SD$) of Döhne Merino, Merino, and South African Mutton Merino (SAM) rams

Variables ($\bar{X}$ ± SD)	**Breed**		
	Döhne (n = 30)	**Merino** (n = 31)	**SAM** (n = 28)
BCS_I	3 ± 0.6	4 ± 0.9	3 ± 0.7
BCS_F	6 ± 1.4	5 ± 1.5[a]	6 ± 1.6[b]
$Weight_I$ (kg)	28.5 ± 2.77[a]	26.9 ± 4.47[a]	35.7 ± 4.08[b]
$Weight_F$ (kg)	63.6 ± 9.31[a]	62.5 ± 11.96[a]	69.9 ± 10.94[b]
$Weight_G$ (kg)	35.1 ± 9.35	35.6 ± 12.50	34.2 ± 9.93
ADG (kg)	0.270 ± 0.046	0.270 ± 0.043	0.270 ± 0.044
MetWeight ($W^{0.75}$)	22.5 ± 2.50[a]	22.2 ± 3.19[a]	24.1 ± 2.86[b]
Kleiber index	101.4 ± 24.72[a]	103.4 ± 24.67[a]	94.7 ± 22.17[b]

[a, b, c] Means with different superscripts, within a row, differ significantly (P < 0.05)

$\bar{X}$ ± SD – Mean ± Standard deviation

BCS_I – Initial body condition score (on a scale from 1 to 9); BCS_F – Final body condition score (on a scale from 1 to 9); $Weight_I$ – Initial weight; $Weight_F$ – Final weight; $Weight_G$ – Weight gained; ADG – Average daily gain; MetWeight – Metabolic weight

Metabolic weight only differed for the SAM rams (the larger breed studied) which had higher values (24.1 ± 2.86 $W^{0.75}$) than the Merino (22.2 ± 3.19 $W^{0.75}$, P < 0.001) and Döhne Merino

(22.5 ± 2.50 $W^{0.75}$, $P < 0.001$) rams. The Kleiber index values also only differed for the SAM breed (94.7 ± 22.17) and was lower ($P < 0.05$) than the Merino (103.4 ± 24.67) and Döhne Merino (101.4 ± 24.72) rams. This suggests that SAM rams grew the least efficiently and possibly had a lower feed conversion ratio (Kleiber, 1961; Talebi, 2012). However, ADG disproves this, as all three the breeds had the same ADG, thus all three breeds grew equally and efficiently.

Finishing treatment x breed interaction effects: Variables which had significant treatment x breed interactions were BCS_F, final weight, weight gained, ADG, metabolic weight, and Kleiber index. Table 3.3 illustrates that although the initial weight of the SAM rams was heavier than the other two breeds within a treatment (and significantly so in the intensive and extensive-intensive treatments), there were no differences in initial weight between treatments in the SAM breed (as was shown in Table 3.1). As stated before, the SAM breed is a large framed breed which explains their heavier initial weight compared to the other two breeds.

The final weight of Merino rams differed between all three treatments ($P < 0.05$), with the lightest rams in the intensive treatment, while the extensive treatment delivered the heaviest rams. The final weight of the extensively kept Döhne Merino rams differed ($P < 0.05$) from the final weight of the Döhne Merino rams in both the extensive-intensive treatment and the intensive treatment. The same was observed in the SAM breed. For both the SAM and Döhne Merino breeds, the lightest rams were in the intensive treatment and the heaviest in the extensive treatment. This was to be expected since the duration of the intensive treatment was much shorter than the extensive treatment (*ca.* 70-77 days versus 200 days) and the rams in the intensive treatment were much younger than the rams in the extensive treatment when they were weighed at the end of the treatment period. Further, although the extensive treatment was only on rangeland, these rams did receive a production lick throughout the trial. The production lick was given to help meet the rams' maintenance requirements.

Weight gained differed between all three finishing treatments ($P < 0.001$) in the SAM breed. The SAM rams in the extensive-intensive treatment were 16kg heavier than the intensive rams, while the extensively kept rams were 23kg heavier than the intensively fed rams. Extensive-intensive treatment SAM rams benefitted the most from the concentrate diet which was only given during the last two months of the trial when the rams were older. These rams were seven months old by the time they received the concentrate feed. According to Popkin *et al.* (2012), by this age in sheep (which were fed a low plane of nutrition) the following skeletal areas would be almost completely fused namely the proximal radius, scapula, distal humerus, pelvis, middle phalange, proximal phalange, distal tibia and distal metacarpal. However, the Popkin *et al.* (2012) study was performed on Shetland sheep, which is a small-framed British

breed. It is possible that the epiphyseal plates of certain long bones of the larger SAM rams had not completely fused yet, allowing for more skeletal growth to occur when the rams received the improved diet. The greater difference in final weight between the intensive treatment and the extensive-intensive treatment SAM rams compared with the difference between the extensive-intensive treatment and extensive treatment rams, supports the claim that the SAM breed is a later maturing breed. This will be further analysed in Section 3.2 as part of the anthropometric measurements.

The influence of finishing treatment on the final weight of Merino rams was the most interesting to observe. Only Merino rams showed differences in final weight between all three treatments ($P < 0.05$). Merino rams showed a slight improvement in final weight in the extensive-intensive treatment, but there was only an eight kilogram difference between that treatment and the rams in the intensive treatment, while the extensively fed Merino rams were 24kg heavier than the intensive rams. During the first 70 days of the finishing period, the Merino rams in all three treatments were in a linear part of the sigmoidal growth phase and would have grown at similar rates. The Merino breed has been selected and bred for high wool quality and quantity (Snyman, 2014b) and thus wool growth requirements are added to the Merino's daily maintenance requirements. The concentrate diet used in the intensive treatment may have provided more nutrients to comply with the nutrient requirements of the Merino rams in terms of growth, maintenance and wool growth, compared to the other two treatments. This may explain the smaller difference in final weight between the intensive treatment and extensive-intensive treatment Merino rams. It follows that Merino rams in the extensive-intensive treatment may not have grown as much in terms of skeletal size to produce a larger and heavier skeletal frame and thus more area for muscle development, compared to rams in the extensive treatment. By the time the extensive-intensive treatment rams were fed the concentrate diet, they may have already attained an almost fully-grown skeletal system, with near-complete fusion of the epiphyseal plates, limiting further skeletal growth. As the intensively fed Merino rams were fed a high-quality diet soon after weaning, and thus at an age when the epiphyseal plates had possibly not yet fused, the concentrate diet could have allowed for appreciably more skeletal growth to fully express the rams' genetic potential for growth. This is supported by numerically higher ADG values (0.306 ± 0.036kg) of the intensively fed Merino rams compared to the extensive-intensive treatment Merino rams (see Table 3.3).

Table 3.3 Effects of finishing treatment and breed on growth results ($\overline{X} \pm SD$) of Döhne Merino, Merino, and South African Mutton Merino (SAM) rams following either an extensive, extensive-intensive, or intensive treatment

Factors		Variables ($\bar{X}$ ± SD)							
Finishing treatment	**Breed**	**BCS_I**	**BCS_F**	**$Weight_I$** (kg)	**$Weight_F$** (kg)	**$Weight_G$** (kg)	**ADG** (kg)	**MetWeight** ($W^{0.75}$)	**Kleiber index**
Intensive	**Döhne** (n = 10)	3 ± 0.5	5 ± 0.5^{A}	28.8 ± 3.42	51.9 ± 4.38^{A}	23.2 ± 3.14^{A}	0.302 ± 0.039^{A}	19.3 ± 1.22^{A}	128.4 ± 13.32^{A}
	Merino (n = 10)	4 ± 0.8	5 ± 0.5^{A}	30.1 ± 4.48	51.4 ± 6.13^{A}	21.3 ± 2.84^{A}	0.306 ± 0.036^{A}	19.2 ± 1.70^{A}	133.2 ± 13.00^{A}
	SAM (n = 10)	3 ± 0.4	4 ± 0.5^{A}	34.3 ± 4.04	57.7 ± 5.68^{A}	23.4 ± 2.59^{A}	0.304 ± 0.034^{A}	20.9 ± 1.54^{A}	120.2 ± 8.60^{A}
Extensive-Intensive	**Döhne** (n = 10)	3 ± 0.6	$5 \pm 1.2^{A}{}_{a}$	$27.6 \pm 2.31_{a}$	$66.0 \pm 3.02^{B}{}_{ab}$	38.5 ± 3.49^{B}	0.289 ± 0.026^{A}	$23.2 \pm 0.80^{B}{}_{ab}$	$103.3 \pm 7.18^{B}{}_{a}$
	Merino (n = 10)	3 ± 0.9	$4 \pm 1.05^{A}{}_{b}$	$25.4 \pm 4.36_{a}$	$59.9 \pm 7.23^{B}{}_{a}$	34.6 ± 6.44^{B}	0.260 ± 0.048^{AB}	$21.5 \pm 1.94^{B}{}_{a}$	99.5 ± 12.15^{B}
	SAM (n = 10)	3 ± 0.8	$7 \pm 1.0^{B}{}_{c}$	$37.4 \pm 2.87_{b}$	$72.7 \pm 4.39^{B}{}_{b}$	35.3 ± 4.84^{B}	0.270 ± 0.037^{AB}	$24.9 \pm 1.13^{B}{}_{b}$	$88.7 \pm 9.04^{B}{}_{b}$
Extensive	**Döhne** (n = 10)	3 ± 0.8	7 ± 0.6^{B}	$28.9 \pm 2.53_{a}$	72.5 ± 4.08^{B}	$43.7 \pm 3.31^{B}{}_{a}$	0.218 ± 0.017^{B}	24.8 ± 1.05^{B}	72.7 ± 3.66^{C}
	Merino (n = 11)	4 ± 0.7	7 ± 0.9^{B}	$25.7 \pm 3.37_{a}$	75.3 ± 5.44^{C}	$49.6 \pm 3.78^{C}{}_{b}$	0.247 ± 0.018^{B}	25.6 ± 1.38^{C}	80.0 ± 3.82^{C}
	SAM (n = 8)	4 ± 0.7	8 ± 0.7^{B}	$34.9 \pm 4.95_{b}$	80.6 ± 5.41^{B}	$45.6 \pm 4.62^{C}{}_{ab}$	0.228 ± 0.023^{B}	26.9 ± 1.35^{B}	70.2 ± 6.00^{C}

$^{A, B, C}$ Different superscripts in the same column within a breed differ significantly ($P < 0.05$)

$_{a, b}$ Different subscripts in the same column within a treatment differ significantly ($P < 0.05$)

$\bar{X}$ ± SD – Mean ± Standard deviation

BCS_I – Initial body condition score (on a scale from 1 to 9); BCS_F – Final body condition score (on a scale from 1 to 9); $Weight_I$ – Initial weight; $Weight_F$ – Final weight; $Weight_G$ – Weight gained; ADG – Average daily gain; MetWeight – Metabolic weight

Differences in final weight were observed between the Döhne Merino rams in the intensive treatment compared to those in the extensive-intensive treatment ($P < 0.05$). Similarly, Döhne Merino rams in the intensive treatment differed from rams in the extensive treatment ($P < 0.05$). The average difference in body weight between the Döhne Merino rams from the intensive treatment and the rams from the extensive-intensive treatment was 14kg (the extensive-intensive Döhne Merino rams were heavier), while the extensive treatment rams were on average 20kg heavier than the rams in the intensive treatment. Döhne Merino rams responded well to an improved diet fed at an older age, but the differences in final body weight between those in the extensive-intensive treatment and the extensive treatment was not as prominent as observed in the Merino breed. Döhne Merino rams in the extensive-intensive treatment may not have been as physiologically mature as Merino rams when the feeding on higher quality diets commenced, allowing for more time for further skeletal growth before the epiphyseal plates closed, which resulted in heavier rams. More time also allowed for more muscle and internal organ growth. This confirms the description of the Döhne Merino breed as a slightly later maturing breed, compared to the Merino breed. Like the SAM rams, the Döhne Merino rams in the extensive-intensive treatment responded well to the concentrate diet fed at the end of the treatment, as they too had not reached maturity yet, which allowed for further skeletal growth to occur.

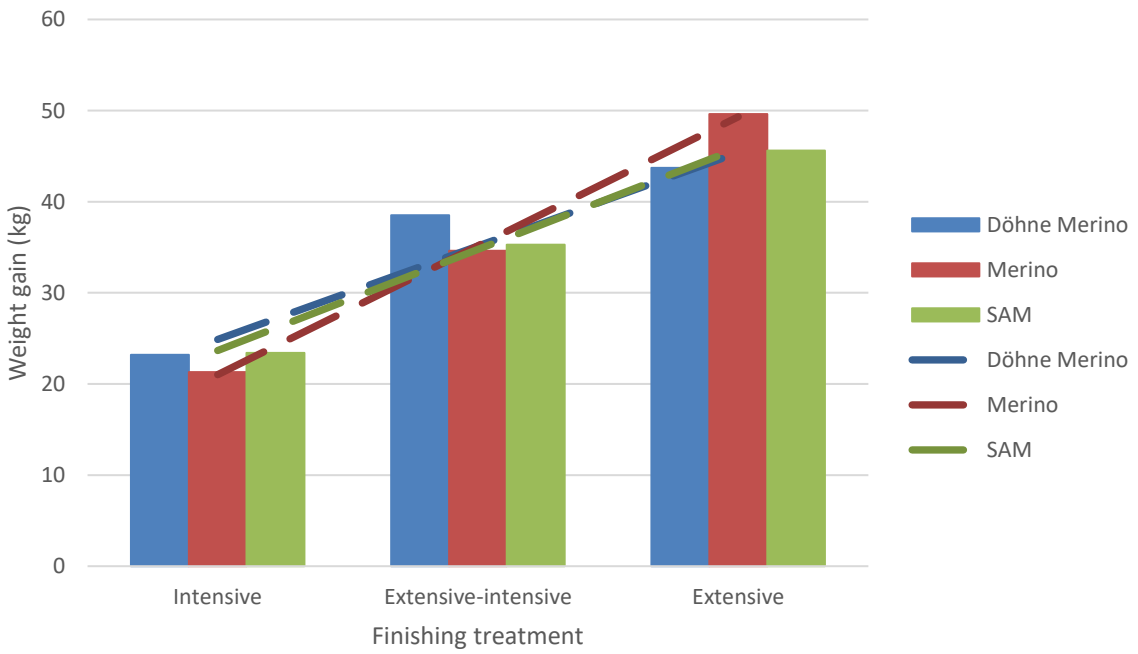


Figure 3.1 Weight gain of Döhne Merino, Merino and South African Mutton Merino (SAM) rams following either an extensive, extensive-intensive, or intensive treatment. (Dotted lines indicate trends for feeding treatments)

Figure 3.1 and Figure 3.2 show treatment x breed interaction effects for weight gained and ADG ($P < 0.01$ and $P < 0.001$ respectively). In the intensive and extensive-intensive treatments, there were no differences ($P > 0.05$) in gained weight between breeds. It was only in the extensive treatment where Merino rams gained more weight than the Döhne Merino rams (49.6 ± 3.78kg versus 43.7 ± 3.31kg, $P < 0.05$).

As for ADG, all three breeds in the intensive treatment differed ($P < 0.001$) from their counterparts in the extensive treatment. This time, the intensive treatment recorded higher ADG than the extensive treatment, showing that the intensive treatment better met the nutrient requirements of the rams. Kleiber indexes were also higher ($P < 0.001$) in the intensive treatment than in the extensive treatment for all three breeds. Thus, all three breeds in the intensive treatment grew more efficiently than the rams in the extensive treatment.

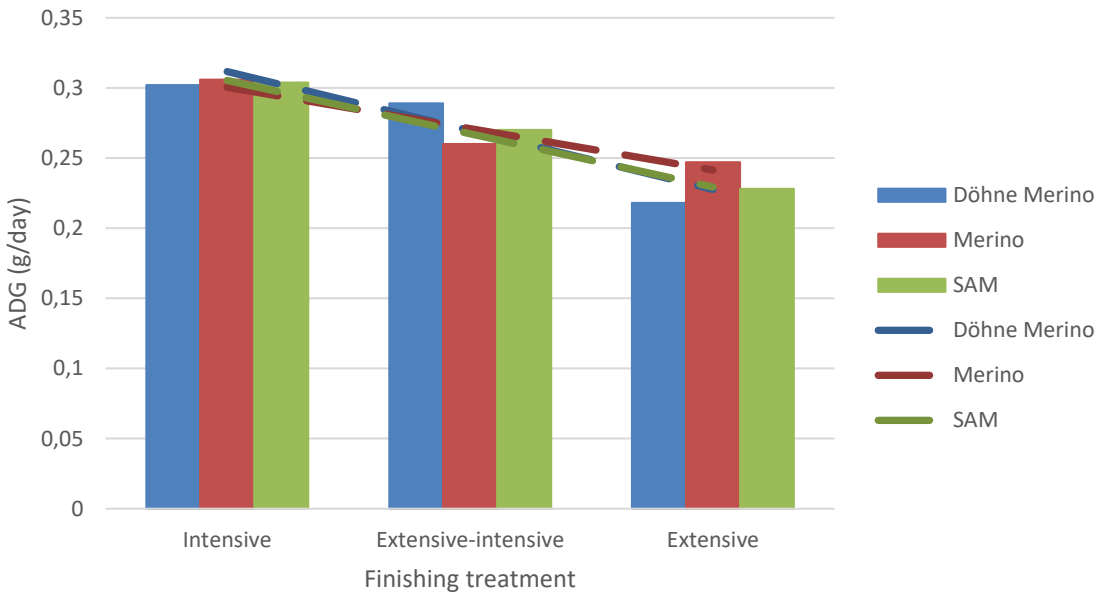


Figure 3.2 Average daily gains (ADG) data of Döhne Merino, Merino and South African Mutton Merino (SAM) rams following either an extensive, extensive-intensive, or intensive treatment. (Dotted lines indicate trends for feeding treatments)

In the extensive-intensive treatment, the SAM and Döhne Merino rams recorded heavier final body weights ($P < 0.05$ for SAM), better ADG and gained more weight than the Merino rams. The Merino rams were probably more mature once they received the improved diet and most of their skeletal and tissue growth had already occurred. The Döhne Merino and SAM rams benefitted more from this treatment than the Merino rams.

All three breeds differed between all three treatments for Kleiber index ($P < 0.05$). As the nutritional value of the grass was most possibly poorer than the concentrate feed, the extensively kept rams would have had to consume more to meet maintenance, growth and wool growth requirements. The extensively kept rams thus grew less efficiently, which is supported by the low Kleiber indexes shown in Figure 3.3. It is possible that all three breeds had poorer feed conversion ratios (FCR). The highest values were reported for rams in the intensive treatment, which received a concentrate diet from after weaning. This diet was high in energy and protein, thus possibly a far better quality than the grass consumed by the extensively kept rams. The growth efficiency and expected feed conversion rate improved as the diets of the treatments improved. This is supported by Vermorel & Bickel (1980) and Meissner (1983).

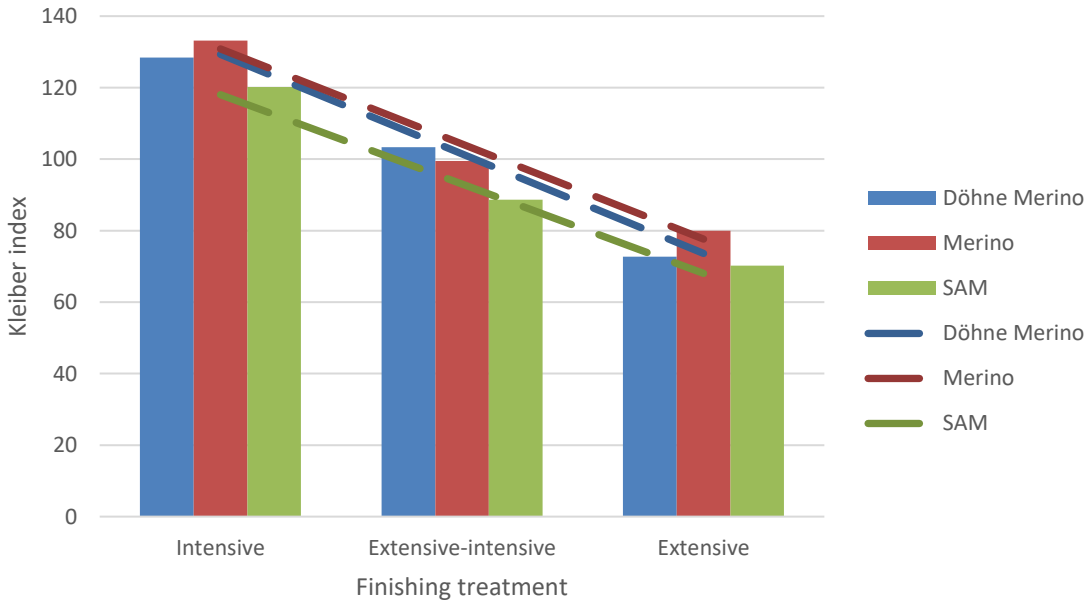


Figure 3.3 Kleiber index data of Döhne Merino, Merino and South African Mutton Merino (SAM) rams following either an extensive, extensive-intensive, or intensive treatment. (Dotted lines indicate trends for feeding treatments)

Differences in Kleiber index were recorded between the Döhne Merino and SAM rams ($P < 0.001$ and $P < 0.05$ respectively) in the extensive-intensive treatment. The SAM rams had the lowest values in all three treatments (significantly so in the extensive-intensive treatment). Results for Kleiber indexes show that SAM rams had the lowest growth efficiency and, possibly, the lowest FCR of the three breeds. As previously stated, SAM rams possibly deposited more subcutaneous fat than the other breeds. This will be further discussed in

section 3.2. In the extensive-intensive treatment, the Döhne Merino rams grew the most efficiently. The Döhne Merino is classed as a wool and mutton type (Meissner, 1983) while the Merino breed is a wool type. Thus, although the Döhne Merino rams would have had higher daily maintenance requirements (as they are the larger breed) the efficiency of growth (k_g) is higher than the efficiency of wool production (k_w) (0.30 – 0.62 vs 0.20 – 0.25) (Lui & Masters, 2003; Regadas Filho *et al.*, 2011).

3.2 Anthropometric measurements

Variables included in this category were initial heart girth, final heart girth, gained heart girth, initial body length, final body length, gained body length, initial shoulder height, final shoulder height, gained shoulder height, initial hip height, final hip height, gained hip height, subcutaneous fat measurement taken at the 13th rib, carcass weight, carcass compactness, and carcass classification score. The rams were sheared at the beginning of the trial as well as at the end of each treatment – before final measurements were taken.

Overall finishing treatment effect: The rams were of a similar age, and were stratified according to weight and randomly allocated to finishing treatments. Heart girth and body length measurements did not differ between treatments at the beginning of the trial (as seen in Table 3.4). Small differences were noted in the initial shoulder heights between the extensive rams (53.7 ± 3.16cm) and the intensively kept rams (51.9 ± 2.72cm, $P < 0.05$), probably as randomisation was based on initial weight and not body measures.

Hearth girth, body length, and shoulder height measurements differed between the three finishing treatments at the end of the trial ($P < 0.001$). The intensive treatment had the lowest values and thus the least skeletal growth, while the extensive treatment had the highest values. This is contradictory to previous zooarchaeological evidence which showed that poorer nutrition resulted in smaller sheep (Davis, 1996). As with final weight, the reason that the rams in the extensive treatment had the highest values for final heart girth, body length and shoulder height, was because this treatment continued for a longer period than the other treatments. The final anthropometric measuring was done on older rams compared to the younger rams in the intensive and extensive-intensive treatments. The rams in the extensive treatment had more time to grow compared to the young rams in the intensive treatment. The increased skeletal growth also explains the heavier final weight seen in the extensively kept rams (Table 3.1).

Table 3.4 Effects of finishing treatment on anthropometric results ($\overline{\mathrm{X}} \pm \mathrm{SD}$) of Döhne Merino, Merino and South African Mutton Merino (SAM) rams following either an extensive, extensive-intensive, or intensive treatment

Variables ($\bar{X}$ ± SD)	**Finishing treatment**		
	Intensive (n = 30)	**Extensive-Intensive** (n = 29)	**Extensive** (n = 29)
HG_I (cm)	77.3 ± 4.71	76.3 ± 5.76	76.1 ± 4.18
HG_F (cm)	92.0 ± 3.97[a]	100.6 ± 5.00[b]	107.3 ± 4.09[c]
HG_G (cm)	14.7 ± 2.29[a]	24.3 ± 3.69[b]	31.2 ± 3.57[c]
BL_I (cm)	59.6 ± 3.43	58.9 ± 4.11	58.7 ± 4.43
BL_F (cm)	69.9 ± 3.39[a]	72.6 ± 3.49[b]	75.2 ± 2.80[c]
BL_G (cm)	10.3 ± 3.05[a]	13.7 ± 3.01[b]	16.5 ± 4.62[c]
SH_I (cm)	53.7 ± 3.16[a]	52.6 ± 3.52[ab]	51.9 ± 2.72[b]
SH_F (cm)	60.3 ± 2.70[a]	62.5 ± 2.82[b]	65.0 ± 2.16[c]
SH_G (cm)	6.6 ± 1.95[a]	9.9 ± 2.57[b]	13.1 ± 2.77[c]
HH_I (cm)	52.6 ± 2.89	51.2 ± 3.32	51.1 ± 2.46
HH_F (cm)	61.4 ± 3.42[a]	62.8 ± 2.66[a]	64.7 ± 2.96[b]
HH_G (cm)	8.8 ± 2.09[a]	11.6 ± 3.13[b]	13.6 ± 3.65[c]
Subcut fat (cm)	1.1 ± 0.21[a]	1.9 ± 0.40[b]	2.0 ± 0.45[b]
Carcass weight (kg)	27.0 ± 3.90[a]	33.3 ± 4.97[b]	38.7 ± 4.90[c]
Carcass comp (kg/cm)	0.39 ± 0.045[a]	0.46 ± 0.054[b]	0.52 ± 0.055[c]
CCS (A category)	2 ± 0.4[a]	2 ± 0.5[a]	4 ± 1.0[b]

[a, b, c] Means with different superscripts, within a row, differ significantly ($P < 0.05$)
$\bar{X}$ ± SD – Mean ± Standard deviation
HG_I – Initial heart girth; HG_F – Final heart girth; HG_G – Gained heart girth; BL_I – Initial body length; BL_F – Final body length; BL_G – Gained body length; SH_I – Initial shoulder height; SH_F – Final shoulder height; SH_G – Gained shoulder height; HH_I – Initial hip height; HH_F – Final hip height; HH_G – Gained hip height; Subcut fat – Subcutaneous fat (taken at the 13th rib); Carcass comp – Carcass compactness; CCS – carcass classification score

Measurements of subcutaneous fat (taken at the 13th rib) was recorded. Growth curves show that adipose tissue is the last body component to develop and is considered “primarily a tissue of maturity” which is used to store excess energy in the form of fat (Batt, 1980; Hammond, 1955; Hossner, 2005). The rams from the extensive-intensive and extensive treatments had

thicker subcutaneous fat layers ($P < 0.001$) (1.9 ± 0.40cm and 2.0 ± 0.45cm respectively) compared to rams in the intensive treatment (1.1 ± 0.21cm). The intensively fed rams had less ($P < 0.001$) subcutaneous fat, indicating that energy utilization in this group was mainly for protein deposition – the rams in this treatment had not yet reached their fattening phase and were thus still physiologically relatively young animals. These animals had high growth requirements, and the concentrate diet was not fed for a long enough period to exceed the animals' nutrient requirements and cause excess fat accretion. The higher protein content of the diet stimulated the growth hormone cascade, thus preventing excessive lipogenesis. The fattening of rams in the extensive-intensive treatment at a physiologically more mature age resulted in a faster shift from protein to fat accretion with thicker subcutaneous fat layers. As the extensive treatment rams had less protein in their diet, the growth hormone cascade was probably not as strongly stimulated compared to the other treatments which had higher protein diets. This resulted in slower growth of the extensive treatment rams, which in turn caused earlier fat deposition. These extensive treatment rams were also dissected at an older age compared to the intensive treatment rams, which further explains why the extensive treatment rams had thicker ($P < 0.05$) subcutaneous fat than the intensive treatment rams.

Carcass weight and carcass compactness differed between all three finishing treatments. As expected, the extensive treatment had the heaviest carcass weight of 38.7 ± 4.90kg ($P < 0.001$), the extensive-intensive treatment followed closely with a carcass weight of 33.3 ± 4.97kg ($P < 0.001$) and the lightest rams were in the intensive treatment, 27.0 ± 3.90kg ($P < 0.001$). Carcass compactness was calculated by dividing warm carcass weight by final body length. This measure was used to determine how sturdy the animals were. Intensively finished rams had the lowest value while the rams in the extensive treatment were sturdier. The intensive treatment had shorter ($P < 0.05$) body lengths as well as lower carcass weights compared with the other two finishing treatments. Even though the rams in the intensive treatment received a concentrate diet, the treatment was short and the rams too young when they were measured, thus they did not grow to their full genetic potential compared to those in the extensive treatments. Although the extensive treatment was on rangeland, the treatment period was longer than the other treatments, and the rams on the lower plane of nutrition had a longer growth period which agrees with the results of Popkin *et al.* (2012).

Overall breed effects: The initial measurements for hip height, shoulder height and heart girth differed between the Döhne Merino and SAM breeds ($P < 0.001$), and between the Merino and SAM breeds ($P < 0.001$) (Table 3.5), with highest values recorded for the SAM rams. Döhne Merino and Merino rams had very similar measurements for shoulder height and hip height, but Döhne Merino rams had a slightly larger heart girth than Merino rams. Initial body length differed ($P < 0.001$) between all three breeds. SAM rams had the longest body

length (62.8 ± 3.39cm, P < 0.001) and Merino rams had the shortest measurements (56.0 ± 2.70cm). Since all rams were of a similar age, the current results show that SAM rams have a larger frame size than the Döhne Merino and Merino rams, while the Döhne Merino rams had a slightly longer body than the Merino rams, but they were of similar height.

Table 3.5 Effects of breed on anthropometric results ($\overline{X} \pm SD$) of Döhne Merino, Merino and South African Mutton Merino (SAM) rams

Variables ($\bar{X}$ ± SD)	**Breed**		
	Döhne (n = 30)	**Merino** (n = 31)	**SAM** (n = 27)
HG_I (cm)	75.3 ± 2.53[a]	73.9 ± 4.95[a]	81.1 ± 3.61[b]
HG_F (cm)	99.7 ± 7.16[a]	97.5 ± 7.25[b]	102.9 ± 7.93[c]
HG_G (cm)	24.4 ± 6.74[a]	23.6 ± 7.86[ab]	21.8 ± 7.96[b]
BL_I (cm)	58.7 ± 2.54[a]	56.0 ± 2.70[b]	62.8 ± 3.39[c]
BL_F (cm)	71.7 ± 3.45[a]	71.6 ± 4.14[a]	74.6 ± 3.31[b]
BL_G (cm)	13.0 ± 4.09[a]	15.5 ± 4.93[b]	11.7 ± 3.11[a]
SH_I (cm)	51.6 ± 2.65[a]	51.7 ± 3.31[a]	55.2 ± 2.26[b]
SH_F (cm)	62.5 ± 3.00[a]	61.2 ± 3.06[a]	64.1 ± 2.95[b]
SH_G (cm)	10.9 ± 3.79[a]	9.5 ± 3.87[b]	9.0 ± 2.84[b]
HH_I (cm)	51.0 ± 2.35[a]	50.4 ± 3.25[a]	53.8 ± 1.88[b]
HH_F (cm)	62.6 ± 3.46[ab]	62.2 ± 3.43[a]	64.2 ± 2.67[b]
HH_G (cm)	11.6 ± 3.88	11.8 ± 3.48	10.4 ± 3.38
Subcut fat (cm)	1.6 ± 0.42[a]	1.5 ± 0.42[a]	1.8 ± 0.75[b]
Carcass weight (kg)	31.8 ± 5.09[a]	30.0 ± 5.78[a]	37.6 ± 6.83[b]
Carcass comp (kg/cm)	0.44 ± 0.060[a]	0.42 ± 0.060[b]	0.50 ± 0.077[c]
CCS (A category)	3 ± 1.1	3 ± 1.0	3 ± 1.1

[a, b, c] Means with different superscripts, within a row, differ significantly (P < 0.05)

$\bar{X}$ ± SD – Mean ± Standard deviation

HG_I – Initial heart girth; HG_F – Final heart girth; HG_G – Gained heart girth; BL_I – Initial body length; BL_F – Final body length; BL_G – Gained body length; SH_I – Initial shoulder height; SH_F – Final shoulder height; SH_G – Gained shoulder height; HH_I – Initial hip height; HH_F – Final hip height; HH_G – Gained hip height; Subcut fat – Subcutaneous fat (taken at the 13th rib); Carcass comp – Carcass compactness; CCS – carcass classification score

The results for final heart girth differed ($P < 0.05$) between all three breeds, with smallest measurements being for Merino rams (97.5 ± 7.25cm), followed by the Döhne Merino rams (99.7 ± 7.16cm) and SAM rams (102.9 ± 7.93cm). Final body length and shoulder height measurements differed between Döhne Merino rams and SAM rams ($P < 0.001$ and $P < 0.05$ respectively), and between Merino rams and SAM rams ($P < 0.001$). SAM rams had the longest body lengths, as well as the highest shoulder heights, while the Döhne Merino rams and Merino rams were very similar in body length, as well as in height. In terms of final hip height, small differences ($P < 0.05$) were observed between the Merino rams and the SAM rams, with the latter being larger. These results support the claim that the SAM breed has a larger frame size than the Merino and Döhne Merino breeds. It would also explain why the SAM rams had heavier carcass weight (37.6 ± 6.83kg, $P < 0.05$) compared with both the Döhne Merino rams (31.8 ± 5.09kg) and Merino rams (30.0 ± 5.78kg). Subcutaneous fat thickness of both the Döhne Merino rams and the Merino rams differed ($P < 0.05$) from the subcutaneous fat thickness of the SAM rams. SAM rams had the thickest subcutaneous fat layer ($P < 0.05$). This explains and supports the low Kleiber index ($P < 0.05$) of the SAM rams.

Carcass compactness differed between all three breeds; Merino rams had the lowest ratio, while the SAM rams had the highest ratio ($P < 0.05$). These results show that the SAM breed is a sturdier, bulkier breed than the other two breeds. Although the Merino rams were the least compact and delivered the lightest carcasses, they also deposited the least amount of fat.

Finishing treatment x breed interaction effects: The following variables had significant treatment x breed interactions: final body length, gained body length, and subcutaneous fat. The initial measurements of heart girth, body length, shoulder height, and hip height (Tables 3.6 and 3.7) did not differ between the finishing treatments within each breed. There were differences for all four these variables between breeds within a finishing treatment. In all the cases where there were differences between breeds within a finishing treatment, the Merino and Döhne Merino breeds were smaller ($P < 0.05$) than the SAM breed. In the extensive-intensive treatment, there were differences in final heart girth ($P < 0.001$), final body length ($P < 0.001$) and final shoulder height ($P < 0.05$) between Merino rams and SAM rams. In the extensive treatment, differences were only noted for final heart girth ($P < 0.01$) between Merino and SAM rams, with the latter being larger.

Hammond (1955) stated that there are two growth wave sequences involved in animal development. The primary wave starts at the head and continues down the trunk of the body while secondary waves start at the limb extremities and travel dorsally. These waves meet at the junction of the last rib and loin area – the final region of the animal to develop. This is clearly illustrated in Figure 1.4 which was adapted from Hammond (1955); the different growth

rates of tissues, as well as the sequence in which tissues develop, is shown. This is called “centripetal” growth or “centre-seeking” growth. Besides the growth from the extremities to the centre of the body, there are also growth waves along the vertebral column, moving from the posterior to the anterior of the animal (Dikeman & Devine, 2014).

These growth wave sequences explain the body length, heart girth, hip height and shoulder height results obtained from the Döhne Merino rams in the different finishing treatments. Within the Döhne Merino breed, final heart girth and final body length measurements differed between the extensive treatment and the intensive treatment ($P < 0.001$), as well as between the intensive treatment and the extensive-intensive treatment ($P < 0.001$). In both cases, the Döhne Merino rams in the intensive treatment were smaller than the Döhne Merino rams in the extensive and extensive-intensive treatments. Because the centre of the body is the last region to develop, and the growth wave moves from the posterior to the anterior area of the animal, the body length and heart girth results of the Döhne Merino differed ($P < 0.05$) between the intensive group and the extensive-intensive treatment, but not between the extensive-intensive and extensive treatments. Thus, although the extensive-intensive Döhne Merino rams were two months older than the intensive Döhne Merino rams when they first received the improved diet, these animals were not finished growing in length and girth, and so the diet could still improve hearth girth and body length growth.

As for final shoulder height and final hip height, there were only differences ($P < 0.05$) between the extensive treatment Döhne Merino rams (65.2 ± 1.40cm and 64.9 ± 2.81cm respectively) and the intensive treatment Döhne Merino rams (59.9 ± 3.14cm and 60.0 ± 3.30cm respectively). The Döhne Merino rams in the intensive treatment were fed the concentrate diet from five-months of age when, according to Popkin *et al.* (2012), the radius, tibia and humerus would not be 100% fused. This concentrate diet increased the rate of skeletal growth. In the extensive-intensive treatment the rams were approximately seven-months old when they received the concentrate diet. The radius, tibia and humerus were probably almost completed ossified at that time, so the concentrate diet contributed more to muscle tissue growth rather than skeletal growth. Although higher levels of nutrition increase growth rate, it also advances fusion of epiphyseal plates thus reducing the duration of the growth period (Popkin *et al.*, 2012). The duration of the fusion process, and thus the growth process, is longer and slower in animals on a low plane on nutrition. That is why the Döhne Merino rams in the extensive treatment, whose treatment duration was the longest, were only slightly larger than the Döhne Merino rams in the extensive-intensive treatment and significantly larger than the Döhne Merino rams in the intensive treatment.

Further, the rams in the intensive treatment were *ca.* two-months younger than the extensive-intensive treatment rams and *ca.* four-months younger than the rams in the extensive treatment. Thus the rams in the extensive and extensive-intensive treatments were given more time to grow and were closer to mature size by the time of their last measurements compared with the rams in the intensive treatment.

A similar trend was seen for shoulder height results in both the Merino breed and the SAM breed. Within both these breeds the only differences ($P < 0.50$) in shoulder height were between the extensive treatment rams and the intensive treatment rams.

There were strong positive correlations between initial heart girth (HG_I) and final weight ($r = 0.71$, $P < 0.05$), ADG ($r = 0.71$, $P < 0.05$), and carcass weight ($r = 0.72$, $P < 0.05$) in the intensive treatment Döhne Merino rams. In the extensive treatment there were also positive correlations between initial heart girth and final weight ($r = 0.67$, $P < 0.05$), and ADG ($r = 0.67$, $P < 0.05$). One can thus already determine which extensively and intensively kept Döhne Merino rams have the potential to grow well. Initial shoulder heights of the extensive treatment Döhne Merinos had a strong negative correlation with subcutaneous fat ($r = -0.77$, $P < 0.05$). The implication is that shorter, stocky ram types tend to be earlier maturing, while the taller types are slightly later maturing.

Table 3.3 and Table 3.6 illustrate that the older Döhne Merino rams in the extensive treatment had very similar body lengths to the slightly younger extensive-intensive treatment rams (73.5 ± 1.72cm and 72.9 ± 3.0cm respectively, Table 3.6). The rams in the extensive treatment were heavier than the extensive-intensive treatment (72.5 ± 4.08kg and 66.0 ± 3.02kg respectively, Table 3.3). The concentrate diet improved both final body length and final weight of the extensive-intensive treatment Döhne Merino rams, but it appears that the concentrate diet contributed more to final body length than weight. In other words, increased body length growth occurred, but, due to time constraints, not as much body weight was gained.

In the Merino breed, there was only a difference in shoulder height between the extensive treatment and the intensive treatment. As the Merino tends to be the earlier maturing breed of the three breeds, the feed fed to the seven-month-old extensive-intensive treatment rams occurred too late to accelerate the growth of the possibly already fused radius, tibia and humerus, as previously explained by Popkin *et al.* (2012). In the intensively maintained Merino group, initial shoulder height had strong positive correlations with final body weight ($r = 0.76$, $P < 0.05$) and ADG ($r = 0.76$, $P < 0.05$). This is helpful when selecting lambs for growth, as these lambs will grow well in intensive feeding systems.

Table 3.6 Effects of finishing treatment and breed on anthropometric results ($\overline{X} \pm SD$) of Döhne Merino, Merino and South African Mutton Merino (SAM) rams following either an extensive, extensive-intensive, or intensive treatment

Factors		Variables ($\bar{X}$ ± SD)								
Finishing treatment	**Breed**	**HG_I** (cm)	**HG_F** (cm)	**HG_G** (cm)	**BL_I** (cm)	**BL_F** (cm)	**BL_G** (cm)	**SH_I** (cm)	**SH_F** (cm)	**SH_G** (cm)
Intensive	**Döhne** (n = 10)	75.4 ± 2.51	91.2 ± 2.44^{A}	15.8 ± 1.58^{A}	59.5 ± 2.51$_{ab}$	68.7 ± 3.34^{A}	9.3 ± 3.30^{A}	52.9 ± 3.70	59.9 ± 3.14^{A}	7.1 ± 2.72^{A}
	Merino (n = 10)	75.8 ± 5.23	90.3 ± 4.40^{A}	14.5 ± 2.31^{A}	57.1 ± 3.07$_{a}$	68.7 ± 2.71^{A}	11.6 ± 3.31^{A}	52.9 ± 2.69	59.0 ± 1.70^{A}	6.1 ± 1.29^{A}
	SAM (n = 10)	80.5 ± 4.49	94.4 ± 3.89^{A}	13.9 ± 2.64^{A}	62.2 ± 2.81$_{b}$	72.3 ± 2.98	10.2 ± 2.24	55.3 ± 2.63	61.9 ± 2.42^{A}	6.6 ± 1.65^{A}
Extensive -Intensive	**Döhne** (n = 10)	74.7 ± 3.17$_{a}$	101.3 ± 4.11$^{B}{}_{ab}$	26.6 ± 2.58$^{B}{}_{a}$	58.5 ± 2.83$_{a}$	72.9 ± 3.00$^{B}{}_{ab}$	14.4 ± 2.94^{B}	51.3 ± 1.32$_{a}$	62.5 ± 1.27$_{ab}$	11.3 ± 1.65^{B}
	Merino (n = 10)	72.2 ± 4.74$_{a}$	96.4 ± 3.78$^{B}{}_{a}$	24.3 ± 3.83$^{B}{}_{ab}$	55.7 ± 2.75$_{a}$	69.6 ± 2.46$^{A}{}_{a}$	14.0 ± 3.40^{A}	51.2 ± 4.18$_{a}$	60.7 ± 3.20$_{a}$	9.6 ± 3.57^{AB}
	SAM (n = 9)	82.7 ± 3.03$_{b}$	104.4 ± 3.61$^{B}{}_{b}$	21.8 ± 3.14$^{B}{}_{b}$	62.9 ± 3.20$_{b}$	75.6 ± 2.13$_{b}$	12.7 ± 2.65	55.8 ± 2.32$_{b}$	64.4 ± 2.51$_{b}$	8.7 ± 1.25^{AB}
Extensive	**Döhne** (n = 10)	75.7 ± 1.92$_{ab}$	106.5 ± 2.76$^{B}{}_{ab}$	30.8 ± 2.02^{B}	58.3 ± 2.36$_{a}$	73.5 ± 1.72^{B}	15.3 ± 3.32$^{B}{}_{a}$	50.7 ± 2.10	65.2 ± 1.40^{B}	14.5 ± 2.26^{B}
	Merino (n = 11)	73.7 ± 4.66$_{a}$	104.9 ± 3.73$^{C}{}_{a}$	31.2 ± 4.45^{C}	55.4 ± 2.21$_{a}$	75.9 ± 2.55^{B}	20.5 ± 2.76$^{B}{}_{b}$	51.2 ± 2.93	63.6 ± 2.16^{B}	12.5 ± 3.30^{B}
	SAM (n = 8)	80.1 ± 2.64$_{b}$	111.6 ± 2.45$^{C}{}_{b}$	31.6 ± 4.13^{C}	63.6 ± 4.41$_{b}$	76.3 ± 3.49	12.6 ± 4.00$_{a}$	54.3 ± 1.58	66.5 ± 2.00^{B}	12.3 ± 2.05^{B}

$^{A, B, C}$ Different superscripts in the same column within a breed differ significantly ($P < 0.05$)

$_{a, b}$ Different subscripts in the same column within a treatment differ significantly ($P < 0.05$)

$\bar{X}$ ± SD – Mean ± Standard deviation

HG_I – Initial heart girth; HG_F – Final heart girth; HG_G – Gained heart girth; BL_I – Initial body length; BL_F – Final body length; BL_G – Gained body length; SH_I – Initial shoulder height; SH_F – Final shoulder height; SH_G – Gained shoulder height

Table 3.7 Effects of finishing treatment and breed on anthropometric results ($\bar{X} \pm SD$) of Döhne Merino, Merino and South African Mutton Merino (SAM) rams following either an extensive, extensive-intensive, or intensive treatment

Factors		Variables ($\bar{X}$ ± SD)						
Finishing treatment	**Breed**	**HH_I** (cm)	**HH_F** (cm)	**HH_G** (cm)	**Subcut fat** (cm)	**Carcass weight** (kg)	**Carcass comp** (kg/cm)	**CCS** (A category)
Intensive	**Döhne** (n = 10)	51.6 ± 2.77	60.0 ± 3.30^{A}	8.5 ± 1.42^{A}	1.1 ± 0.13^{A}	26.0 ± 2.76$^{A}_{a}$	0.38 ± 0.037$^{A}_{ab}$	2 ± 0.4^{A}
	Merino (n = 10)	51.6 ± 3.20	60.9 ± 3.90	9.4 ± 2.24	1.1 ± 0.24^{A}	24.4 ± 3.46$^{A}_{a}$	0.36 ± 0.044$^{A}_{a}$	2 ± 0.3^{A}
	SAM (n = 10)	54.7 ± 1.27	63.2 ± 2.35	8.5 ± 2.54^{A}	1.0 ± 0.23^{A}	30.4 ± 2.77$^{A}_{b}$	0.42 ± 0.027$^{A}_{b}$	2 ± 0.3^{A}
Extensive-Intensive	**Döhne** (n = 10)	50.6 ± 2.28$_{ab}$	62.9 ± 2.51^{AB}	12.3 ± 3.29^{AB}	1.8 ± 0.11$^{B}_{ab}$	32.1 ± 0.92$^{B}_{a}$	0.44 ± 0.024$^{B}_{a}$	2 ± 0.5^{A}
	Merino (n = 10)	49.2 ± 3.52$_{a}$	62.0 ± 3.06	12.8 ± 3.16	1.5 ± 0.19$^{AB}_{a}$	29.1 ± 3.35$^{B}_{a}$	0.42 ± 0.036$^{B}_{a}$	2 ± 0.3^{A}
	SAM (n = 9)	54.1 ± 1.92$_{b}$	63.6 ± 2.35	9.4 ± 1.83^{AB}	2.2 ± 0.46$^{B}_{b}$	39.2 ± 3.12$^{B}_{b}$	0.52 ± 0.038$^{B}_{b}$	2 ± 0.5^{A}
Extensive	**Döhne** (n = 10)	50.8 ± 2.07	64.9 ± 2.81^{B}	14.2 ± 4.10^{B}	1.8 ± 0.36$^{B}_{a}$	37.3 ± 2.10$^{C}_{a}$	0.52 ± 0.022$^{C}_{a}$	4 ± 0.8^{B}
	Merino (n = 11)	50.4 ± 2.93	63.5 ± 3.11	13.1 ± 3.76	1.9 ± 0.36$^{B}_{ab}$	35.8 ± 3.21$^{C}_{a}$	0.47 ± 0.029$^{C}_{a}$	4 ± 1.0^{B}
	SAM (n = 8)	52.4 ± 1.84	66.3 ± 2.43	13.8 ± 3.25^{B}	2.4 ± 0.47$^{B}_{b}$	44.6 ± 4.43$^{C}_{b}$	0.58 ± 0.042$^{C}_{b}$	4 ± 1.1^{B}

$^{A, B, C}$ Different superscripts in the same column within a breed differ significantly ($P < 0.05$)

$_{a, b}$ Different subscripts in the same column within a treatment differ significantly ($P < 0.05$)

$\bar{X}$ ± SD – Mean ± Standard deviation

HH_I – Initial hip height; HH_F – Final hip height; HH_G – Gained hip height; Subcut fat – Subcutaneous fat (taken at the 13th rib); Carcass comp – Carcass compactness; CCS – carcass classification score

Differences in body length between the older extensive treatment and younger intensive treatment Merino rams, and between the extensive-intensive and extensive treatments, were significant ($P < 0.001$). While no difference ($P > 0.05$) in body length was recorded between the younger intensive and slightly older extensive-intensive treatments. Growth in body length may have slowed down or ceased by the time the early maturing Merino rams in the extensive-intensive treatment finally received the concentrate feed. When fed a concentrate feed from a younger age, it seems growth in body length was better which would explain why there was no difference between the younger intensive treatment and the slightly older extensive-intensive treatment Merino rams. Thus, Merino rams may be slightly earlier maturing. This is clearly illustrated in Figure 3.4. Merino rams in the extensive treatment were not much smaller (75.9 ± 2.55cm) than the SAM rams (76.3 ± 3.49cm) and narrowly outperformed the Döhne Merino rams (73.5 ± 1.72cm) (but not significantly in either cases) as can be seen in Figure 3.4. As for the final heart girth results of the Merino, there were differences ($P < 0.05$) between Merino rams in all three finishing treatments. This is understandable, the centre of the body is the last region to develop. Thus, although the Merino ram is an earlier maturing breed, feeding the rams at an older age (such as the case with the extensive-intensive rams) did increase heart girth growth. While feeding the rams for longer (such as in the extensive treatment) allowed for more growth to occur.

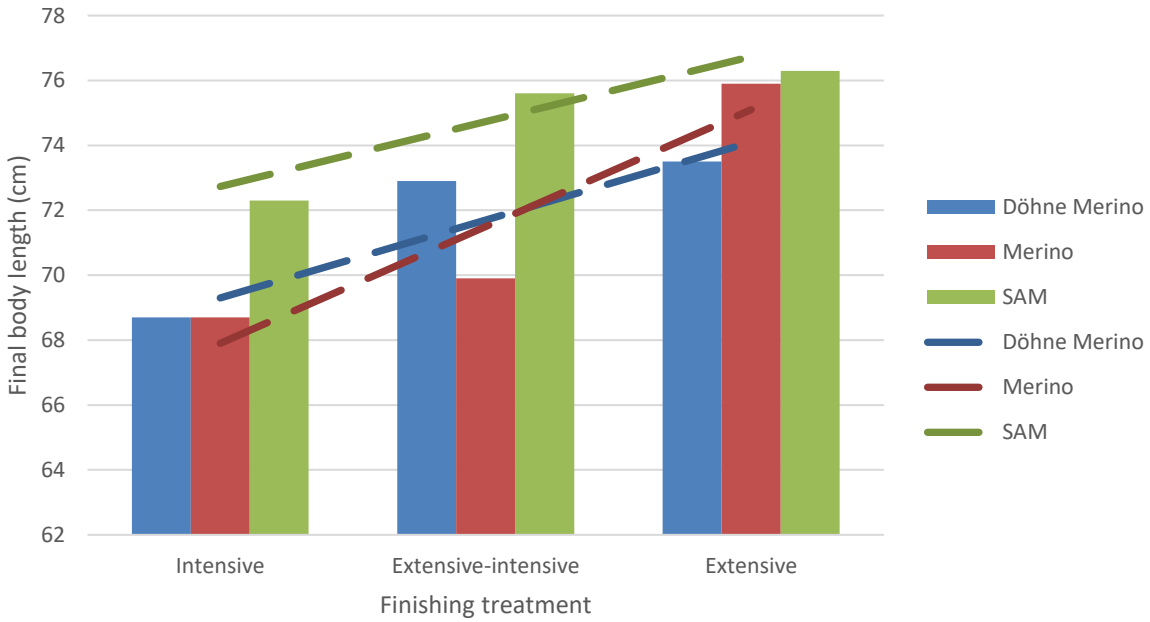


Figure 3.4 Final body length data of the Döhne Merino, Merino and South African Mutton Merino (SAM) rams following either an extensive, extensive-intensive, or intensive treatment. (Dotted lines indicate trends for feeding treatments)

As mentioned before, the heart girth area is one of the last areas of the body to develop. The SAM breed also tends to be a later maturing breed, which supports the differences ($P < 0.05$) observed in heart girth between all three finishing treatments (Table 3.6). It is interesting to note that, although the SAM breed tends to be later maturing, there was no difference ($P > 0.05$) in final body length between the three treatments. Body length is an area which should reach mature size at a later stage than body height. Yet the extensive-intensive treatment SAM rams were not significantly longer than the extensively kept SAM rams, nor were the intensive treatment SAM rams shorter. The SAM breed is described as a long-bodied breed. When referring to Table 3.6, one can see that the SAM breed's initial body length is already quite long compared with the other two breeds. When considering Table 3.6, it clearly shows how there was very little body length gain in the SAM breed. In fact, the SAM rams in all three finishing treatments gained a similar amount, while both other breeds had significantly better body length gains in the longer duration finishing treatments. Thus, although the rams in all three breeds in each finishing treatment had very similar final body length results, the SAM rams were already longer than the other breeds at the onset of each treatment.

The thickness of the subcutaneous fat layer of the rams increased as the length of the different treatments increased. Thus, the lowest values were those of younger rams in the intensive treatment and the highest values were those of the older rams which were in the extensive treatments. In the SAM rams and Döhne Merino rams there were differences in subcutaneous fat thickness between the intensive treatments and the extensive-intensive treatments ($P < 0.001$ for both breeds) and differences between extensive treatments and intensive treatments ($P < 0.001$ for both breeds). The intensive SAM rams had an average fat layer thickness of 1.0 ± 0.23cm and the extensive-intensive SAM rams averaged 2.2 ± 0.46cm ($P < 0.001$). This explains and supports the low Kleiber index values ($P < 0.05$) of the SAM rams in these treatments. Although there was a difference in subcutaneous fat between these two groups, there was no difference in carcass classification score.

Fat deposition appears to be breed specific and the SAM breed tends to deposit more fat subcutaneously. The same can be hypothesised for the medium-maturing Döhne Merino rams that showed a difference ($P < 0.001$) between the intensive and extensive-intensive treatment for subcutaneous fat, but not for carcass classification score. Both the SAM rams and the Döhne Merino rams in the extensive-intensive treatment were nearing 68% of their mature weight – these rams were thus nearing the rapid fattening stage (Warren, 1979). The rams were also older than their intensive treatment counterparts. This may explain why these rams had thicker ($P < 0.001$) subcutaneous fat layers. The Döhne Merino and SAM rams in the extensive treatment were older than the rams in the intensive treatment and had reached (or, in the case of the SAM rams, was close to) 68% of their mature weight, which explains the

difference ($P < 0.001$) in subcutaneous fat thickness. Subcutaneous fat being more sensitive to the plane of the diet, thus the lower plane of diet of the extensive treatment may have resulted in less subcutaneous fat to be deposited.

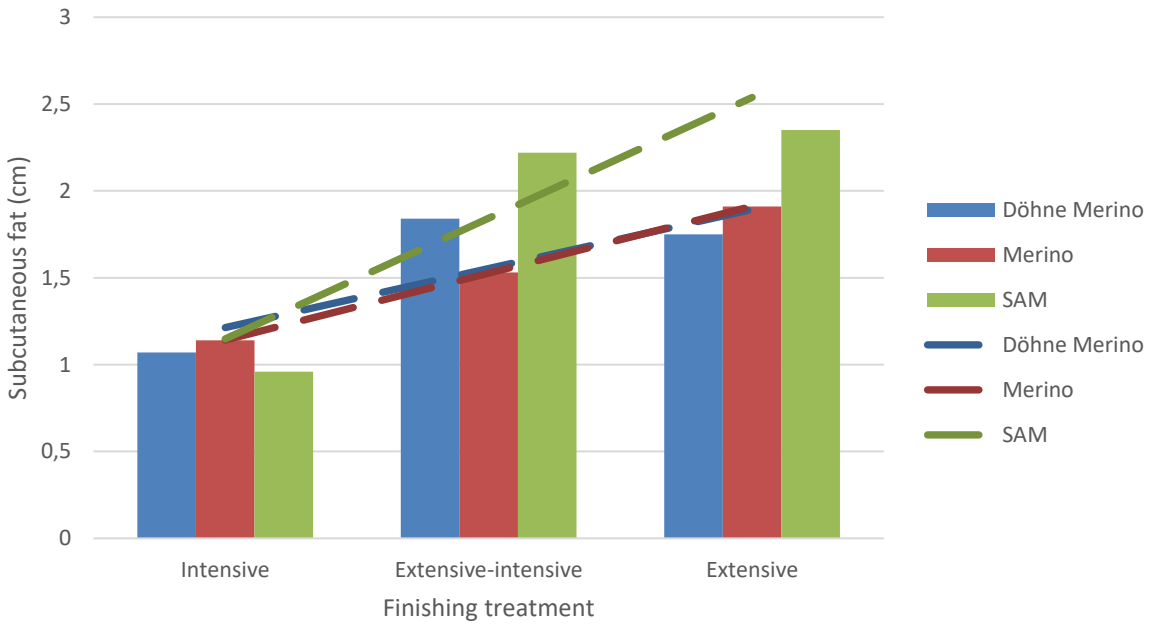


Figure 3.5 Subcutaneous fat data of the Döhne Merino, Merino and South African Mutton Merino (SAM) rams following either an extensive, extensive-intensive or intensive treatment. (Dotted lines indicate trends for feeding treatments)

One should not assume that the Merino breed is later maturing when studying Figure 3.5, just because the breed deposited the least amount of subcutaneous fat during the extensive-intensive treatment period. The Merino breed has been intensively selected and bred for wool production, which has caused the breed to have high wool growth nutrient requirements – adding to the rams' total nutritional requirements. Although the seven-month-old Merino rams were more mature by the time they started to receive the improved diet (evident by the difference in body length gain between the extensive-intensive treatment rams and the intensive treatment rams), they did not deposit more fat than the other two breeds. The improved nutrition was probably used to meet the added wool growth requirements. In the intensive treatment the rams received a high-quality diet from after weaning meaning that all the Merino rams' nutritional requirements were probably met. The only difference for subcutaneous fat thickness was between the intensive treatment and the extensive treatment

Merino rams ($P < 0.001$), which is explained by the more advanced age of the extensive treatment Merino group.

Warren (1979) reported that there was a steady increase in subcutaneous fat (as long as there was no weight loss due to poor diet), intermuscular fat and internal fat as rams aged. This explains why all three breeds in the extensive treatment had significantly higher carcass classification scores compared with their counterparts in the other two treatments.

Within all three breeds there were differences ($P < 0.05$) in carcass weight between the three finishing treatments. The rams of all three breeds in the intensive treatment had the lightest carcass weight, while the heaviest carcass weight was of the rams in the extensive treatment (these rams were the oldest of the treatments when they were slaughtered). In all three finishing treatments, the Döhne Merino and Merino rams recorded carcass weights significantly lighter to the carcass weight of the SAM rams. This was expected as the SAM breed is the largest of the three breeds, while the Merino breed is the smallest.

Carcass compactness values of SAM rams were significantly higher than the values of the Merino rams in all three finishing treatments ($P < 0.001$). In the extensive-intensive and extensive treatments, the SAM rams also had significantly higher carcass compactness values than the Döhne Merino rams ($P < 0.001$). These results are in line with the work done by Souza Júnior *et al.* (2013) who also found that the large framed Santa Inês lambs were more compact than the medium framed Santa Inês lambs. This again shows that the SAM breed has a larger frame size compared to the other two breeds, and that the SAM breed is a very sturdy breed. In each breed, the lowest carcass compactness values were for those younger rams in the intensive treatment, while the older extensive treatment rams had the highest values.

3.3 Scrotal measurements

The variables included in this category were initial scrotal circumference (SC_I), final scrotal circumference (SC_F), gained scrotal circumference (SC_G), scanned scrotal neck fat (SSNF), scrotal weight, scrotal fat weight (SFW), *Pampiniform venous plexus* circumference (PPC), testes weight, testes length, testes width, testes circumference, testes volume, effective *Pampiniform venous plexus* (PPC:SSNF), the ratio between *Pampiniform venous plexus* circumference to SFM (PPC:SFM), the ratio between *Pampiniform venous plexus* circumference and testes weight (PPC:TW), the ratio between effective *Pampiniform venous plexus* and testes weight (EffecPP:TW) and SFW as a percentage of testes volume. The rams were sheared at the beginning of the trial as well as at the end of each treatment – before the final measurements were taken.

Overall finishing treatment effect: Scrotal circumference was measured at the beginning of the study and the results showed no difference between the three treatments (Table 3.8). Measurements of scrotal circumference a week before slaughter of each respective treatment, differed between the extensive treatment (34.6 ± 2.81cm) compared to the intensive treatment (32.7 ± 2.49cm, $P < 0.05$). Dissection of the scrotum and testes revealed further differences ($P < 0.05$) in scrotal weight, PPC, testes weight, width, length, circumference and volume. For all these variables, the intensive treatment was significantly smaller/lighter than the extensive treatment. The longer duration of the extensive-intensive treatment resulted in heavier/larger scrotal weight ($P < 0.001$), PPC ($P < 0.001$), testes length ($P < 0.01$) and volume ($P < 0.05$) compared to the intensive treatment. Testes width ($P < 0.001$) and circumference ($P < 0.05$) were significantly smaller in the extensive-intensive treatment rams than the extensive rams.

Braden *et al.* (1974), Cameron *et al.* (1988), Hötzel *et al.* (1998), Kheradmand *et al.* (2006) and Martin *et al.* (2010) found that rams that received an improved diet had larger scrotal circumferences than the control rams. It is well established that nutrition influences testicular development (Setchell *et al.*, 1965; Cameron *et al.*, 1988; Hötzel *et al.*, 1998; Martin *et al.*, 2010) and that a diet high in protein and energy stimulates testicular growth and development (Braden *et al.*, 1974; Hötzel *et al.*, 1998). Treatment effects in the present study differ from the previous findings because this study simulated typical South African farm conditioning practices, which involved differences in the duration of treatments with subsequent effects on the age, weights of rams at slaughter, and season of slaughter.

Table 3.8 Effects of finishing treatment on scrotal results ($\overline{X} \pm SD$) of Döhne Merino, Merino and South African Mutton Merino (SAM) rams following either an extensive, extensive-intensive, or intensive treatment

Variables ($\bar{X}$ ± SD)	**Treatment group**		
	Intensive (n = 29)	**Extensive-intensive** (n = 30)	**Extensive** (n = 30)
SC_I (cm)	22.1 ± 2.98	21.8 ± 3.82	21.6 ± 3.45
SC_F (cm)	32.7 ± 2.49[a]	34.2 ± 2.39[ab]	34.6 ± 2.81[b]
SC_G (cm)	10.6 ± 2.63[a]	12.4 ± 4.85[ab]	13.0 ± 4.40[b]
SSNF (cm)	1.1 ± 0.22[a]	1.6 ± 0.24[b]	1.6 ± 0.33[b]
Scrotal weight (g)	620.3 ± 116.86[a]	833.3 ± 119.72[b]	854.1 ± 135.57[b]
Scrotal fat weight (g)	29.6 ± 8.26[a]	48.1 ± 15.91[b]	30.4 ± 12.23[a]
PPC (cm)	53.0 ± 6.36[a]	65.6 ± 8.17[b]	68.3 ± 6.70[b]
PPC:SSNF	51.7 ± 10.20[a]	41.4 ± 7.73[b]	44.6 ± 9.88[b]
PPC:SFM	1.9 ± 0.52[a]	1.6 ± 0.84[a]	2.8 ± 1.74[b]
PPC:TM	0.3 ± 0.06	0.3 ± 0.06	0.3 ± 0.07
EffecPPC:TM	0.3 ± 0.07[a]	0.2 ± 0.04[b]	0.2 ± 0.06[b]
Testes weight (g)	214.5 ± 45.08[a]	239.8 ± 36.70[ab]	258.0 ± 50.21[b]
Testes length (cm)	10.7 ± 0.82[a]	11.6 ± 0.72[b]	11.6 ± 1.35[b]
Testes width (cm)	6.6 ± 0.50[a]	6.8 ± 0.47[a]	7.4 ± 0.60[b]
Tescir (cm)	18.0 ± 1.47[a]	18.6 ± 2.38[a]	19.8 ± 1.50[b]
Testes volume (ml)	187.8 ± 39.95[a]	215.5 ± 31.08[b]	224.3 ± 57.34[b]
ScrFatWtTes (%)	16.5 ± 5.73[a]	22.5 ± 7.27[b]	15.0 ± 8.87[a]

[a, b] Means with different superscripts, within a row, differ significantly (P < 0.05)

$\bar{X}$ ± SD – Mean ± Standard deviation

SC_I – Initial scrotal circumference; SC_F – Final scrotal circumference; SC_G – Gained scrotal circumference; SSNF – Scanned scrotal neck fat; PPC – *Pampiniform venous plexus* circumference; PPC:SSNF – ratio of the *Pampiniform venous plexus* circumference to scanned scrotal neck fat (effective *Pampiniform venous plexus*); PPC:SFM – ratio of the *Pampiniform venous plexus* circumference to scrotal fat weight; PPC:TM – ratio of the *Pampiniform venous plexus* circumference to testes weight; EffecPPF:TM – ratio of the effective *Pampiniform venous plexus* to testes weight; Tescir – Testes circumference; ScrFatWtTes – Scrotal fat weight as a percentage of average testes volume

Salhab *et al.* (2001) found that the age of lambs significantly influenced testicular measurements. Thus, even though the rams in the intensive treatment received a concentrate diet from weaning onwards, the treatment period was relatively short (e.g. 70-77 days)

compared to the extensive treatment. These rams were still young when slaughtered and had not yet reached maturity. By contrast, the duration of the extensive treatment was 200 days long, which allowed those rams to be older, more mature and with better developed testes by the time they were slaughtered.

Al-Haboby *et al.* (1994) and Salhab *et al.* (2001) found that most testicular growth occurred from seven months of age onward, when the lambs had achieved a certain body weight. Results from the study of Elmaz *et al.* (2007), suggested that the rapid increase in testicular dimensions occurred when rams were four to five months of age, but also at a similar weight compared to those in the studies of Al-Haboby *et al.* (1994) and Salhab *et al.* (2001). This explains the second reason for the dissimilar results: weight of the rams. Salhab *et al.* (2001) showed that body weight significantly influenced testicular measurements (especially testes volume which increased three-fold compared to the increase in body weight), and that the correlations between body weight and testicular measurements were greater ($r = 0.61 - 0.91$, $P < 0.01$) than between age and testicular measurements ($r = 0.51 - 0.81$, $P < 0.01$). The rams in the intensive treatment were significantly lighter in body weight than those in the other two treatments which would explain their significantly smaller testicular measurements.

A third factor that contributed to variations in testicular measurements, was seasonal differences between the intensive treatment versus the extensive treatment (Pelletier & Almeida, 1987; Schoeman & Combrink,1987; Webb *et al.*, 2004; Sarlós *et al.*, 2013). In order to quantify this factor in the present study, season was included as a random factor in the analysis of variance procedures. Thus, although the photoperiod effect is not as strong in southern hemisphere rams (Hafez, 1952; Martin *et al.*, 1999; Blache *et al.*, 2002), possibly due to the small variations in day:night ratio between summer and winter, the rams were still slaughtered during different seasons. The rams in the intensive and extensive-intensive treatments were slaughtered during summer, while the extensive treatment rams were slaughtered during autumn. Apart from SC_F, the other testicular variables were significantly influenced by season. The movement into autumn would have stimulated further gonadal development in the extensive treatment rams. Similar findings were recorded in the studies of Pelletier & Almeida (1987), Schoeman & Combrink (1987), Webb *et al.* (2004) and Sarlós *et al.* (2013). The rams of the extensive treatment would have ultimately benefitted from plentiful, nutritious summer pastures for the entirety of summer. Thus, although the intensive treatment rams were fed a concentrate diet, the extensive treatment rams were both older than the intensive treatment rams and were slaughtered during a season which stimulated testicular development. The extensive-intensive treatment rams were younger than the extensive treatment rams and were slaughtered during a season where further testicular development was slowly being initiated – yet only testes width and circumference differed between these

two treatments. The concentrate diet fed to the extensive-intensive treatment rams, helped improve gonadal development. This shows that nutrition still had a more significant influence on ram fertility than season as stated by Martin *et al.* (1999).

A number of researchers (Oldham *et al.*, 1978; Hötzel *et al.*, 1998; Fernandez *et al.,* 2004; Kheradmand *et al.*, 2006) have confirmed that the increase in testicular size is due to an increase in diameter of seminiferous tubules and an increase in the volume of the seminiferous epithelium. The smaller testes volume of rams in the intensive treatment indicates that the volume of seminiferous epithelium and the diameter of seminiferous tubules had not yet developed as much as those in the other treatments. The testes of the rams in the intensive group were not as dense as those of the older and larger extensive and extensive-intensive treatment rams. This is supported by the low testes volume of the intensive treatment rams. Nevertheless, if rams in the intensive treatment did not receive the concentrate diet, their testicular measurements would have been smaller at slaughter, based on the findings of Hötzel *et al.* (1998) stating that rams fed higher energy diets had longer seminiferous tubules with greater diameters and heavier testes weight. Braden *et al.* (1974) found that diets with higher protein contents increased testicular weight, while the addition of energy increased testicular weight even more.

Rams in the intensive treatment group had significantly less scanned scrotal neck fat (SSNF) than the extensive-intensive and extensive treatments ($P < 0.001$), even though they were fed the concentrate diet for the entirety of their treatment. These were young rams and the intensive treatment was short – both of these factors prevented excessive fat deposition to occur as is often seen in mature animals or in animals fed a concentrate diet for extended periods of time. Although the rams in the extensive treatment were older than the intensive treatment rams, and thus it would be expected that the former would have deposited more total scrotal fat than the latter, the rangeland on which the extensive treatment rams grazed was likely lower in nutritional value than the concentrate diet fed to the intensive treatment rams. The extensive-intensive treatment had an effect on scrotal fat weight and resulted in more scrotal fat deposition compared to the other two treatments ($P < 0.001$). Concentrate diet fed to the rams during the finishing off phase in the extensive-intensive treatment did improve scrotal and testicular development (larger testes volume, length and mass which did not differ from the extensive treatment), but may have been fed too late when rams were too mature resulting in more fat being deposited in the scrotum.

Regression analyses were done to describe the relationship between gained weight and SSNF (an S curve mathematical function) (Figure 3.6) as well as between ADG and SSNF (a compound mathematical function) (Figure 3.7). Figure 3.6 illustrates that higher weight gains

were associated with an increase in SSNF (R^2 = 0.43, P < 0.05). Figure 3.7 shows that as ADG increased, the amount of SSNF decreased (R^2 = 0.14, P < 0.001). Gained weight also showed positive correlations (r = 0.60; P < 0.05) with SSNF, while ADG recorded a negative correlation (r = -0.34; P < 0.05) with SSNF.

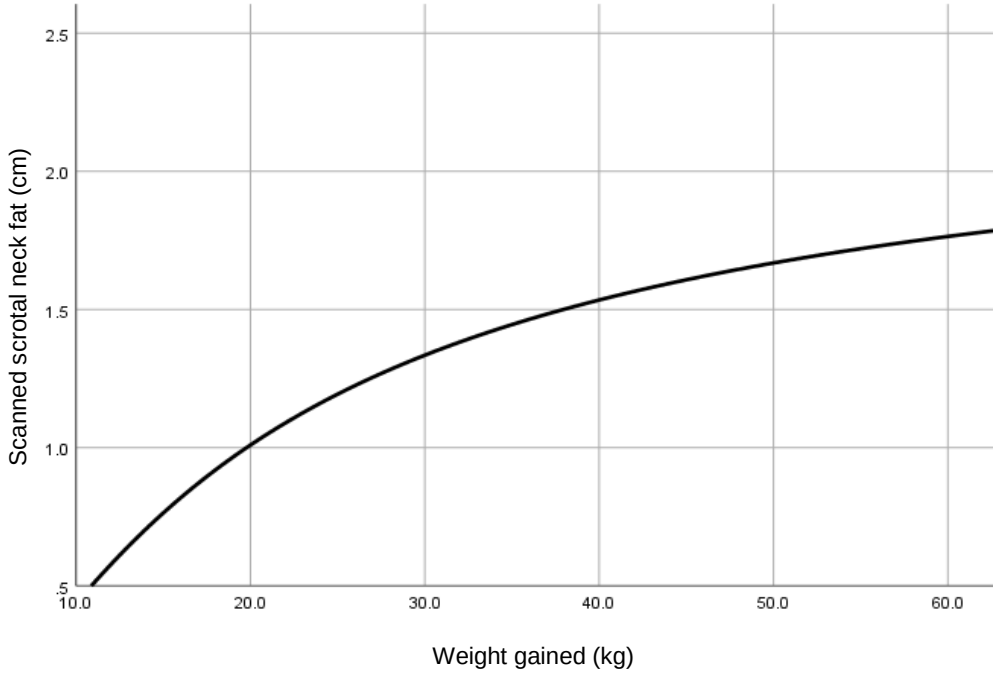


Figure 3.6 Regression of gained weight on scanned scrotal neck fat (pooled over breeds and treatments)

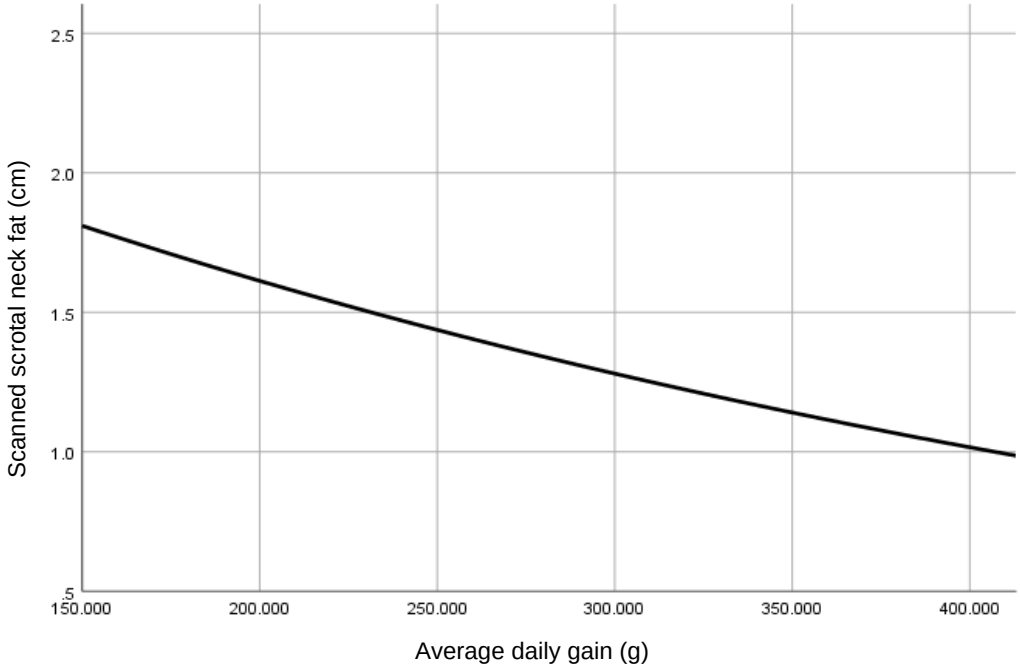


Figure 3.7 Regression of average daily gain on scanned scrotal neck fat (pooled over breeds and treatments)

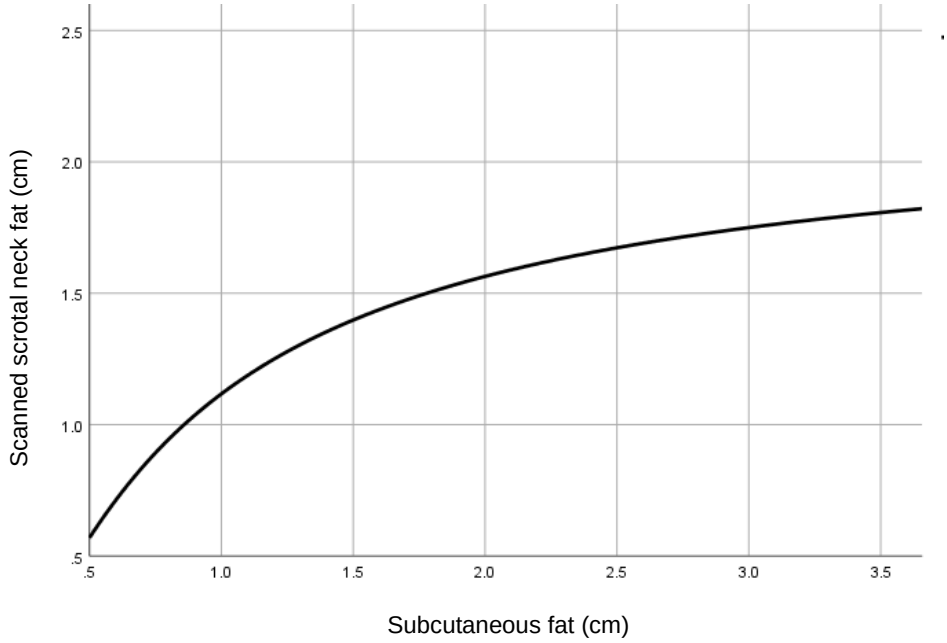


Figure 3.8 Regression of subcutaneous fat on scanned scrotal neck fat (pooled over breeds and treatments)

Regression analyses were done to describe the relationship between subcutaneous fat and SSNF (an S curve mathematical function) (Figure 3.8), as well as between subcutaneous fat and scrotal fat weight (a logarithmic mathematical function) (Figure 3.9). Figures 3.9 and 3.10 show that an increase in subcutaneous fat was associated with a concomitant increase in both SSNF (R^2 = 0.40; P < 0.001) and scrotal fat weight (R^2 = 0.06, P < 0.05). Subcutaneous fat and SSNF were positively correlated (r = 0.56, P < 0.05).

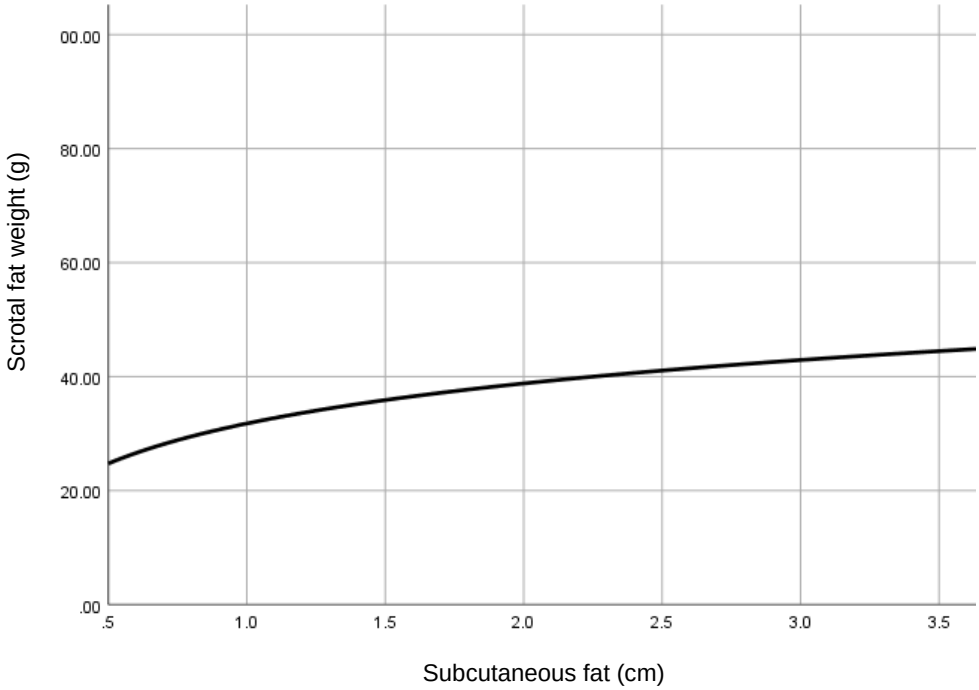


Figure 3.9 Regression of subcutaneous fat on scrotal fat weight (pooled over breeds and treatments)

An important measurement to consider was the *Pampiniform venous plexus* circumference (PPC), which is the area where thermoregulation occurs and which, in turn, influences the functionality of sperm (Senger, 2003; Bearden *et al.*, 2004). Furthermore, the amount of fat deposited around the PPC (as fat serves as an insulating agent) and the ratio between PPC and SSNF may help to explain the functionality of the testes. The intensive treatment had the smallest PPC (53.0 ± 6.36cm) while the extensive treatment had the largest PPC (68.3 ± 6.70cm; $P < 0.001$). The extensive-intensive treatment had a similar PPC size as the extensive treatment (65.6 ± 8.17cm) and differed from the intensive treatment ($P < 0.001$). The smaller PPC and other testicular measurements of the rams in the intensive treatment may have been due to their younger age and lighter body weight, than the rams in the other two treatments.

Due to little SSNF, the ratio of PPC to SSNF in the intensive treatment was the highest (51.7 ± 10.20), compared to the extensive treatment (44.6 ± 9.88; $P < 0.01$) and the extensive-intensive treatment (41.4 ± 7.73; $P < 0.001$). A larger PPC:SSNF ratio is beneficial as it indicates less SSNF and thus better thermoregulation potential. However, the circumference of the *Pampiniform venous plexus* must still be considered. As in this case, the smaller PPC of the intensive treatment could still pose a possible problem to thermoregulation and subsequently to ram fertility. It was anticipated that an ideal PPC:SSNF ratio exists, which equates to a certain PPC:SSNF threshold where PPC is large enough to ensure adequate thermoregulation. The PPC:SFM variable illustrates this well, where the rams in the extensive treatment had a significantly larger ratio (2.8 ± 1.74) than the rams in the intensive treatment (1.9 ± 0.52). Both treatments had similar scrotal fat weight, but the extensive treatment had significantly larger PPC than the intensive treatment.

If an ideal threshold for PPC:SSNF ratio exists, then there should also be an ideal threshold for EffecPPC:TM ratio (which is the ratio of PPC:SSNF to testes weight). A smaller EffectPPC:TM ratio would be preferred, but a smaller EffectPPC:TM does not only mean that the animal had heavier testes, it may also be that the animal had more SSNF and thus a smaller PPC:SSNF ratio. In this study it was observed that the smaller EffectPPC:TM ratio of the extensive-intensive and the extensive treatments were better than the larger EffectPPC:TM ratio of the intensive treatment ($P < 0.001$), as the rams in the extensive-intensive and extensive treatments had heavier testes than the rams in the intensive treatment. These ratios will be further discussed in Section 2.4 where the ratios will be compared to the results of the semen analyses.

Scrotal fat weight as a percentage of testes volume is another ratio which may explain the thermoregulatory ability of testes. This ratio is another complex variable where it was difficult to determine an ideal value. Further research in this regard is necessary to make meaningful

conclusions about the most favourable values. So, for example, a low percentage seems to be beneficial, but in the present study the intensive treatment and the extensive treatment had very similar values (16.5 ± 5.73% and 15.0 ± 8.87%). With similar scrotal fat / testis volume values, a similar sperm producing capacity was expected, but on closer inspection one would see that this was not the case. The extensive treatment had higher testes volume ($P < 0.05$) compared to the intensive treatment, and therefore also a greater sperm producing capacity (Oldham *et al.*, 1978; Hötzel *et al.*, 1998; Fernandez *et al.,* 2004; Kheradmand *et al.*, 2006). The extensive-intensive treatment had a significantly higher scrotal fat to testes volume percentage due to the significantly higher scrotal fat weight.

Overall breed effects: Differences in scrotal results between breeds are set out in Table 3.9. Initial scrotal circumference measurements differed between SAM rams and Döhne Merino rams ($P < 0.001$) and between SAM rams and Merino rams ($P < 0.001$). SAM rams had the largest scrotal circumference, while the Merino rams recorded the smallest. These findings agree with the findings that larger framed breeds, with heavier live weights, correlate with larger scrotal circumference (Salhab *et al.*, 2001; Elmaz *et al.,* 2007). Although the SAM rams recorded heavier final weights ($P < 0.05$), final scrotal circumferences did not differ ($P > 0.05$) between the three breeds as there is a limit to the size that SC can reach. Although no breed differences were reported for scrotal fat weight, SSNF differed ($P < 0.05$) between Döhne Merino rams and Merino rams. No differences were observed between breeds for PPC, PPC:SSNF ratio or PPC:SFM ratio, which suggest a similar testicular thermoregulation ability in all three breeds studied.

There existed a difference in testes weight ($P < 0.05$) between the Döhne Merino and the Merino rams, where the former recorded the heaviest testes (just heavier than the SAM) while the latter had the lightest testes. Merino rams measured a smaller testes width ($P < 0.05$) compared with the other two breeds and a smaller testes circumference ($P < 0.05$) than the Döhne Merino. This implies that there was probably more seminiferous epithelial development in the testes of the SAM and Döhne Merino rams. This may also be breed specific.

When scrotal fat weight was calculated as a percentage of testes volume, differences were reported between the Merino and the Döhne Merino rams ($P < 0.01$). The Merino rams had the highest percentage scrotal fat/testes volume, while the Döhne Merino recorded the lowest. The Döhne Merino rams deposited less fat in the scrotum compared with the other two breeds and recorded the highest testicular volume and scrotal weight. This could also be breed specific.

Table 3.9 Effects of breed on scrotal results ($\overline{X} \pm SD$) of Döhne Merino, Merino and South African Mutton Merino (SAM) rams

Variables ($\bar{X}$ ± SD)	**Breed**		
	Döhne (n = 30)	**Merino** (n = 31)	**SAM** (n = 28)
SC_I (cm)	21.4 ± 2.51[a]	19.8 ± 2.71[a]	24.5 ± 3.24[b]
SC_F (cm)	34.6 ± 2.87	33.5 ± 2.62	33.3 ± 2.34
SC_G (cm)	13.2 ± 3.11[a]	13.7 ± 3.61[a]	8.8 ± 4.00[b]
SSNF (cm)	1.5 ± 0.32[a]	1.4 ± 0.39[b]	1.4 ± 0.40[ab]
Scrotal weight (g)	795.7 ± 170.96	726.5 ± 168.85	785.1 ± 140.94
Scrotal fat weight (g)	32.3 ± 14.94	38.1 ± 16.78	37.9 ± 12.83
PPC (cm)	63.2 ± 9.65	60.2 ± 10.75	63.5 ± 8.52
PPC:SSNF	43.5 ± 8.89	46.5 ± 8.54	47.8 ± 12.70
PPC:SFM	2.5 ± 1.56	1.9 ± 1.23	1.9 ± 0.71
PPC:TM	0.3 ± 0.06[a]	0.3 ± 0.07[b]	0.3 ± 0.06[ab]
EffecPPC:TM	0.2 ± 0.05[a]	0.2 ± 0.07[b]	0.2 ± 0.07[ab]
Testes weight (g)	247.6 ± 48.61[a]	220.9 ± 44.74[b]	244.1 ± 45.27[ab]
Testes length (cm)	11.5 ± 0.93	10.9 ± 1.19	11.4 ± 1.02
Testes width (cm)	7.1 ± 0.57[a]	6.6 ± 0.60[b]	7.1 ± 0.58[a]
Tescir (cm)	19.4 ± 2.47[a]	18.2 ± 1.59[b]	18.8 ± 1.57[ab]
Testes volume (ml)	220.3 ± 43.72	195.8 ± 46.03	211.6 ± 46.92
ScrFatWtTes (%)	14.8 ± 6.19[a]	20.2 ± 8.63[b]	19.0 ± 8.12

[a, b] Means with different superscripts, within a row, differ significantly (P < 0.05)

$\bar{X}$ ± SD – Mean ± Standard deviation

SC_I – Initial scrotal circumference; SC_F – Final scrotal circumference; SC_G – Gained scrotal circumference; SSNF – Scanned scrotal neck fat; PPC – *Pampiniform venous plexus* circumference; PPC:SSNF – ratio of the *Pampiniform venous plexus* circumference to scanned scrotal neck fat (effective *Pampiniform venous plexus*); PPC:SFM – ratio of the *Pampiniform venous plexus* circumference to scrotal fat weight; PPC:TM – ratio of the *Pampiniform venous plexus* circumference to testes weight; EffecPPF:TM – ratio of the effective *Pampiniform venous plexus* to testes weight; Tescir – Testes circumference; ScrFatWtTes – Scrotal fat weight as a percentage of average testes volume

Finishing treatment x breed interaction effects: Scanned scrotal neck fat (Table 3.10) and PPC:SSNF ratio (Table 3.11) were the variables which showed significant treatment x breed interactions. Scrotal circumference measurements, taken at the beginning of the trial (Table 3.10), did not differ between treatments within a breed (P > 0.05). In the extensive-intensive treatment the SAM rams recorded larger scrotal circumferences than both the Merino (P <

0.001) and Döhne Merino rams ($P < 0.01$), and in the extensive treatment SAM rams were larger than Merino rams ($P < 0.05$). As the SAM breed is the largest of the three breeds, and SC is correlated to body weight, it is thus understandable that the SAM rams had larger SC.

Scrotal circumference taken at the end of the trial showed no differences ($P > 0.05$) between breeds in the same treatments. This implies that there is a limit to the size that SC can reach, and that differences in SC between rams of different breeds, approaching maturity, decreases.

Although it is widely accepted that SC indirectly predicts male fertility by being highly correlated to testes size, in this trial, for some breeds within certain treatments, there were no correlations between SC_F and testicular measurements. SAM rams, as well as the Döhne Merino rams, in the intensive treatment had positive correlations between testes weight and SC_F ($r = 0.76$; $P < 0.05$ and $r = 0.82$, $P < 0.01$ respectively), testes volume and SC_F ($r = 0.74$, $P < 0.05$ and $r = 0.83$, $P < 0.01$), and testes circumference and SC_F ($r = 0.69$, $P < 0.04$ and $r = 0.80$, $P < 0.05$ respectively). There were no significant correlations for the Merino rams in the intensive treatment. The opposite was observed for these breeds in the extensive-intensive treatment: the Merinos recorded positive correlations between testes weight and SC_F ($r = 0.75$; $P < 0.05$), scrotal weight and SC_F ($r = 0.72$, $P < 0.05$), testes circumference and SC_F ($r = 0.79$, $P < 0.01$), and testes volume and SC_F ($r = 0.81$, $P < 0.01$). Neither the Döhne Merinos nor the SAM rams showed any significant correlations. In the extensive treatment, only the SAM rams had correlations between SC_F and scrotal weight ($r = 0.83$; $P < 0.05$), SC_F and testes weight ($r = 0.88$; $P < 0.01$), testes volume and SC_F ($r = 0.91$, $P < 0.01$), and testes circumference and SC_F ($r = 0.80$, $P < 0.05$). This inconsistency in correlations may be due to all rams of all breeds in all treatments were still relatively immature.

Treatment influenced the SSNF in all three breeds. Scanned scrotal neck fat was the thinnest ($P < 0.05$) in the intensive treatment for all three breeds. Within breed, the extensive-intensive treatment Döhne Merino and SAM rams, and the extensive treatment Merino rams had the thickest SSNF compared to their counterparts in other treatments. Döhne Merino rams of the intensive treatment differed ($P < 0.001$) from the extensive-intensive Döhne Merino rams (1.2 ± 0.30cm versus 1.7 ± 0.19cm). The intensive treatment Döhne Merino rams were young when they received the concentrate diet – thus most of the nutrients should have been directed towards growth – leaving little to be deposited as fat. In the older rams of the extensive-intensive treatment, less nutrients were directed towards growth, leaving more to be deposited as fat in the neck of the scrotum. The same applies to the SAM and Merino breeds whose SSNF also differed significantly between the intensive and extensive-intensive treatments.

What is of interest, was that the extensive-intensive Merino rams recorded less ($P < 0.05$) SSNF than both the Döhne Merino and SAM rams in the same treatment group. The

extensive-intensive Merino rams tended to have heavier scrotal fat weight than the Döhne Merino and SAM rams, but not significantly so. It is possible that place of fat deposition is breed specific, where the Döhne Merino and SAM breeds (both dual-purpose breeds) have a tendency to deposit fat in the neck of the scrotum while the Merino breed (single-purpose breed) rather deposits fat in the body of the scrotum.

In Figure 3.10 a larger amount of SSNF was observed in the extensive-intensive treatment group. On closer inspection it can be seen that the large amount of SSNF is only applicable to the Döhne Merino and SAM rams. In the intensive treatment it was clear that the Döhne Merino had a thicker average SSNF (1.2 ± 0.30cm) than both the Merino (1.0 ± 0.09cm, $P < 0.05$) and the SAM (1.0 ± 0.15cm). Although the Döhne Merino rams had, numerically, the thickest SSNF in the intensive treatment, in all three treatments the Döhne Merino rams always recorded the least scrotal fat weight of the three breeds ($P > 0.05$). It is possible that this breed does not easily deposit fat in the neck or body of the scrotum, but when fat deposition does occur, it is deposited in the neck of the scrotum rather than around the testes, which may be detrimental in terms of thermoregulation.

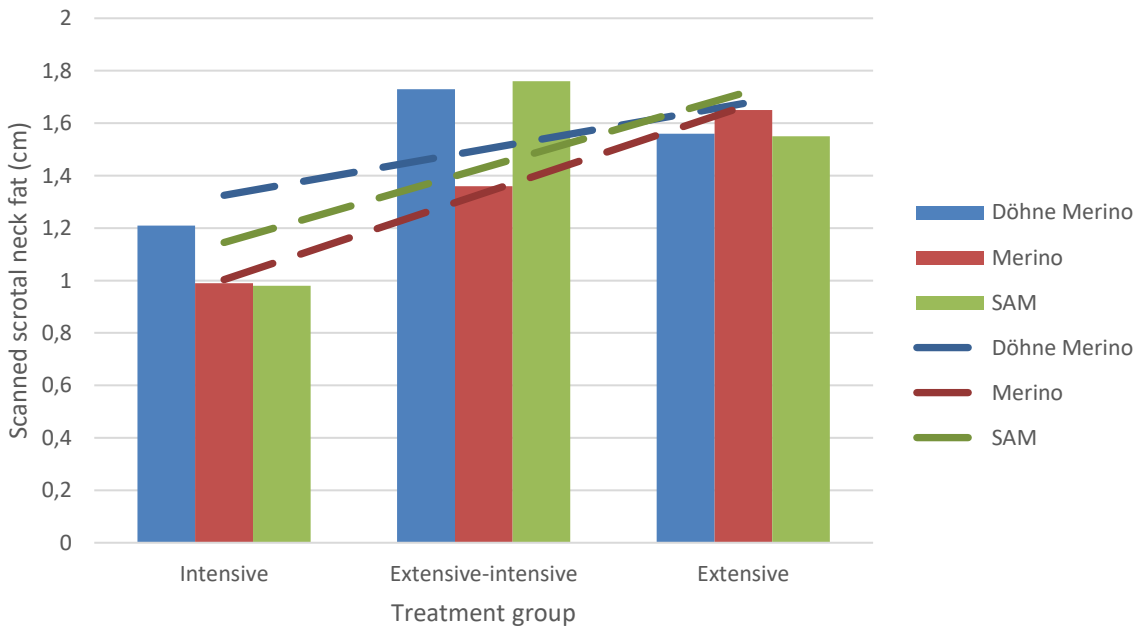


Figure 3.10 Scanned scrotal neck fat data of Döhne Merino, Merino and South African Mutton Merino (SAM) rams following either an extensive, extensive-intensive, or intensive treatment. (Dotted lines indicate trends for feeding treatments)

Table 3.10 Effects of finishing treatment and breed on scrotal results ($\bar{X} \pm SD$) of Döhne Merino, Merino and South African Mutton Merino (SAM) rams following either an extensive, extensive-intensively, or intensive treatment

Factors		Variables ($\bar{X}$ ± SD)						
Finishing treatment	**Breed**	**SC_I** (cm)	**SC_F** (cm)	**SC_G** (cm)	**SSNF** (cm)	**Scrotal weight** (g)	**Scrotal fat weight** (g)	**PPC** (cm)
Intensive	**Döhne** (n = 10)	22.5 ± 2.42	33.4 ± 3.13	10.9 ± 2.73	1.2 ± 0.30^{A}	635.5 ± 120.31^{A}	27.5 ± 6.67^{AB}	52.3 ± 4.69^{A}
	Merino (n = 11)	20.7 ± 3.16	32.5 ± 2.59	11.8 ± 1.87	1.0 ± 0.09^{A}	555.1 ± 101.34^{A}	29.3 ± 6.54^{A}	49.3 ± 6.87^{A}
	SAM (n = 8)	23.2 ± 3.01	32.3 ± 1.64	9.1 ± 2.69	1.0 ± 0.15^{A}	670.2 ± 107.22^{A}	32.2 ± 10.95	57.6 ± 4.68^{A}
Extensive-Intensive	**Döhne** (n = 10)	20.6 ± 2.80$_{a}$	35.0 ± 2.36	14.4 ± 3.34$_{a}$	1.7 ± 0.19$^{B}{}_{a}$	880.8 ± 142.78^{B}	45.4 ± 17.42^{A}	67.9 ± 6.31^{B}
	Merino (n = 10)	18.9 ± 2.69$_{a}$	34.1 ± 2.51	15.2 ± 3.65$_{a}$	1.4 ± 0.08$^{B}{}_{b}$	815.4 ± 114.84^{B}	52.5 ± 18.64^{B}	63.8 ± 9.11^{B}
	SAM (n = 10)	25.9 ± 1.52$_{b}$	33.4 ± 2.27	7.5 ± 3.37$_{b}$	1.8 ± 0.17$^{B}{}_{a}$	803.6 ± 93.63^{AB}	46.3 ± 11.51	65.2 ± 9.09^{AB}
Extensive	**Döhne** (n = 10)	21.2 ± 2.15$_{ab}$	35.4 ± 2.95	14.2 ± 1.99	1.6 ± 0.19^{AB}	870.9 ± 128.41^{B}	24.1 ± 8.91^{B}	69.5 ± 6.00^{B}
	Merino (n = 10)	19.8 ± 2.23$_{a}$	33.9 ± 2.70	14.1 ± 4.23	1.7 ± 0.46^{B}	801.5 ± 144.68^{B}	33.1 ± 13.48^{A}	66.91 ± 6.92^{B}
	SAM (n = 10)	24.4 ± 4.53$_{b}$	34.4 ± 2.88	10.0 ± 5.71	1.6 ± 0.30^{B}	905.6 ± 120.94^{B}	34.6 ± 12.21	68.8 ± 7.71^{B}

$^{A, B}$ Different superscripts in the same column within a breed differ significantly ($P < 0.05$)

$_{a, b}$ Different subscripts in the same column within a treatment differ significantly ($P < 0.05$)

$\bar{X}$ ± SD – Mean ± Standard deviation

SC_I – Initial scrotal circumference; SC_F – Final scrotal circumference; SC_G – Gained scrotal circumference; SSNF – Scanned scrotal neck fat; PPC – *Pampiniform venous plexus* circumference

For all three breeds, the most scrotal fat deposition occurred in the extensive-intensive treatment. The Merino and SAM rams of the intensive treatment and the extensively kept Döhne Merino rams recorded the least scrotal fat of their respective breeds. There was a difference ($P < 0.001$) between the extensive-intensive Döhne Merinos (45.4 ± 17.42g) and the extensive Döhne Merinos (24.1 ± 8.91g). Merino rams in both the intensive treatment (29.3 ± 6.54g) and the extensive treatment (33.1 ± 13.48g) differed ($P < 0.05$) from the Merino rams in the extensive-intensive treatment (52.5 ± 18.64g). As the rams in the intensive treatment were young, the high energy and protein content of the diet in the intensive treatment group was probably used mostly for skeletal growth, resulting in less fat deposition around the testes. Since rams in the extensive-intensive treatment were fed a concentrate diet at an older age, it is reasonable that they had the most scrotal fat. Rams in the extensive treatment, although they were older, were not fed a concentrate diet which explains why these rams had less scrotal fat than the extensive-intensive rams.

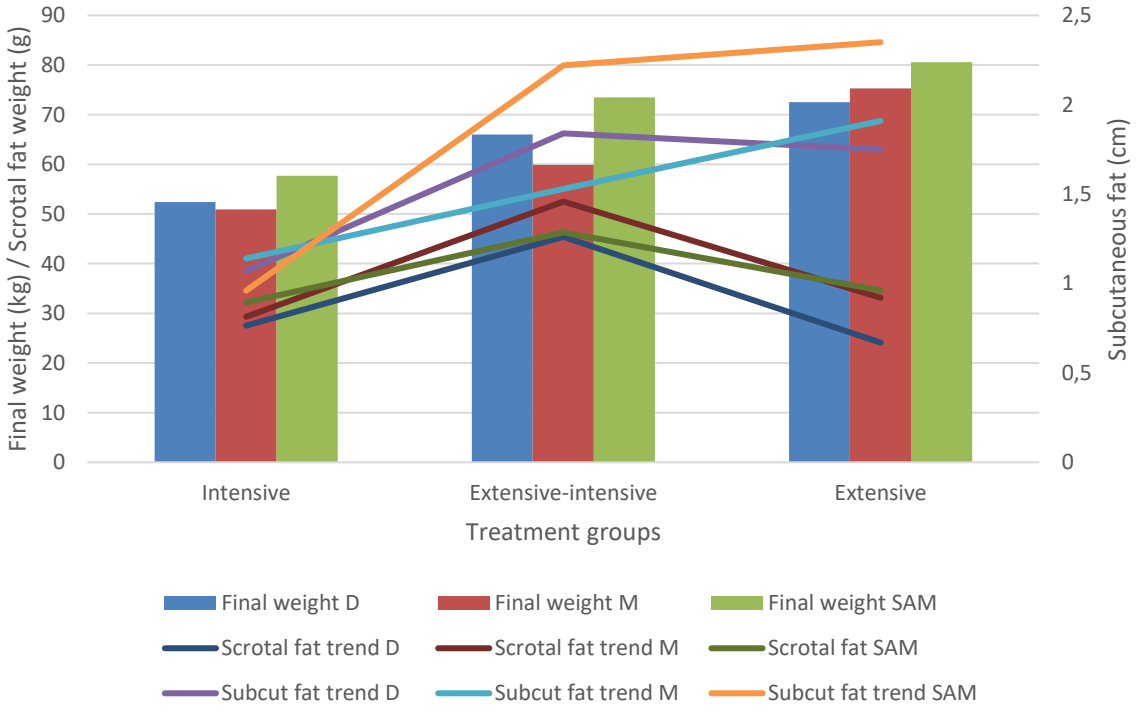


Figure 3.11 The relationship between final weight (kg), scrotal fat weight (g), and subcutaneous fat (cm) of Döhne Merino (D), Merino (M), and South African Mutton Merino (SAM) rams following either an extensive, extensive-intensive, and intensive treatment

Figure 3.11 illustrates how treatment influenced final weight, subcutaneous fat and scrotal fat weight, as well as the relationship between these variables. From Figure 3.11 it would seem

that as the final body weight increased, so the subcutaneous fat increased. While, although the trends for final weight and subcutaneous fat was higher in the extensive treatment, the scrotal fat weight trend was higher in the extensive-intensive treatment. SAM and Döhne Merino rams in the extensive-intensive treatment recorded much more subcutaneous fat ($P < 0.001$) than their counterparts in the intensive treatment. The extensive treatment Merino and SAM rams in turn had numerically more subcutaneous fat than their extensive-intensive treatment counterparts, while the Döhne Merinos recorded less. In the intensive treatment, the Döhne Merino rams recorded a positive correlation between scrotal fat weight and final weight ($r = 0.73$; $P < 0.05$), so did the Merino rams of the extensive-intensive treatment ($r = 0.66$; $P < 0.05$). Only the Merinos in the intensive treatment recorded a strong negative correlation ($r = -0.86$; $P < 0.01$) between subcutaneous fat and SSNF.

The extensive-intensive treatment Merino rams recorded positive correlations between subcutaneous fat and scrotal weight, subcutaneous fat and PPC, and subcutaneous fat and testes weight ($r = 0.70$, $P < 0.05$; $r = 0.72$, $P < 0.05$ and $r = 0.68$, $P < 0.05$ respectively). There were correlations between subcutaneous fat and PPC ($r = 0.71$, $P < 0.05$) and between subcutaneous fat and testes circumference ($r = 0.76$, $P < 0.05$) in SAM rams of the extensive-intensive treatment. While the Merino rams of the extensive treatment recorded negative correlations between the following variables: subcutaneous fat and testes weight ($r = -0.90$, $P < 0.001$); subcutaneous fat and testes circumference ($r = -0.82$, $P < 0.01$); and subcutaneous fat and testes volume ($r = -0.78$, $P < 0.01$). The opposite correlations between the extensive-intensive and extensive treatments may be due to the differences in the maturity of the rams in the respective treatments. The extensive-intensive treatment rams were younger than the extensive treatment rams, thus further testicular growth was still possible.

Scrotal weight (Table 3.10) differed ($P < 0.05$) between the rams in the intensive treatment and the rams in the extensive-intensive treatment, as well as between the extensive treatment and intensive treatment within both the Merino breed and Döhne Merino breed. In the SAM breed, the only difference was between the extensive treatment and the intensive treatment ($P < 0.01$). The intensive treatment rams were younger than the rams of the other treatments when scrotal weight was measured. These rams would have just reached puberty, but not yet maturity, and thus their scrotums would not be as well developed as the slightly older rams in the other two treatments. The scrotal weight of the Döhne Merino rams in the extensive-intensive treatment were very similar to the scrotal weight of the Döhne Merino rams in the extensive treatment, as was the case for Merino rams as well. Rams in the extensive-intensive treatment benefitted from the concentrate diet because, although the extensive-intensive treatment rams were *ca.* two months younger than the extensive treatment rams, they had similar scrotal weights. As scrotal weight includes scrotal skin, testes, and scrotal fat, thus

scrotal weight does not show true testicular development and how nutrition influenced testicular development. It is important to compare testes weight and testes volume to determine testicular development.

Testes weight (Table 3.11) did not differ between breeds within a treatment group or between treatment groups within a breed ($P > 0.05$). The same was observed for testes circumference and testes volume (Table 3.12). The intensive treatment rams, which were the youngest rams, had the lightest testes and the lowest testes volume (for all three breeds), but not significantly so. All the rams were older than six months when slaughtered, thus all of them had reached puberty (Bearden *et al.*, 2004). As all the rams had reached puberty, all the rams would have had well developed testes. The concentrate diet, which was fed from after weaning, was high in energy and protein, which improved testicular development. The increase in testes weight was previously described as an increase in volume of seminiferous epithelium and seminiferous tubule diameter (Braden *et al.*, 1974; Oldham *et al.*, 1978; Hötzel *et al.*, 1998; Fernandez *et al.,* 2004; Kheradmand *et al.*, 2006).

This trial also demonstrated strong positive correlations between testicular measurements and body weight as supported by the studies of Salhab *et al.* (2001), Bearden *et al.* (2004) and Elmaz *et al.* (2007). The SAM rams in the intensive treatment had the following correlations: final weight and testes circumference ($r = 0.68$, $P < 0.05$), testes volume and final weight ($r = 0.68$, $P < 0.05$), testes weight and final weight ($r = 0.69$; $P < 0.05$), and scrotal weight and final weight ($r = 0.69$; $P < 0.05$). Correlations were also observed for Döhne Merino rams in the extensive-intensive treatment between scrotal weight and final weight ($r = 0.82$; $P < 0.01$), testes weight and final weight ($r = 0.78$, $P < 0.01$), and testes volume and final weight ($r = 0.88$, $P < 0.01$). In the extensive treatment, none of the breeds had correlations between final weight and testes weight. There was only one correlation between final weight and scrotal weight ($r = 0.71$; $P < 0.05$) for the Döhne Merino rams.

Table 3.11 Effects of finishing treatment and breed on scrotal results ($\overline{X} \pm SD$) of Döhne Merino, Merino and South African Mutton Merino (SAM) rams following either an extensive, extensive-intensively, or intensive treatment

Factors		**Variables** ($\bar{X}$ ± SD)						
Finishing treatment	**Breed**	**PPC:SSNF**	**PPC:SFM**	**PPC:TM**	**EffecPPC:TM**	**Testes weight** (g)	**Testes length** (cm)	**Testes width** (cm)
Intensive	**Döhne** (n = 10)	45.6 ± 11.65$_{a}$	2.0 ± 0.58^{AB}	0.3 ± 0.05	0.2 ± 0.04	217.6 ± 39.78	10.5 ± 0.53^{A}	6.6 ± 0.42^{A}
	Merino (n = 11)	49.7 ± 4.26$_{ab}$	1.8 ± 0.46	0.3 ± 0.08	0.3 ± 0.08^{A}	191.4 ± 42.34	10.5 ± 0.77	6.3 ± 0.56^{A}
	SAM (n = 8)	59.7 ± 8.01^{A}$_{b}$	1.9 ± 0.51	0.2 ± 0.05	0.3 ± 0.06^{A}	234.5 ± 46.08	11.0 ± 1.05	6.8 ± 0.39^{A}
Extensive-Intensive	**Döhne** (n = 10)	39.8 ± 6.17	1.8 ± 1.16^{A}	0.3 ± 0.07	0.2 ± 0.05	258.0 ± 42.40	12.0 ± 0.72^{B}	7.1 ± 0.45^{AB}
	Merino (n = 10)	47.0 ± 6.82	1.4 ± 0.71	0.3 ± 0.03	0.2 ± 0.02^{AB}	234.0 ± 30.47	11.3 ± 0.77	6.5 ± 0.43^{AB}
	SAM (n = 10)	37.5 ± 7.73^{B}	1.5 ± 0.52	0.3 ± 0.06	0.2 ± 0.03^{B}	227.4 ± 32.18	11.4 ± 0.54	6.8 ± 0.34^{A}
Extensive	**Döhne** (n = 10)	45.2 ± 7.58	3.5 ± 2.06^{B}	0.3 ± 0.05	0.2 ± 0.04	267.2 ± 51.86	12.0 ± 0.70^{B}	7.5 ± 0.51^{B}$_{ab}$
	Merino (n = 10)	43.0 ± 11.70	2.5 ± 1.80	0.3 ± 0.08	0.2 ± 0.07^{B}	235.8 ± 47.64	10.9 ± 1.67	7.0 ± 0.59^{B}$_{a}$
	SAM (n = 10)	46.0 ± 10.69^{B}	2.3 ± 0.94	0.3 ± 0.05	0.2 ± 0.06^{B}	277.0 ± 45.53	12.0 ± 1.26	7.8 ± 0.40^{B}$_{b}$

$^{A, B, C}$ Different superscripts in the same column within a breed differ significantly (P < 0.05)

$_{a, b}$ Different subscripts in the same column within a treatment differ significantly (P < 0.05)

$\bar{X}$ ± SD – Mean ± Standard deviation

PPC:SSNF – ratio of the *Pampiniform venous plexus* circumference to scanned scrotal neck fat (effective *Pampiniform venous plexus*); PPC:SFM – ratio of the *Pampiniform venous plexus* circumference to scrotal fat weight; PPC:TM – ratio of the *Pampiniform venous plexus* circumference to testes weight; EffecPPF:TM – ratio of the effective *Pampiniform venous plexus* to testes weight

Table 3.12 Effects of finishing treatment and breed on scrotal results ($\overline{\mathrm{X}} \pm \mathrm{SD}$) of Döhne Merino, Merino and South African Mutton Merino (SAM) rams following either an extensive, extensive-intensively, or intensive treatment

Factors		Variables ($\bar{X}$ ± SD)		
Finishing treatment	**Breed**	**Tescir** (cm)	**Testes volume** (ml)	**ScrFatWtTes** (%)
Intensive	**Döhne** (n = 10)	18.2 ± 1.39	192.0 ± 33.27	14.69 ± 4.62
	Merino (n = 11)	17.2 ± 1.50	166.0 ± 39.21	18.56 ± 5.81
	SAM (n = 8)	18.5 ± 1.36	205.5 ± 40.03	16.21 ± 6.48
Extensive-Intensive	**Döhne** (n = 10)	20.0 ± 3.59	231.5 ± 35.67	19.26 ± 6.49
	Merino (n = 10)	17.9 ± 0.96	212.0 ± 22.51	24.89 ± 8.67
	SAM (n = 10)	17.9 ± 1.01	203.0 ± 29.36	23.22 ± 5.88
Extensive	**Döhne** (n = 10)	20.0 ± 1.50	237.5 ± 49.22	10.54 ± 4.24
	Merino (n = 10)	19.3 ± 1.52	208.2 ± 56.54	17.52 ± 9.64
	SAM (n = 10)	20.2 ± 1.47	230.0 ± 69.13	17.18 ± 10.74

$^{A, B, C}$ Different superscripts in the same column within a breed differ significantly (P < 0.05)

$_{a, b}$ Different subscripts in the same column within a treatment differ significantly (P < 0.05)

$\bar{X}$ ± SD – Mean ± Standard deviation

Tescir – Testes circumference; ScrFatWtTes – Scrotal fat weight as a percentage of average testes volume

Figure 3.12 illustrates how the treatments influenced final body weight, testes weight, and scrotal fat weight, as well as showing the relationship between these variables. The trend was that as final weight increased, so did testes weight. The only exception was the SAM breed, where the rams in the extensive-intensive treatment tended to have lighter testes weight than the rams in the intensive treatment. The trend of scrotal fat weight was higher in the extensive-intensive treatment.

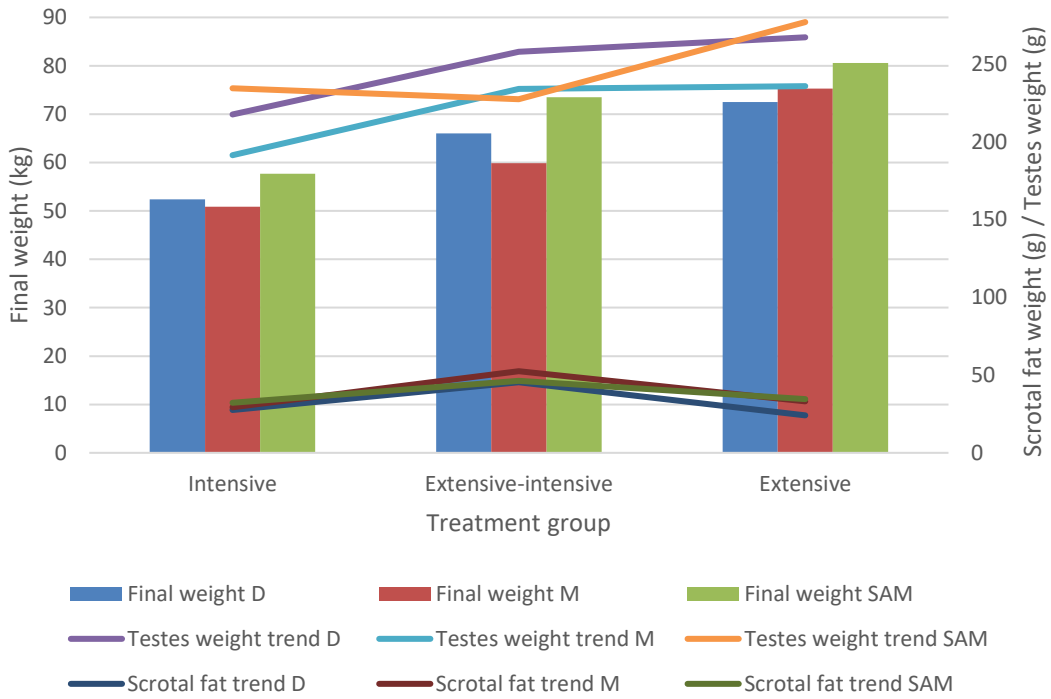


Figure 3.12 The relationship between final weight (kg), testes weight (g), and scrotal fat weight (g) of Döhne Merino (D), Merino (M), and South African Mutton Merino (SAM) rams following either an extensive, extensive-intensive, and intensive treatment

An important variable, PPC, differed ($P < 0.05$) between the intensive treatment and extensive treatment, as well as between the intensive treatment and extensive-intensive treatment for both the Merino and the Döhne Merino breed. While the SAM breed only differed between the intensive treatment and the extensive treatment ($P < 0.05$). The thickest (thus most developed) PPC was for the extensive treatment in all three breeds. These rams were the oldest and heaviest. Thus, a better developed PPC can be expected, although the rams were just kept on rangeland. The thinnest PPC was for the lightest and youngest rams – in the intensive treatment group of rams. It is thus expected that the extensive treatment rams have a better testicular thermoregulation ability than the intensive treatment rams.

The relationship between final weight, PPC and SSNF, and how treatment influenced these variables, is illustrated in Figure 3.13. As the duration of the treatments, and the final weights, increased so did the PPC. The trend of the SSNF of the Döhne Merino and SAM rams followed a similar trend to scrotal fat weight in Figures 3.12 and 3.13. The SSNF trend was higher in the extensive-intensive treatment for the Döhne Merino and SAM rams. Merino rams in the extensive treatment recorded thicker SSNF than their counterparts in the other treatments.

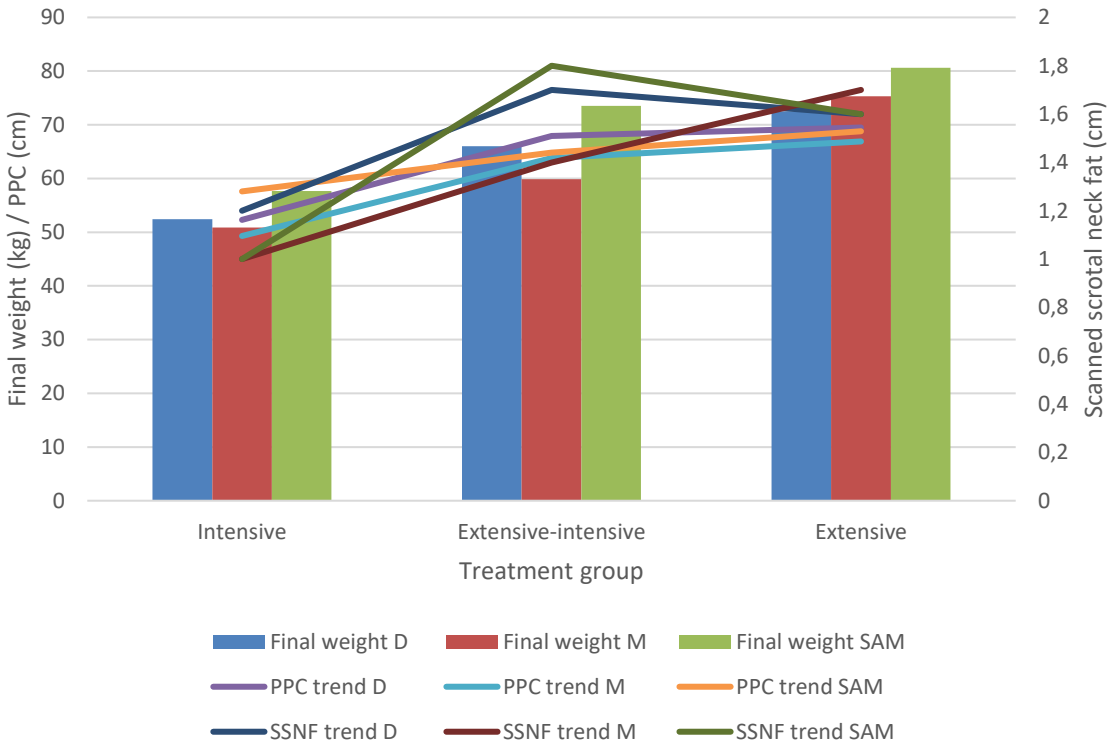


Figure 3.13 The relationship between final weight (kg), *Pampiniform venous plexus* circumference (PPC) (cm), and scanned scrotal neck fat (SSNF) (cm) of Döhne Merino (D), Merino (M), and South African Mutton Merino (SAM) rams following either an extensive, extensive-intensive, and intensive treatment

The PPC:SSNF ratio can be used to determine how effectively the *Pampiniform venous plexus* functions and its potential to maintain thermoregulation. A larger ratio is generally desired as this would indicate either larger PPC or smaller SSNF or both. However, the PPC:SSNF ratio is a complicated ratio which could be misleading. Figure 3.14 is the perfect example why this ratio can be misleading. From Figure 3.14 one would assume that the SAM rams of the intensive treatment had the most effective PPC (they had the largest PPC:SSNF ratio; $P < 0.05$) of all the SAM rams, as well as the other two breeds. Table 3.11 also shows that the PPC:SSNF ratio of the SAM rams in the intensive treatment was larger than the ratios of the SAM rams in the extensive ($P < 0.05$) and extensive-intensive treatments ($P < 0.001$). However, Table 3.10 shows that, although the intensive treatment SAM rams recorded the largest PPC:SSNF ratio, it is not necessarily that they had the most effective PPC. Table 3.10 shows that the intensive treatment SAM rams had numerically smaller PPC (57.6 ± 4.68cm) than the extensive-intensive rams (65.2 ± 9.09cm) ($P > 0.05$) and significantly smaller PPC than the extensive treatment (68.8 ± 7.71cm) SAM rams. Thus, the intensive treatment rams had the smallest surface area where thermoregulation could occur.

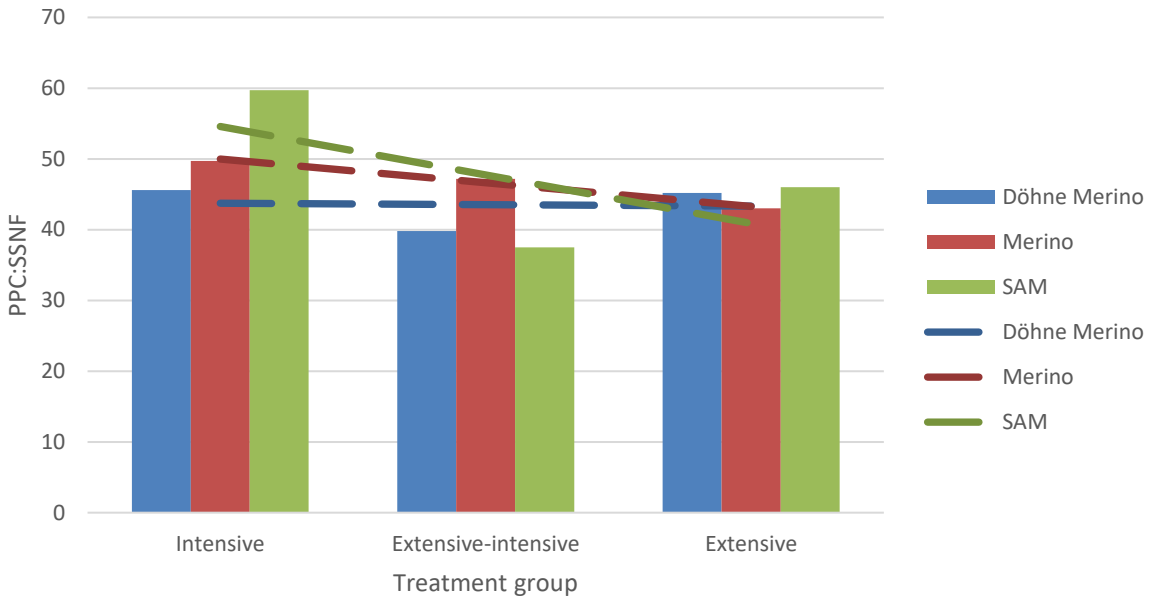


Figure 3.14 Ratio of *Pampiniform venous plexus* circumference to scanned scrotal neck fat (PPC:SSNF) data of Döhne Merino, Merino and South African Mutton Merino (SAM) rams following either an extensive, extensive-intensive, or intensive treatment. (Dotted lines indicate trends for feeding treatments)

The SAM rams in the intensive treatment recorded significantly less SSNF than the extensive-intensive treatment and extensive treatment SAM rams. In the semen analyses section, it will be analysed if, and to what extent, the thicker SSNF of the extensive-intensive and extensive treatments were detrimental. However, comparing the PPC and the SSNF of the SAM rams in the different treatments, it would seem that the extensive treatment SAM rams had the most effective PPC as they had the largest PPC, and less SSNF than the extensive-intensive treatment (although, not significantly so). The same can be said for the Döhne Merino and Merino rams. The intensive and extensive treatment Döhne Merino rams had the same PPC:SSNF ratio, but the extensive treatment Döhne Merino rams could have a more effective PPC, as they recorded larger ($P < 0.05$) PPC than the intensive rams. The extensive treatment Merino rams had the smallest PPC:SSNF ratio and the intensive treatment Merino rams had the largest PPC:SSNF ratio ($P > 0.05$), but the extensive treatment Merino rams recorded the largest PPC ($P < 0.001$). Thus, it can be assumed that these rams would have a more effective PPC than the intensive treatment rams.

EffecPPC:TM is another ratio which can be used to determine how effectively viable sperm is produced, but it is also a complicated ratio which could be misleading. As previously stated, a smaller ratio is desired, but one must ensure that the smaller ratio was not due to the animal having a smaller PPC or more SSNF. The difference between the intensive treatment SAM

rams and the extensive-intensive treatment rams ($P < 0.001$) and between the intensive treatment and extensive treatment SAM rams ($P < 0.01$) is presented in Table 3.11. The extensive-intensive treatment and extensive treatment SAM rams had the smallest ratios (very similar ratios). However, the ratio of the extensive treatment SAM rams is the more accurate representation, because SAM rams in this group will effectively produce more viable sperm. If one compares testes weight of the extensive-intensive and extensive treatments SAM rams, it is clear that SAM rams in the extensive treatment had numerically heavier testes ($P > 0.05$). The extensive treatment also had slightly larger PPC and slightly less SSNF than the extensive-intensive treatment SAM rams. There was also a difference between the Merino rams in the intensive treatment and the extensive treatment ($P < 0.01$). In the Merino breed, the extensive treatment recorded the smaller EffecPPC:TM ratio. This ratio can be accepted and trusted as the extensive treatment Merino rams recorded heavier testes weight and larger PPC than the intensive treatment Merino rams. Thus, more research is required to determine the ideal ratios.

3.4 Semen analyses

The variables of this category were semen volume, semen colour, spermatozoa mass motility, progressive spermatozoa motility, aberrant motile spermatozoa, immotile/dead spermatozoa, and percentage normal spermatozoa.

Overall finishing treatment effects: Finishing treatment influenced semen volume and percentage normal spermatozoa ($P < 0.05$) (Table 3.13). All the rams in the extensive-intensive treatment produced a larger volume of semen ($P < 0.05$) than the extensive treatment. This implies that the older rams in the present study had lower semen volumes, which differed from the general findings that semen characteristics improve in quality and quantity with age (Courot, 1979; Wiemer & Ruttle, 1987). It also differed from the findings of Elmaz *et al.* (2007) who found no increase in semen volume in rams between the ages of seven to 14 months old. Testes weight, volume and length did not differ ($P > 0.05$) between the extensive-intensive and extensive treatments, only testes width and circumference differed ($P < 0.001$), and the extensive treatment had larger testicular width and circumference. Thus, no difference in semen volume between rams in the extensive-intensive treatment and extensive treatment was expected, and neither was it expected that the rams in extensive treatment would have lower semen volume than the extensive-intensive treatment rams.

Although rams in the intensive treatment had significantly smaller and lighter testes volume and weight, the volume of semen production was not lower compared to the extensive treatment ($P > 0.05$), although semen volume of the intensive treatment was numerically less than the semen volume of the extensive-intensive treatment. This differs somewhat from the results of Pisselet *et al.* (1984) which indicated positive correlations between testes weight and spermatozoa production per hour, and between tubular wall area and spermatozoa production per hour. Thus, heavier testes are suggested to have longer seminiferous tubules with larger diameters and thus more tubular wall area, which produce more spermatozoa (Hötzel *et al.*, 1994). In this case rams in the intensive treatment were expected to produce the lowest semen volumes. Furthermore, in this study, season had an effect on semen volume ($P < 0.05$) as well. The rams in the extensive treatment were the rams nearing their natural breeding season and were therefore expected to produce increasing quality and quantities of semen.

Regression analyses, $y = -5.1 + 0.5x - 0.01x^2 + 7.6x^3$ (a cubic mathematical function), were performed to describe the relationship between gained weight and semen volume (Figure 3.15), as well as between subcutaneous fat and semen volume (Figure 3.16). From Figure 3.15 It is evident that once weight gained exceeded 30kg that semen volume started to decline

(R^2 = 0.13, P < 0.01). This may be due to increased weight gain resulting in increased fat deposition. This correlation of determination indicates that a small (0.13 ~ 13%) but significant portion of the variation in semen volume can be explained by gained body weight. This is in line with the generally low heritability values for fertility.

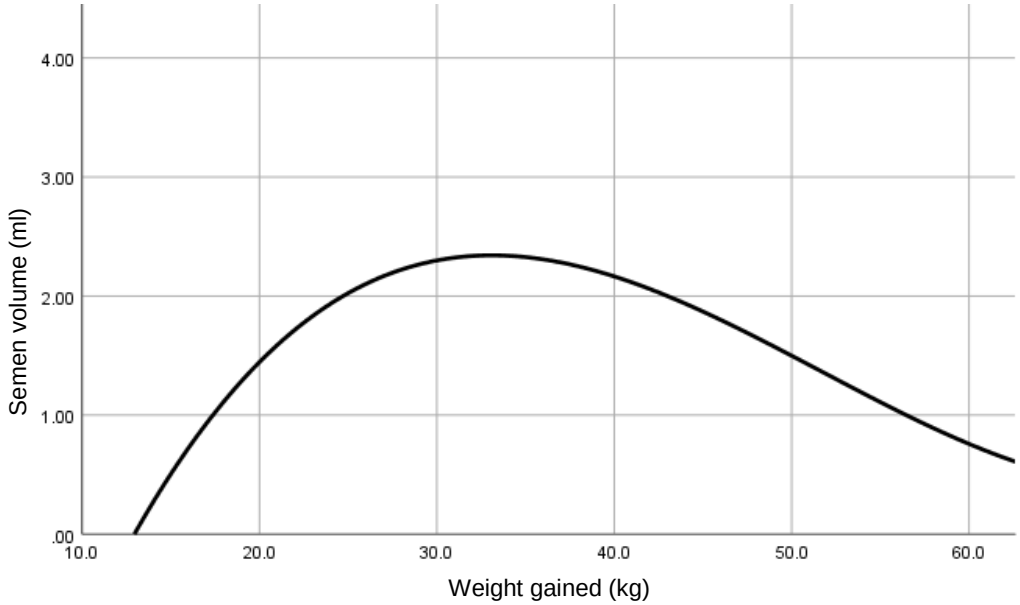


Figure 3.15 Regression of gained weight on semen volume (pooled over breeds and treatments)

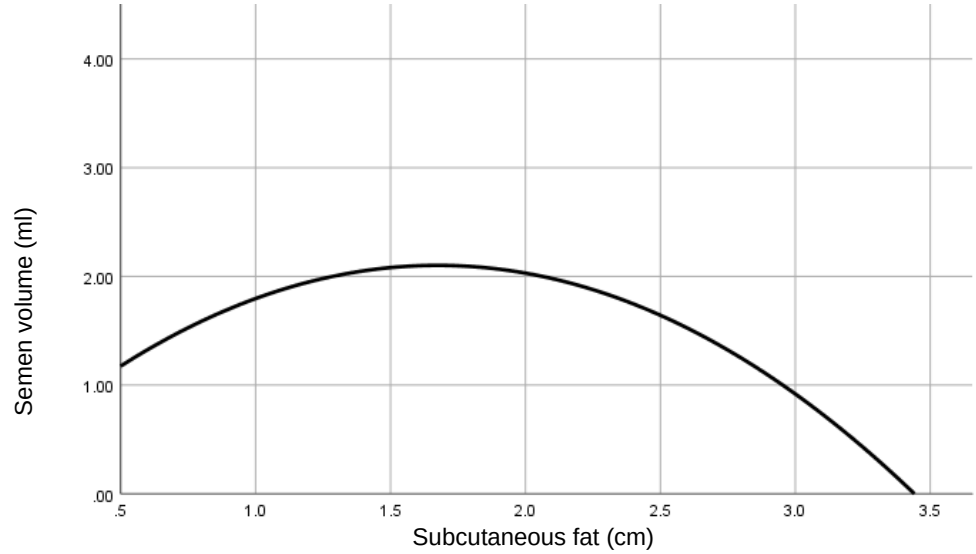


Figure 3.16 Regression of subcutaneous fat on semen volume (pooled over breeds and treatments)

A similar detrimental effect on semen volume was observed in the regression analysis, $y = 0.2 + 2.3x - 0.7x^2$ (a quadratic mathematical function) of subcutaneous fat and semen volume (Figure 3.16). When the subcutaneous fat becomes thicker than 1.6cm, then semen volume may begin to decrease (R^2 = 0.07, P < 0.05). This may be because increased subcutaneous

fat resulted in increased SSNF and scrotal fat deposition (R^2 = 0.40; P < 0.001 and R^2 = 0.06, P < 0.05 respectively). Similar to other fertility characteristics, the R^2-value of semen volume over subcutaneous fat was small, but significant. It is also important to note that there was a threshold for subcutaneous fat thickness, after which the effect on semen volume showed a negative trend (Figure 3.16).

Table 3.13 Effects of finishing treatment on semen results ($\overline{X} \pm SD$) of Döhne Merino, Merino and South African Mutton Merino (SAM) rams following either an extensive, extensive-intensive, or intensive treatment

Variables ($\bar{X}$ ± SD)	**Finishing treatment**		
	Intensive (n = 28)	**Extensive- Intensive** (n = 30)	**Extensive** (n = 28)
Semen volume (ml)	1.8 ± 0.89[ab]	2.3 ± 1.02[a]	1.6 ± 0.70[b]
Semen colour	4 ± 1.4	5 ± 1.5	5 ± 1.4
Mass motility	4 ± 1.3	4 ± 1.0	4 ± 0.7
Progressive Motility (%)	71.4 ± 25.45	77.0 ± 13.49	80.0 ± 7.58
Aberrant motile spermatozoa (%)	11.0 ± 9.65	10.2 ± 6.88	8.4 ± 3.61
Immotile/dead spermatozoa (%)	17.6 ± 20.26	12.8 ± 7.27	11.6 ± 5.45
Normal spermatozoa (%)	69.0 ± 20.04[a]	81.7 ± 9.88[b]	83.0 ± 10.09[b]

[a, b] Means with different superscripts, within a row, differ significantly (P < 0.05)
$\bar{X}$ ± SD – Mean ± Standard deviation
Semen colour – on a scale of 0 to 5; Mass motility – on a scale of 0 to 5

The extensive treatment recorded slightly better progressive spermatozoa motility and fewer aberrant motile and immotile/dead spermatozoa than the other two treatments, although not significant. Season also did not have an effect on these variables (P > 0.05). The findings of the present study agree with those of Alexopoulos *et al.* (1991) and Elmaz *et al.* (2007) who reported no major fluctuations in semen motility in rams between the ages of seven and 14 months. However, Alexopoulos *et al.* (1991) did report that abnormal spermatozoa percentage decreased rapidly after five months of age.

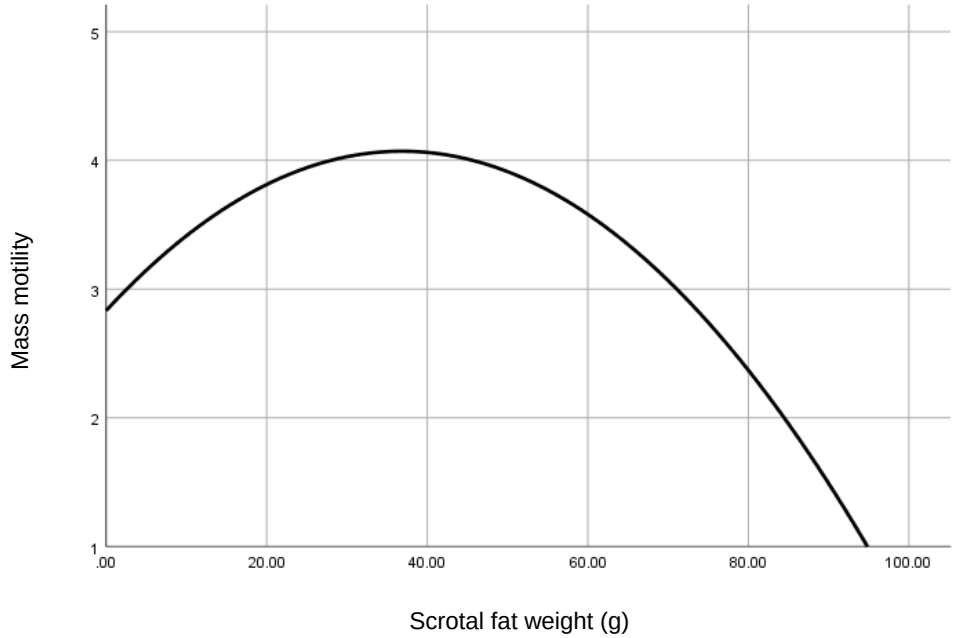


Figure 3.17 Regression of scrotal fat weight on mass motility (pooled over breeds and treatments)

The regression analysis, $y = 2.8 + 0.07x – 0.0009x^2$ (a quadratic mathematical function) of scrotal fat weight and spermatozoa mass motility (Figure 3.17) shows that there is a possible threshold scrotal fat weight (*ca.* 39g), which, when breached, will result in decreased mass motility ($R^2 = 0.07$, $P < 0.05$). Spermatozoa mass motility is a categorical variable, thus values/the shape of the curve might be overexaggerated, but that does not take away from the fact that there is a scrotal fat threshold.

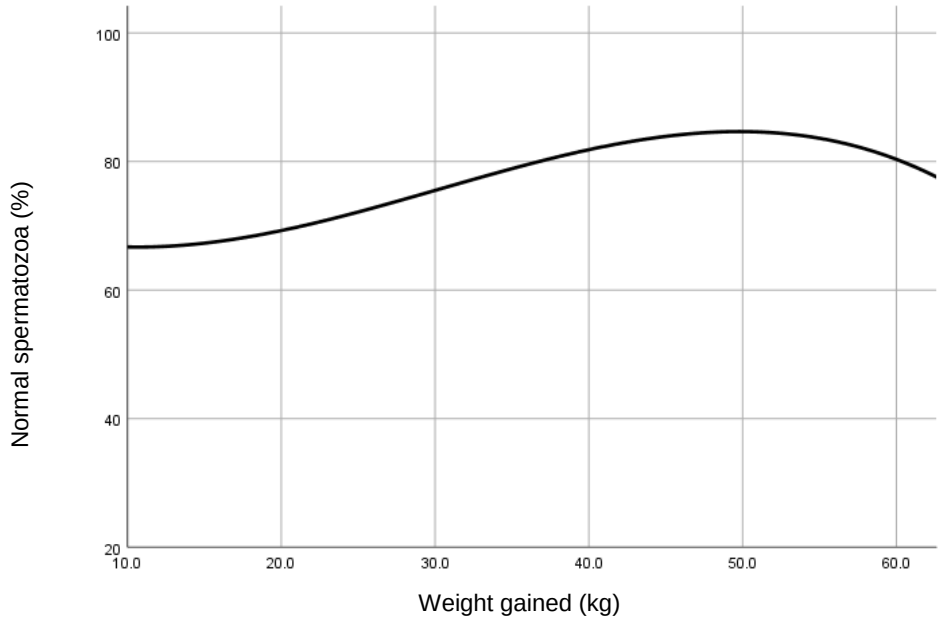


Figure 3.18 Regression of gained weight on percentage normal spermatozoa (pooled over breeds and treatments)

Treatment did affect the percentage normal spermatozoa. The younger rams in the intensive treatment recorded less normal spermatozoa than the older rams in both the extensive (P = 0.001) and extensive-intensive (P = 0.002) treatments. This is in accordance to the accepted understanding than semen characteristics improve as animals age, e.g. more abnormal sperm are found in the ejaculates of pubescent rams compared to adult rams (Courot., 1979), and as testicular dimensions increase. Season also had an effect on this variable (P < 0.05), which adds to the explanation of the difference between the intensive and extensive treatments.

The regression analysis, $y = 71.5 - 0.96x + 0.05x^2 – 0.0006x^3$ (a cubic mathematical function) of weight gained and percentage normal spermatozoa (Figure 3.18) shows that above the weight gained threshold of 50kg that the percentage normal spermatozoa begins to decrease ($R^2 = 0.14$, $P < 0.01$). Figure 3.19 illustrates the regression analysis, $y = 36.5 + 41.8x – 8.99x^2$ (a quadratic mathematical function), of subcutaneous fat over percentage normal spermatozoa. The regression also shows a fat threshold which, when breached, will result in a decreased percentage of normal spermatozoa. The threshold of the subcutaneous fat layer is at a thickness of *ca.* 2.2cm ($R^2 = 0.19$, $P < 0.001$). Both gained body weight and subcutaneous fat recorded positive correlations ($P < 0.05$) with percentage normal spermatozoa ($r = 0.40$ and $r = 0.36$ respectively). Again, both these R^2-values were small, but they were significant and there were clear threshold values. As previously mentioned, these low R^2-values are in line with the generally low heritability values of fertility.

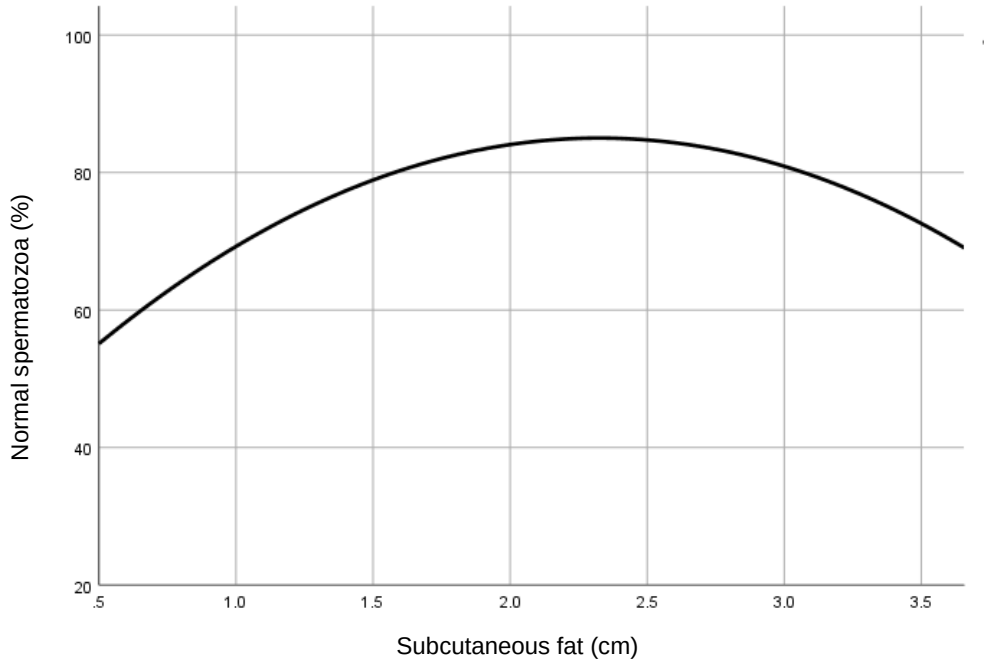


Figure 3.19 Regression of subcutaneous fat on percentage normal spermatozoa (pooled over breeds and treatments)

Overall breed effects: Breed also had very little effect on semen measurements (Table 3.14). The only differences were between the Döhne Merino rams and the Merino rams for semen volume ($P < 0.05$) and for mass motility ($P < 0.05$), as well as between Döhne Merino rams and SAM rams for mass motility ($P < 0.05$). The Döhne Merino rams recorded heavier testes ($P < 0.05$) than the Merino rams which would explain why these rams recorded a higher semen volume. It is also well documented that breeds differ in the volume of semen they produce (Barrell & Lapwood, 1979; Boland *et al.*, 1985; Langford *et al.*, 1998; Gündoğan, 2007).

Table 3.14 Effects of breed on semen results ($\overline{X} \pm SD$) of Döhne Merino, Merino and South African Mutton Merino (SAM) rams

Variables ($\bar{X}$ ± SD)	**Breed**		
	Döhne (n = 29)	**Merino** (n = 29)	**SAM** (n = 28)
Semen volume (ml)	2.2 ± 0.88[a]	1.6 ± 0.83[b]	1.9 ± 0.97[ab]
Semen colour	5 ± 1.3	5 ± 1.6	4 ± 1.4
Spermatozoa mass motility	4 ± 0.7[a]	4 ± 1.2[b]	4 ± 1.1[b]
Progressive spermatozoa motility (%)	76.6 ± 15.65	77.1 ± 17.55	74.8 ± 19.08
Aberrant motile spermatozoa (%)	10.2 ± 7.73	10.3 ± 8.86	9.0 ± 4.02
Immotile/dead spermatozoa (%)	13.3 ± 8.48	12.6 ± 9.32	16.2 ± 18.59
Normal spermatozoa (%)	73.5 ± 19.92	80.2 ± 10.80	80.4 ± 12.95

[a, b] Means with different superscripts, within a row, differ significantly ($P < 0.05$)
$\bar{X}$ ± SD – Mean ± Standard deviation
Semen colour – on a scale of 0 to 5; Mass motility – on a scale of 0 to 5

Finishing treatment x breed interaction effects: Treatment had an effect in the Döhne Merino breed and only on one variable – percentage normal spermatozoa (Table 3.15). The intensive treatment Döhne Merino rams recorded far less normal sperm than their counterparts in the extensive-intensive ($P < 0.01$) and the extensive ($P < 0.05$) treatments. Seeing as there were no differences in testes weight between the treatments, it could be ascribed to the fact that the rams in the extensive-intensive and extensive treatments were older than the rams in the intensive treatment. Although the extensive-intensive treatment

rams recorded thicker SSNF than the rams of the intensive treatment ($P < 0.05$), it would seem not have had too much of a detrimental effect on the percentage normal spermatozoa. Precautions would have to be taken if Döhne Merino rams are fed intensively for a longer period of time, as SSNF would then be detrimental to semen quality traits, as seen in the following correlations between SSNF: progressive motility ($r = -0.76$, $P < 0.05$), percentage normal spermatozoa ($r = -0.80$, $P < 0.05$), aberrant motile spermatozoa ($r = 0.78$, $P < 0.05$), and immotile/dead spermatozoa ($r = 0.73$, $P < 0.05$). Extensive-intensive treatment Döhne Merino rams recorded a positive correlation between semen volume and testes weight ($r = 0.68$, $P < 0.05$).

Bester *et al.* (2004) recorded no significant improvement or decline in semen parameters when rams were fed high energy diets. This was in contrast to the findings of Braden *et al.* (1974) who found that increasing the energy intake of Merino rams had a marked influence in improving the daily sperm production. In the present study, the intensive treatment rams were in their pubescent stage, which could explain why these rams did not have significantly better semen characteristics, but it is possible that the concentrate diet improved their semen characteristics (via improved testicular growth) compared to if they had not received a concentrate diet. This is supported by the positive correlation seen in the intensive treatment Döhne Merino rams between testes weight and percentage normal spermatozoa ($r = 0.76$, $P < 0.05$) and the negative correlation between testes weight and aberrant motile spermatozoa in the SAM rams ($r = -0.75$, $P < 0.05$). The statement is further supported by the positive correlation observed in the intensive treatment Döhne Merino rams between semen volume and BCS_F ($r = 0.73$, $P < 0.05$), as well as the following correlations observed in the Merino rams: progressive motility and BCS_F ($r = 0.93$, $P < 0.01$), BCS_F and aberrant motile spermatozoa ($r = -0.91$, $P < 0.01$), BCS_F and immotile/dead spermatozoa ($r = -0.95$, $P = 0.001$), and between BCS_F and percentage normal spermatozoa ($r = 0.84$, $P < 0.05$). A better BCS implies that an animal is healthier and heavier, and, as was found in this treatment, body weight was positively correlated to testes weight. A higher BCS means more subcutaneous fat, thus there is also a threshold for BCS which, if breached, could result in poorer semen parameters (as previously discussed for subcutaneous fat).

The extensive treatment rams were both older and nearing their natural breeding season, which could possibly explain why they had better semen characteristics. The extensive-intensive treatment had good semen characteristics due to their older age and because they were fed a concentrate diet.

Table 3.15 Effects of finishing treatment and breed on semen results ($\overline{X} \pm SD$) of Döhne Merino, Merino and South African Mutton Merino (SAM) rams following either an extensive, extensive-intensive or intensive treatment

Factors		Variables ($\bar{X}$ ± SD)						
Finishing treatment	**Breed**	**Semen volume** (ml)	**Semen colour**	**Mass motility**	**Progressive motility** (%)	**Aberrant motile spermatozoa** (%)	**Immotile/dead spermatozoa** (%)	**Normal spermatozoa** (%)
Intensive	**Döhne** (n = 10)	1.9 ± 0.95	4 ± 1.5	5 ± 0.5	70.0 ± 25.37	13.3 ± 12.50	16.7 ± 12.99	57.9 ± 24.79[A]
	Merino (n = 10)	1.3 ± 0.56	5 ± 1.5	4 ± 1.3	76.1 ± 21.76	12.2 ± 10.93	11.7 ± 10.90	75.4 ± 13.54
	SAM (n = 8)	2.1 ± 0.98	4 ± 1.3	4 ± 1.6	68.5 ± 30.28	7.7 ± 3.89	23.8 ± 29.94	73.3 ± 17.60
Extensive-Intensive	**Döhne** (n = 10)	2.7 ± 1.03	5 ± 1.2	4 ± 0.4	77.5 ± 7.55	10.5 ± 4.38	12.0 ± 4.22	82.2 ± 12.18[B]
	Merino (n = 10)	2.1 ± 1.02	5 ± 1.6	3 ± 1.3	75.5 ± 21.40	10.5 ± 10.66	14.0 ± 11.26	80.8 ± 10.63
	SAM (n = 10)	2.1 ± 1.01	5 ± 1.7	4 ± 0.8	78.0 ± 8.23	9.5 ± 4.38	12.5 ± 4.86	82.2 ± 7.19
Extensive	**Döhne** (n = 9)	2.0 ± 0.47	5 ± 1.1	4 ± 0.7	81.5 ± 7.84	7.0 ± 2.58	11.5 ± 6.26	78.9 ± 13.42[B]
	Merino (n = 9)	1.5 ± 0.69	4 ± 1.9	4 ± 1.0	79.5 ± 8.32	8.5 ± 4.12	12.0 ± 5.87	83.9 ± 6.98
	SAM (n = 10)	1.4 ± 0.83	5 ± 0.7	4 ± 0.4	78.8 ± 6.94	10.0 ± 3.78	11.3 ± 4.43	87.1 ± 7.34

[A, B] Different superscripts in the same column within a breed differ significantly (P < 0.05)

$\bar{X}$ ± SD – Mean ± Standard deviation

Semen colour – on a scale of 0 to 5; Mass motility – on a scale of 0 to 5

In the scrotal measurements section, PPC:SSNF ratios were compared between treatments within the same breed. Although it seemed that the intensive treatment recorded more efficient PPC:SSNF ratio values, it could be argued that, although the extensive treatment had more SSNF, the extensive treatment actually recorded a better PPC:SSNF ratio due to their larger PPC. The pertinent question at this stage is if the thicker SSNF of rams in the extensive treatment had any detrimental effect on the semen parameters. Progressive spermatozoa motility was better in the extensive treatment for all rams of the three breeds compared to the intensive treatment (although not significantly). Döhne Merino and SAM rams in the extensive-intensive treatment (both of which contained significantly more SSNF), recorded better progressive motility than their counterparts in the intensive treatment (although not significant).

Both Döhne Merino and Merino rams exhibited the least aberrant motile spermatozoa in the extensive treatment and highest in the intensive treatment (even though Merino rams in the extensive treatment had thicker ($P < 0.001$) SSNF than those in the intensive treatment). A negative correlation between immotile/dead spermatozoa and SSNF was observed in the extensive treatment Merino rams ($r = -0.78$, $P < 0.05$). As for the percentage normal spermatozoa, the Merino rams of the extensive treatment had the highest percentage normal spermatozoa, while their counterparts in the intensive treatment had the lowest percentage spermatozoa ($P > 0.05$). In the Döhne Merino breed, it was also the treatment which had the most SSNF and had the highest percentage normal spermatozoa – the extensive-intensive treatment. Although the SAM rams of the extensive-intensive treatment (who had the thickest SSNF) recorded more normal spermatozoa than the SAM rams in the intensive treatment, it was the rams in the extensive treatment who recorded the highest percentage normal spermatozoa and the least immotile/dead spermatozoa ($P > 0.05$). These rams may possibly be slightly more sensitive to the thicker SSNF. It would be advisable to take care that SSNF does not get too thick in this breed. Thus, although none of these values were significant, there was a trend. As long as a ram has well developed testes and PPC, SSNF will not be as detrimental, provided SSNF does not get too thick.

Figure 3.20 shows the relationship between percentage normal spermatozoa, testes weight and scrotal fat weight and how treatment influenced these variables. The trend for number of normal spermatozoa seemed to increase as the duration of treatments, and testes weight, increased and scrotal fat decreased. Except in the extensive-intensive treatment, where percentage normal spermatozoa was higher ($P > 0.05$) for all three breeds compared with the rams in the younger rams in the intensive treatment, although the former had more scrotal fat than the latter. This was especially true for rams of the Döhne Merino breed in the extensive-intensive treatment, which had the highest percentage normal spermatozoa ($P < 0.05$), despite having the most scrotal fat ($P < 0.05$) compared to its Döhne Merino counterparts in the other treatments. There will be a limit to the

amount of scrotal fat which can be deposited before it becomes detrimental to semen quality traits, especially in the Merino breed in the extensive treatment as there was a negative correlation between scrotal fat weight and percentage normal sperm ($r = -0.71$, $P < 0.05$).

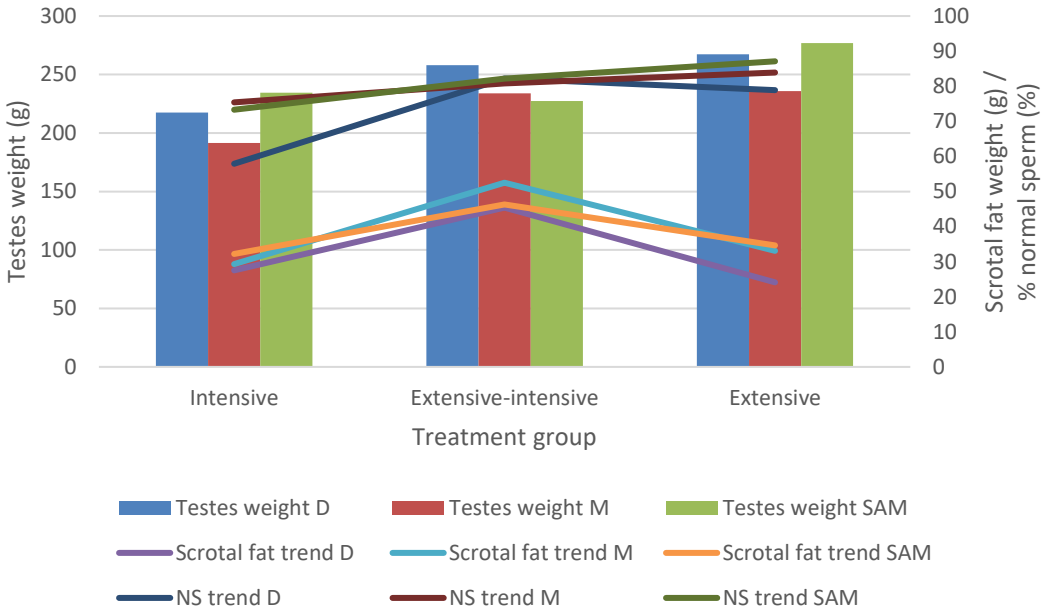


Figure 3.20 The relationship between testes weight (g), scrotal fat weight (g), and normal spermatozoa (NS) (%) of Döhne Merino (D), Merino (M), and South African Mutton Merino (SAM) rams following either an extensive, extensive-intensive, and intensive treatment

The relationship between SSNF, PPC and percentage normal spermatozoa is illustrated in Figure 3.21. It also shows how the treatments affected these variables. Scanned scrotal neck fat increased as treatment duration increased, except for the Döhne Merino and SAM rams in the extensive-intensive treatment which had more SSNF than the Döhne Merino and SAM rams in the extensive treatment. Although SSNF increased as treatment duration increased, so did the percentage normal spermatozoa which was due to 1) the increase in testes weight (and thus nutrition), 2) the increase in PPC and 3) an increase in age of rams. Larger testes mean a higher spermatozoa production, and larger PPC means a larger surface area for thermoregulation to occur, regardless of the presence of SSNF.

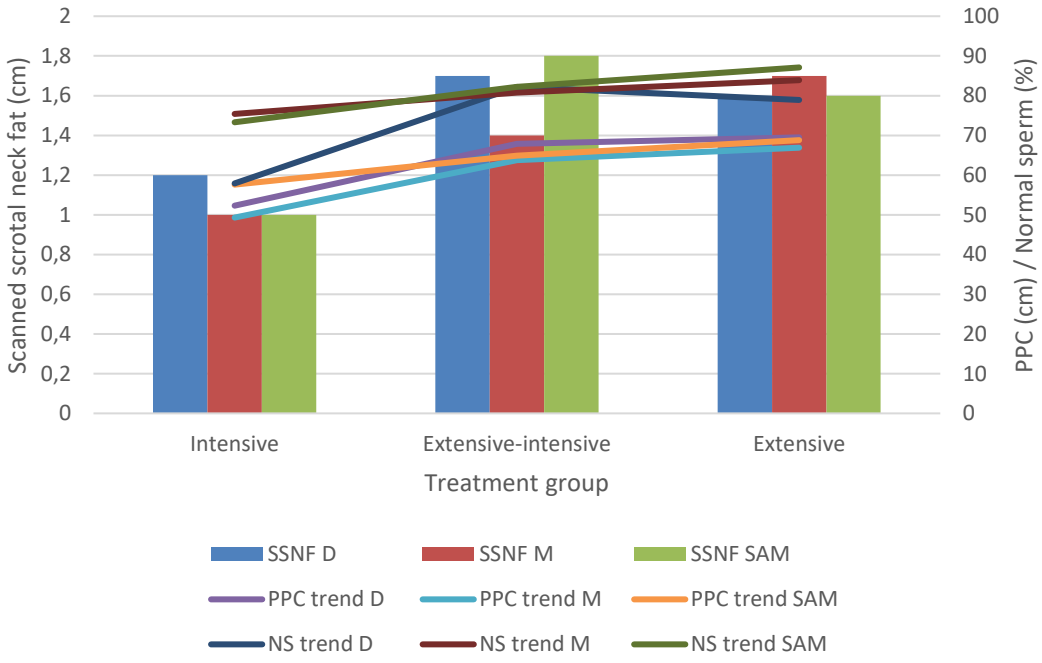


Figure 3.21 The relationship between SSNF (cm), *Pampiniform venous plexus* (PPC) (cm), and normal spermatozoa (NS) (%) of Döhne Merino (D), Merino (M), and South African Mutton Merino (SAM) rams following either an extensive, extensive-intensive, and intensive treatment

It is widely accepted that SC can be used as an indirect estimate of semen quantity (as it indirectly measures testes circumference) (Schoeman & Combrink, 1987; Kheradmand *et al*., 2006; Elmaz *et al*., 2007). In the current study, only four of the nine treatment-breed combinations showed positive correlations between SC_F and testes weight (intensive Döhne Merino and SAM rams, extensive-intensive Merino rams, and extensive treatment SAM rams). The few SC_F correlations with semen characteristics were regarding spermatozoa mass motility of the SAM rams in the intensive treatment ($r = 0.66$, $P < 0.05$), and progressive spermatozoa motility ($r = 0.73$, $P < 0.05$) and immotile/dead spermatozoa ($r = -0.79$, $P < 0.05$) for the extensive treatment Döhne Merino rams. A negative correlation between SC_F and percentage normal spermatozoa was recorded for the extensive-intensive treatment Döhne Merino rams ($r = -0.87$, $P < 0.01$). The negative correlation could possibly be due to the high scrotal fat deposition which occurred in the Döhne Merino rams in this treatment. The rams of all breeds and treatments may have been too immature at time of slaughter to achieve significant correlations.

In the scrotal measurements section, very few significant correlations were observed between final body weight and testes weight. The same can be said for this section; the only notable correlations observed were for Döhne Merino and SAM rams in the extensive treatment. The Döhne Merino rams

recorded a positive correlation between spermatozoa mass motility and final body weight ($r = 0.70$, $P < 0.05$), while the correlation in the SAM rams was between final body weight and percentage normal spermatozoa ($r = 0.76$, $P < 0.05$). It would seem that subcutaneous fat was not detrimental to semen characteristics in the younger, intensive treatment rams – while it may become detrimental once a certain threshold thickness is reached in the older, extensive treatment SAM rams. In the intensive treatment, the Döhne Merino rams recorded a positive correlation between subcutaneous fat and mass motility ($r = 0.86$, $P < 0.01$). The intensive treatment SAM rams showed a negative correlation between subcutaneous fat and aberrant motile spermatozoa ($r = -0.70$, $P < 0.05$), while their extensive treatment counterparts had a negative correlation between subcutaneous fat and semen volume ($r = -0.88$, $P < 0.01$). The reason why subcutaneous fat was not as detrimental in the intensive treatment as in the extensive treatment may be because the rams in the intensive treatment were still young and thus did not have much subcutaneous fat. This is supported by the regression analyses of subcutaneous fat over percentage normal spermatozoa and semen volume, which were discussed earlier. The subcutaneous fat of the intensive treatment rams did not exceed the 1.6cm threshold. Subcutaneous fat is generally an indicator of maturity and, as previously stated, semen characteristics improve as rams age.

Absolutely no correlations were observed in the SAM rams in the extensive-intensive treatment and there were no correlations between scrotal measurement and semen characteristics in the intensive treatment Merino rams. This has been reported in other studies, such as the research done by Fernandez-Abella *et al.* (1999), while Elmaz *et al.* (2007) found no correlations in older rams (nine to 14 months old). Although, in the current study, a few correlations were observed between scrotal measurements and semen characteristics such as mass motility and testes weight in the extensive treatment Döhne Merino rams ($r = 0.71$, $P < 0.05$), and scrotal weight and aberrant motile spermatozoa in the intensive treatment SAM rams ($r = -0.70$, $P < 0.05$). Other correlations have already been mentioned or can be seen in Addendum B.

There was also no increase in the number of correlations for semen quality traits or scrotal measurements between the extensive treatment and the other two treatments for the Döhne Merino and SAM breeds. Thus, although the extensive treatment rams were nearing the natural breeding season and season had an effect on semen volume and percentage normal spermatozoa, it seems that the finishing treatment had a greater effect on scrotal measurements and semen characteristics in these breeds. In the Merino breed there were more correlations in the extensive-intensive and extensive treatments than in the intensive treatment.

It would seem that there were treatment effects on correlations between semen characteristics and the various testicular ratios (PPC:SSNF, PPC:SFM, PPC:TM and EffecPPC:TM). In the intensive

treatment (where PPC was the smallest and SSNF the thinnest compared to the other treatments) Döhne Merino rams recorded a positive correlation between PPC:SSNF ration and the percentage normal spermatozoa ($r = 0.90$, $P < 0.01$). Thus, greater PPC meant more effective PPC and a higher percentage normal spermatozoa. The intensive treatment SAM rams had negative correlations between PPC:TM ratio and the percentage normal spermatozoa ($r = -0.68$, $P < 0.05$) and EffecPPC:TM ratio and the percentage normal spermatozoa ($r = -0.70$, $P < 0.05$), but positive correlations between PPC:TM ratio and aberrant motile spermatozoa ($r = 0.84$, $P < 0.01$) and EffecPPC:TM ratio and immotile/dead spermatozoa ($r = 0.70$, $P < 0.05$).

The extensive treatment Merino rams had correlations between EffecPPC:TM and immotile/dead spermatozoa ($r = 0.96$, $P < 0.001$), as well as between EffecPPC:TM and progressive motility ($r = -0.85$, $P < 0.01$), showing that testes size was more important. There was also a correlation between PPC:SSNF and immotile/dead spermatozoa ($r = 0.83$, $P < 0.05$). In the Merino breed in the extensive-intensive treatment, PPC seemed to be more important as supported by the following correlations: PPC:SSNF and aberrant motile spermatozoa ($r = -0.68$, $P < 0.05$), PPC:TM and aberrant motile spermatozoa ($r = -0.98$, $P < 0.001$), PPC:TM and immotile/dead spermatozoa ($r = -0.85$, $P < 0.01$), PPC:TM and progressive motility ($r = 0.93$, $P < 0.001$), PPC:TM and percentage normal spermatozoa ($r = 0.82$, $P < 0.01$), EffecPPC:TM and aberrant motile spermatozoa ($r = -0.70$, $P < 0.05$) and lastly, EffecPPC:TM and percentage normal spermatozoa ($r = 0.072$, $P < 0.05$). The same can be said for the Döhne Merino breed in the extensive-intensive and extensive treatments – testes weight was more important in the extensive treatment (negative correlations between PPC:TM and mass motility, and between EffecPPC:TM and mass motility, and a positive correlation between PPC:TM and immotile/dead spermatozoa), while larger PPC was more important in the extensive-intensive treatment (positive correlation between EffecPPC:TM and percentage normal spermatozoa).

3.5 Hormone assays

Only three blood hormones were determined in this study due to the cost of blood hormone analyses and the possible adverse effects of frequent blood sample collections. The three hormones monitored were plasma triiodothyronine (T_3) as indicator of metabolic rate and physiological maturity, serum testosterone as male reproductive hormone produced by the testes, and plasma calcitonin as indicator of bone mineralisation and physiological maturity.

Overall finishing treatment effects: Finishing treatments had an effect on plasma T_3 ($P < 0.001$) and serum testosterone concentrations ($P < 0.001$, Table 3.16). Triiodothyronine (T_3) concentrations were lower in rams in the extensive treatment compared to those in the intensive treatment ($P < 0.001$) and the extensive-intensive treatment ($P < 0.01$). Triiodothyronine (the active form of thyroxine) plays an essential role in physiological processes such as growth and development, the regulation of metabolic rate (metabolism), and oxygen consumption by most cells in the body (Hossner, 2005). Triiodothyronine increases the basal metabolic rate (thus oxygen and energy consumption by the body's cells are increased), increases protein turnover rate, increases glucose synthesis (through increased glycogen breakdown), and increases lipolysis (Reece, 2015). The higher concentration of plasma T_3 in the intensive and extensive-intensive treatment ram groups suggests that these rams had greater protein turnover rates, glucose synthesis, and lipolysis than the rams in the extensive treatment. As the intensive treatment consisted of young rams, and both these treatments received concentrate diets, it is not surprising that plasma T_3 concentrations were higher. These results are in agreement with those reported by Zhang *et al.* (2004).

A number of factors influence the blood concentrations of plasma T_3 and Thyroxin (T_4), such as day light length and environmental temperature, season (which, in this study was included as a random factor, had an effect on T_3; $P < 0.001$), physiological state, metabolism and feed intake (which is rest/activity related) (Todini, 2007). Todini (2007) also noted interactions between these factors and T_3 and T_4. A possible reason for the lower plasma T_3 concentrations in the extensive treatment may be because the rams in the extensive treatment were more mature than those in the other two treatments, and hence had lower metabolic rates. This can be verified by the amount of fat the rams deposited. Adipose tissue is the last tissue to develop and is associated with maturity (Hossner, 2005). As was observed and explained in the anthropometric results section, the rams in the extensive treatment had more ($P < 0.001$) subcutaneous fat than rams in the intensive treatment.

Gündoğan (2007) showed that season influenced blood T_3 concentrations in Turkish sheep breeds, with significantly higher values reported for the summer and autumn months. An inverse relationship was also observed between environmental temperature and blood thyroid hormone concentrations (Valtorta *et al*.,1982; Webster *et al*., 1991; Starling *et al*., 2005). This variation in plasma T_3

concentrations according to season, which indicates a change in thyroid activity, is generally observed in grazing animals as their physiological functions are seasonal due to nutritional changes. This allows animals to adapt to the homeoretic changes of their physiology i.e. to change their metabolic balance according to changes in environmental conditions, their nutrient requirements during a certain physiological stage, and nutrient availability (Todini, 2007). Contradictory results for the seasonal influence on thyroid hormones have been found, as nutrition has an important influence on modifying thyroid hormone concentrations, especially in southern hemisphere breeds.

Table 3.16 Effects of finishing treatment on blood hormone concentration results ($\overline{X} \pm SD$) of Döhne Merino, Merino and South African Mutton Merino (SAM) rams following either an extensive, extensive-intensive, or intensive treatment

Variables ($\bar{X}$ ± SD)	**Treatment group**		
	Intensive (n = 29)	**Extensive- Intensive** (n = 30)	**Extensive** (n = 29)
Triiodothyronine (g/ml)	2.44 ± 0.370[a]	2.38 ± 0.460[a]	1.99 ± 0.520[b]
Testosterone (g/ml)	10.15 ± 5.972[a]	3.50 ± 4.949[b]	5.41 ± 6.000[b]
Calcitonin (g/ml)	161.92 ± 52.658	158.46 ± 35.738	140.42 ± 24.489

[a, b] Means with different superscripts, within a row, differ significantly (P<0.05)

$\bar{X}$ ± SD – Mean ± Standard deviation

The rams kept intensively recorded significantly higher serum testosterone concentrations compared to the other two treatments. These findings are in agreement with the findings of Walkden-Brown *et al.* (1994) and Hötzel *et al.* (1998) who found that testosterone concentrations taken at the jugular vein were higher in rams fed higher energy diets than those fed low energy diets. Thus, although the intensive treatment rams were younger than the extensive treatment, the intensive treatment received a concentrate diet for two months.

In this trial, treatment had a significant effect on blood testosterone concentrations, while season did not. Hötzel *et al.* (1998) argued that more testosterone is produced by heavier testes, as the total volume of Leydig cells is higher (as well as the surface area of the endoplasmic reticulum) in larger testes and that heavier testes would have a greater total volume of blood and lymph vessels. Thus, increasing the concentrations of testosterone reaching the peripheral circulation. Rams in the

intensive treatment had significantly smaller testes than the other treatments, but nutrition may have stimulated increasing Leydig cell volume, and or the surface area of the endoplasmic reticulum at that stage. Steriodogenic activity is not only regulated by the size and number of Leydig cells, but also by the number of LH receptors found on the surface of Leydig cells which would influence LH sensitivity (Barenton *et al.*, 1983). How nutrition affects LH receptor populations on the Leydig cells is not well understood, but this may explain why the older extensive treatment rams (who were also nearing their natural breeding season) had lower testosterone concentrations than the younger intensive treatment rams. It may also be due to the significantly lower plasma T_3 concentrations observed in the extensive treatment group. Hypothyroidism induced in both goats (Gupta *et al.*, 1991) and sheep (Chandrasekhar *et al.*, 1986) caused a decrease in serum testosterone concentrations as plasma T_3 concentrations decreased, which was due to a depressed response in both the pituitary to GnRH and testis to LH. It may also be due to fewer LH receptors in the testis, as was observed in hypothyroid rats by Valle *et al.* (1985).

Circulating oestradiol concentration was not measured in the present study, but Hötzel *et al.* (1998) suggested that nutrition may influence the rate of aromatization of testosterone to oestradiol, and peripheral testosterone concentrations are also influenced by the clearance rate (Gupta *et al.*, 1991). It is possible that the lower serum testosterone values of the extensive treatment group were due to a higher aromatization rate of testosterone to oestradiol, and or higher clearance rate of testosterone. There are significant correlations between the effect of time and the effect of diet on both testicular and peripheral testosterone circulations (Hötzel *et al.*, 1998). The severity and duration of the diet also affects blood testosterone concentrations, which explains the differences observed between studies (Martin *et al.*, 1994).

What remains unclear is the difference ($P < 0.001$) in testosterone concentrations between the intensive and extensive-intensive treatments. These rams had similar testicular dimensions (except for testes volume and length – the intensive treatment had lower ($P < 0.05$) values than the extensive-intensive treatments), were fed the concentrate diet for the same duration of time and the extensive-intensive treatment rams were older. The results from the present study are in agreement with Yarney & Sanford (1990), but this study was done on Suffolk sheep (which is sensitive to photoperiodism), where testosterone samples were taken in 6-7-month-old rams during the breeding season and retested again in 13-14-month-old rams when it was not during the breeding season. The results in this study are dissimilar to those of Elmaz *et al.*, (2007) – who showed a spike in testosterone concentrations in rams aged 260 days – and Saeed & Zaid (2019) who showed no difference between seven-month-old and nine-month-old rams.

Table 3.17 Effects of breed on blood hormone concentration results ($\overline{X} \pm SD$) of Döhne Merino, Merino and South African Mutton Merino (SAM) rams

Variables ($\bar{X}$ ± SD)	**Breed**		
	Döhne (n = 30)	**Merino** (n = 30)	**SAM** (n = 28)
Triiodothyronine (g/ml)	2.24 ± 0.428	2.40 ± 0.526	2.16 ± 0.500
Testosterone (g/ml)	7.19 ± 7.127	7.31 ± 6.428	4.34 ± 4.600
Calcitonin (g/ml)	155.00 ± 30.894	153.61 ± 57.790	152.27 ± 23.240

$\bar{X}$ ± SD – Mean ± Standard deviation

Overall breed effects: There were no significant differences in blood T_3 or calcitonin concentrations between the three breeds, implying that all three breeds were of a similar maturity at the time of blood collection. There were also no significant differences in serum testosterone concentrations between the three breeds, although the SAM rams did have numerically lower concentrations, which could be a breed effect.

Finishing treatment x breed interaction effects: From Table 3.18 the only significant differences occurred in the T_3 concentration variable. The SAM rams in the intensive treatment recorded higher plasma T_3 concentrations ($P < 0.001$) than the SAM rams in the extensive treatment. As previously stated, T_3 can be used as an indicator of physiological maturity as its concentrations decreases as an animal matures. This is substantiated by the negative correlation observed between SSNF and T_3 concentrations ($r = - 0.72$, $P < 0.05$) in SAM rams in the intensive treatment. Merino and Döhne Merino rams in the extensive treatment also recorded the lowest T_3 concentrations compared to their counterparts in the other treatments (although not significantly). The extensive-intensive Merino rams had the highest plasma T_3 concentrations numerically ($P > 0.05$) compared to the Merino rams in the other treatments, while the extensive treatment Döhne Merino rams recorded the highest blood T_3 concentrations ($P > 0.05$) compared to its counterparts in the other treatments.

The results summarised in Table 3.18 indicate that there were no significant differences in the blood testosterone concentrations between finishing treatments nor between breeds. A trend was observed for breed effect as the SAM rams in every treatment had the lowest concentration of testosterone compared to the other two breeds ($P > 0.05$). The highest concentrations ($P > 0.05$) of testosterone were observed in the intensive treatment for all three breeds ($P > 0.05$). As mentioned

before, these results are in accordance with those of Hötzel *et al.* (1998). The low concentrations of testosterone in the SAM rams in the extensive treatment may, as previously stated, be due to the low plasma T_3 concentrations (Chandrasekhar *et al.*, 1986; Gupta *et al.*, 1991), which were also observed for these rams. Although, the lowest testosterone concentrations measured in SAM rams were for those in the extensive-intensive treatment.

Table 3.18 Effects of finishing treatment and breed on blood hormone concentration results ($\overline{X} \pm SD$) of Döhne Merino, Merino and South African Mutton Merino (SAM) rams following either an extensive, extensive-intensively, or intensive treatment

Factors		**Variables** ($\bar{X}$ ± SD)		
Treatment group	**Breed**	**Triiodothyronine** (g/ml)	**Testosterone** (g/ml)	**Calcitonin** (g/ml)
Intensive	**Döhne** (n = 10)	2.35 ± 0.497	10.82 ± 7.820	160.62 ± 24.896
	Merino (n = 11)	2.29 ± 0.182	11.01 ± 4.882	175.02 ± 89.751
	SAM (n = 8)	2.66 ± 0.249^{A}	8.71 ± 5.005	151.42 ± 23.467
Extensive-Intensive	**Döhne** (n = 10)	2.31 ± 0.269$_{ab}$	5.49 ± 7.147	160.62 ± 44.116
	Merino (n = 10)	2.73 ± 0.510$_{a}$	3.58 ± 4.076	157.80 ± 39.822
	SAM (n = 10)	2.09 ± 0.335^{AB}$_{b}$	1.44 ± 1.460	156.95 ± 23.985
Extensive	**Döhne** (n = 10)	2.08 ± 0.472	5.25 ± 5.423	143.74 ± 17.267
	Merino (n = 9)	2.18 ± 0.609	7.67 ± 7.707	132.29 ± 29.721
	SAM (n = 10)	1.62 ± 0.193^{B}	2.50 ± 1.887	147.47 ± 24.021

$^{A, B}$ Different superscripts in the same column within a breed differ significantly (P < 0.05)

$_{a, b}$ Different subscripts in the same column within a treatment differ significantly (P < 0.05)

$\bar{X}$ ± SD – Mean ± Standard deviation

The intensive treatment Döhne Merino rams recorded a positive correlation between testes length and testosterone concentrations (r = 0.81, P < 0.05), but in the Merino rams in this treatment, the correlations between testosterone concentrations and scrotal dimensions were all negative (scrotal

weight, r = -0.94, P < 0.01; PPC, r = -0.80, P < 0.05; testes weight, r = -0.80, P < 0.05; testes volume, r = -0.78, P < 0.05). In the study of Walkden-Brown *et al.* (1994), the group fed the high-quality diet also showed a negative correlation between testes weight and testosterone concentration. The inclusion of season as a random factor in the model also influenced the testicular dimensions (P < 0.001), with larger values obtained for rams during their natural breeding season. Just like the study of Walkden-Brown *et al.* (1994), the present study showed that treatment and season had an effect on testicular dimensions (P < 0.001), but stronger correlations were noted between treatment and testicular dimensions. Unlike Walkden-Brown *et al.* (1994), this study only observed treatment effects on testosterone (P = 0.001) and not seasonal effects as well. Thus, change in testicular dimensions was less dependent on testosterone concentrations, and more so on the ram's metabolic status.

This nutritionally induced dissociation between serum testosterone concentrations and testicular growth has been documented in Merino rams, in Australia, by Ritar *et al.* (1984), Martin *et al.* (1987) and Martin *et al.* (1994). Walkden-Brown *et al*. (1994) postulated that this is a characteristic of rams living in regions of inconsistent food supply or that is not in phase with photoperiodic responses. This may be a mechanism to ensure that the testes are well developed before testosterone-induced behavioural responses occur indicating the mating season. This may further explain why the intensive treatment Merino rams recorded negative correlations between testosterone and testicular dimensions (discussed above) and why Döhne Merino and SAM rams in the extensive-intensive treatment showed detrimental correlations between testosterone and semen characteristics – these measurements were taken a few months before the natural breeding season (SAM rams: percentage normal spermatozoa, r = -0.93, P = 0.001; Döhne Merino rams: progressive motility, r = -0.86, P < 0.01; aberrant motile spermatozoa, r = 0.67, P < 0.05; immotile/dead spermatozoa, r = 0.86, P < 0.01).

No significant differences were observed for plasma calcitonin concentrations between the finishing treatments nor between breeds. The numerically lowest calcitonin concentrations were observed in the extensive treatment for all three breeds, suggesting that these rams were the more mature, and which agrees with the chronological age of rams in the extensive treatment as compared to the other two treatments.

Figure 3.22 shows the relationship between testes weight, scrotal fat weight and testosterone concentrations, and how treatment influenced these variables. In this case, the SAM rams had the lowest serum testosterone concentrations (P > 0.05), despite having the heaviest testes (P > 0.05) in the intensive and extensive treatments. The finding from the present study that SAM rams in the extensive-intensive treatment had the lightest testes compared to SAM rams in the other treatments (P > 0.05), explains why these rams also recorded the lowest testosterone concentrations (P > 0.05).

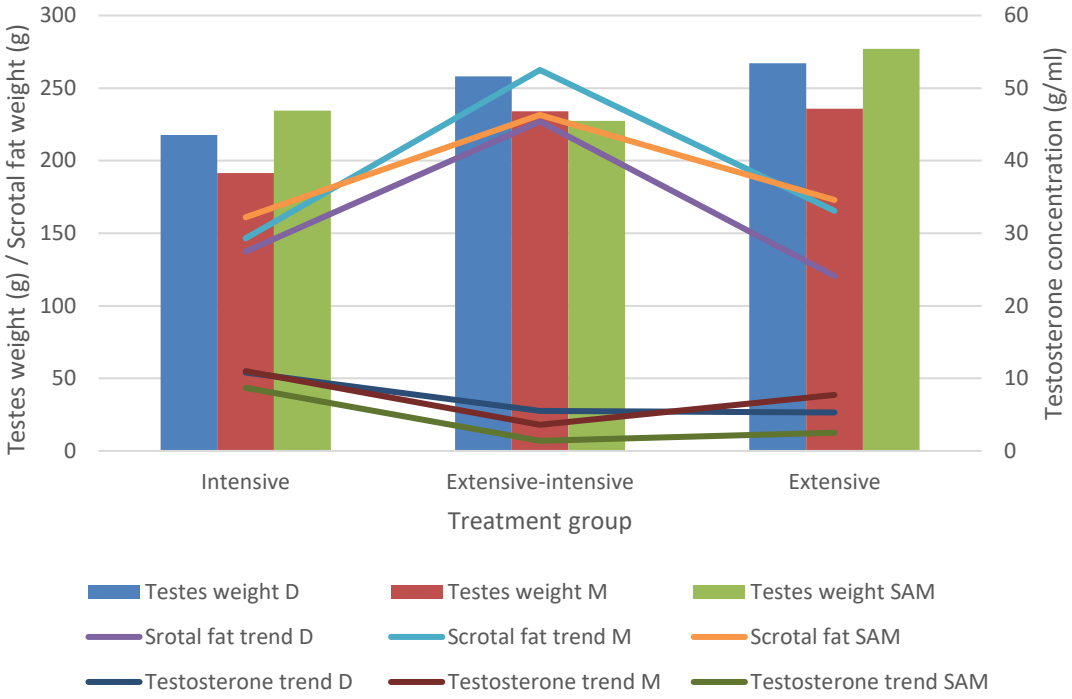


Figure 3.22 The relationship between testes weight (g), scrotal fat weight (g), and testosterone concentrations (g/ml) of Döhne Merino (D), Merino (M), and South African Mutton Merino (SAM) rams following either an extensive, extensive-intensive, and intensive treatment

The effect of treatment on serum testosterone concentration, semen volume and percentage normal spermatozoa is shown in Figure 3.23. The trend observed was that breeds in the intensive treatment recorded the highest blood testosterone concentrations, but the lowest percentage normal spermatozoa ($P > 0.05$). While the breeds in the extensive treatment recorded lower testosterone concentrations and the highest percentage normal spermatozoa ($P > 0.05$). Testosterone is necessary for spermatozoa to mature (Senger, 2003; Bearden *et al.*, 2004), but based on the findings of Oldham *et al.* (1978), Hötzel *et al.* (1998), Fernandez *et al.* (2004) and Kheradmand *et al.* (2006), rams in the extensive treatment probably had better developed seminiferous tubules and Sertoli cells than the intensive treatment, since they were physiologically more mature. However, there was a positive correlation between mass motility and serum testosterone concentrations ($r = 0.73$, $P < 0.05$) for Döhne Merino rams in the intensive treatment.

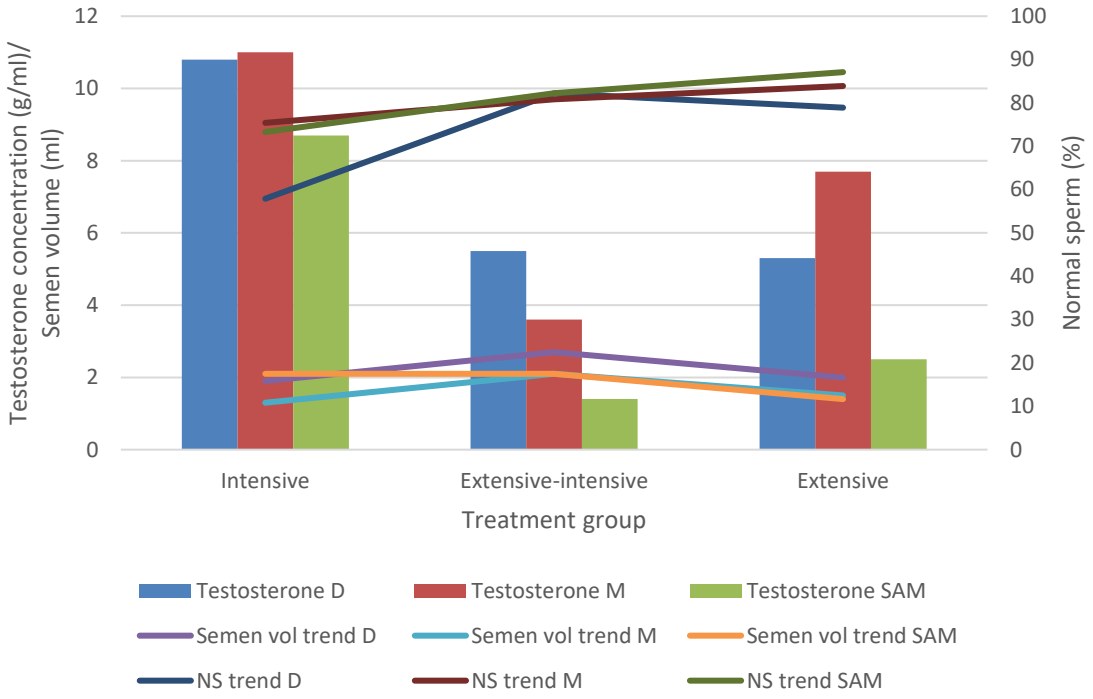


Figure 3.23 The relationship between serum testosterone concentrations (g/ml), semen volume (ml), and normal spermatozoa (%) of Döhne Merino (D), Merino (M), and South African Mutton Merino (SAM) rams following either an extensive, extensive-intensive, and intensive treatment.

CHAPTER 4

CONCLUSIONS

In this study, three current ram feeding systems commonly practised in South African sheep farming (for the conditioning of young rams from weaning until auction) were studied to investigate the effects of different ram finishing systems on growth, gonadal development and semen quality in the subtropics. The effects of the different feeding systems were also tested in rams of different Merino-type breeds which represent different production types, e.g. wool, wool-mutton and mutton-wool.

Overall finishing treatment effects: As the duration of the treatments differed, there was a confounding effect with age. Thus, when comparing the different treatments to each other, the goal was to see whether growth rate was influenced by treatment. Finishing treatment had an effect ($P < 0.05$) on growth (final body weight as well as final anthropometric measurements) with the intensive treatment delivering smaller, lighter rams while the extensive treatment recorded the heaviest, largest rams. Despite this, the rams in the intensive treatment had a higher ADG than those in the extensive-intensive and extensive treatments ($P < 0.05$). Rams in the intensive treatment also had the lowest metabolic weights ($P < 0.05$), the highest Kleiber indexes ($P < 0.05$), and the least subcutaneous fat ($P < 0.05$) compared to the rams in extensive-intensive and extensive treatments, substantiating that rams in the intensive treatment were physiologically younger compared to the rams in the other treatments. High metabolic weights and lower Kleiber index ($P < 0.05$) of rams in the extensive treatment supports the notion that these rams were physiologically older than the extensive-intensive treatment rams.

There was a treatment effect on scrotal measurements, but most of the differences ($P < 0.05$) were between the extensive and intensive treatments and between the extensive and extensive-intensive treatments. Rams in the intensive treatment recorded smaller ($P < 0.05$) SC, scrotal weight, testes weight, testes width, length, circumference and volume than those in the extensive-intensive and extensive treatments. The rams in the extensive-intensive treatment had smaller scrotal measurements than the extensive treatment, with both testes width and testes circumference being significantly smaller. Testes size correlated with body size, which explains why the rams in the intensive treatment recorded smaller testes dimensions compared to rams in the other treatments, while the heavier rams in the extensive treatment had the largest testes.

The *Pampiniform venous plexus* circumference (PPC) of the intensive treatment was smaller ($P < 0.05$) than the PPC of the other treatments. Treatment influenced the area of fat deposition in the scrotum. The intensive treatment had the least scanned scrotal neck fat (SSNF) ($P < 0.05$) compared to the extensive-intensive and extensive treatments. In turn, the extensive-intensive treatment had

significantly more scrotal fat than the other treatments. Regression analyses (pooled over treatments and breeds) showed that an increase in weight gain was associated with higher SSNF (R^2 = 0.43, P < 0.05), while higher ADG was associated with a lower SSNF (R^2 = 0.14, P < 0.001). Gained body weight also showed positive correlations (pooled over treatments and breeds; P < 0.05) with SSNF, while ADG showed a negative correlation (P < 0.05) with SSNF. Thicker subcutaneous fat was associated with more SSNF (R^2 = 0.40; P < 0.001) and heavier scrotal fat weights (R^2 = 0.06, P < 0.05). Subcutaneous fat was positively correlated (P < 0.05) with SSNF and scrotal fat weight. Thus, higher ADG implied more efficient growth (more protein deposition than fat deposition), while more weight gained over the duration of the study was associated with more fat deposition. Subcutaneous fat is sensitive to change in nutrition and is a reliable indicator of overall body fat deposition, which explains why thicker subcutaneous fat is associated with more SSNF and scrotal fat.

Finishing treatment had an effect on semen volume and the percentage normal spermatozoa (P < 0.05). Rams in the extensive-intensive treatment had higher semen volumes than the extensive treatment (P < 0.05) and the intensive treatment. The intensive treatment had the fewest normal spermatozoa compared to both the extensive-intensive and extensive treatments (P < 0.05). The underdeveloped testes of the younger rams in the intensive treatment resulted in poorer semen quality compared to those in the other treatments. The excess scrotal fat deposition of rams in the extensive-intensive treatment did not negatively influence semen quality. Although, regression analyses showed that there were certain gained weight and fat accumulation thresholds which, when breached, may result in decreased semen quality. Regressions showed that semen volume would start to decrease if gained body weight exceeded 30kg (R^2 = 0.13, P < 0.01) or if subcutaneous fat exceeded 1.6cm (R^2 = 0.07, P < 0.05). If gained weight exceeded 50kg (R^2 = 0.14, P < 0.01) or subcutaneous fat exceeded *ca.* 2.2cm (R^2 = 0.19, P < 0.001), then percentage normal spermatozoa may possibly start to decrease. Scrotal fat weights above *ca.* 39g could cause a decrease in spermatozoa mass motility (R^2 = 0.07, P < 0.05).

The present study also focussed on how effectively thermoregulation was maintained and provided data to formulate new ratios to estimate the “Effective PPC” (PPC:SSNF). Other ratios formulated included PPC to scrotal fat weight (PPC:SFM), PPC to testes weight (PPC:TM), and Effective PPC to testes weight (EffecPPC:TM). The intensive treatment recorded larger ratios for PPC:SSNF and Effective PPC:TM (P < 0.05) compared with the extensive-intensive and extensive treatments. While both intensive and extensive-intensive treatments recorded smaller PPC:SFM ratios (P < 0.001) than the extensive treatment. A larger PPC:SSNF ratio is beneficial as it indicates less SSNF and thus a better thermoregulation potential. The circumference of the *Pampiniform venous plexus* must be considered as the smaller PPC of the younger intensive treatment rams could potentially pose a problem in terms of thermoregulation and subsequently to ram fertility. It was anticipated that an

ideal PPC:SSNF ratio exists, which equates to a certain PPC:SSNF threshold where the PPC is large enough to ensure adequate thermoregulation. The PPC:SFM variable illustrated this well as rams in the extensive treatment recorded a significantly larger ratio than those in the intensive treatment. Both treatments had similar scrotal fat weight, but the extensive treatment recorded a significantly larger PPC than the intensive treatment. There should also be an ideal threshold for the EffecPPC:TM ratio. In this study it was observed that the smaller EffectPPC:TM ratio of the extensive-intensive and the extensive treatments were better than the larger EffectPPC:TM ratio of the intensive treatment ($P < 0.001$), as the rams in the extensive-intensive and extensive treatments recorded heavier testes than the rams in the intensive treatment. More research is required in this regard as it appears that each of these ratios probably has an ideal threshold.

Treatment influenced blood hormone concentrations of T_3 and testosterone ($P < 0.05$). The intensive and extensive-intensive treatments had higher plasma T_3 concentrations ($P < 0.05$) than the extensive treatment. The rams fed intensively recorded significantly higher blood testosterone concentrations ($P < 0.05$) compared to the other two treatments.

Finishing treatment x breed interaction effects: In the intensive treatment, the rams of all three breeds were similar in size and weight and even deposited similar amounts of subcutaneous fat. There were no significant differences between breeds for any of the scrotal measurements. The anatomical location of fat deposition (subcutaneous versus SSNF versus scrotal fat) differed between breeds. There was a difference ($P < 0.05$) in PPC:SSNF ratio between the SAM and Döhne Merino rams of the intensive treatment. The SAM rams recorded the highest PPC:SSNF ratio of the three breeds, while the Döhne Merino rams recorded the lowest ratio ($P < 0.05$). Since SAM rams had the highest PPC:SSNF ratio, they may have maintained thermoregulation the most effectively. The SAM rams had the largest PPC and the least SSNF, which substantiates the previous statement. Although, there were no significant differences in semen quality traits between the three breeds.

In the extensive-intensive treatment, SAM rams were the heaviest and largest (significantly so compared to the Merino rams). All three breeds gained more than 30kg during this treatment period which may result in decreased semen volumes. The SAM rams in the extensive-intensive treatment had significantly more subcutaneous fat than the extensive-intensive treatment Merino rams which, in turn, had the least subcutaneous fat of the three breeds in the extensive-intensive treatment. South African Mutton Merino and Döhne Merino rams had subcutaneous fat layers thicker than 1.8cm, which could possibly cause a decrease in semen volume. Mass motility could be a problem for all three breeds in the extensive-intensive treatment as all the rams had scrotal fat weights of above 39g. There were no significant differences in testicular dimensions between the three breeds in the extensive-intensive treatment. The Merino rams recorded less SSNF ($P < 0.05$) compared to the

SAM and Döhne Merino rams but deposited slightly more scrotal fat compared to the SAM and Döhne Merino rams. Due to the low SSNF, the Merino rams had the best PPC:SSNF and thus may have maintained thermoregulation the best.

The extensive treatment Döhne Merino rams were lighter than the extensive treatment SAM rams ($P < 0.05$) and Merino rams. All three breeds gained more than 30kg during this treatment period which may result in decreased semen volumes. South African Mutton Merino rams also had the most subcutaneous fat compared to the Döhne Merino rams ($P < 0.05$) and Merino rams, while the Döhne Merino rams had the least subcutaneous fat ($P < 0.05$). Merino and Döhne Merino rams had subcutaneous fat layers thicker than 1.8cm, which could possibly cause a decrease in semen volume. The SAM rams in the extensive treatment could experience decreased semen volume and less percentage normal spermatozoa as these rams had a subcutaneous fat layer thickness of 2.4cm. In the extensive treatment, the only testicular measurement which differed ($P < 0.05$) was testes width, which differed between the Merino and SAM rams – the Merino rams recorded a smaller width than the SAM rams. There was not much difference in PPC, SSNF and scrotal fat between the three breeds. As PPC was similar between breeds, the PPC ratios (PPC:SSNF, PPC:SFM, PPC:TM and EffecPPC:TM) were also similar between the breeds.

In the extensive-intensive and extensive treatments, there were no significant differences in semen quality traits between the three breeds. In both these treatments, all three breeds had similar quality semen. Thus the thicker SSNF of the Döhne Merino and SAM rams in the extensive-intensive treatment was not detrimental to semen quality, nor was the excess scrotal fat of the extensive-intensive treatment Merino rams. However, there is a threshold for scrotal fat weight, above which possible detrimental effects may be seen in semen parameters. It was only the rams of the intensive treatment which recorded poorer semen quality, which may be due to their younger age.

In terms of growth, all three breeds benefited from the intensive treatment and had this treatment been longer, these rams would be comparable to the rams of the extensive treatment. The later maturing Döhne Merino and SAM rams benefitted more from the extensive-intensive treatment than the Merino rams. It appears that the SAM breed deposits subcutaneous fat rather easily as this breed had the thickest subcutaneous layer in both the extensive-intensive and extensive treatments. Thus, precautions need to be taken to ensure that SAM rams do not become over-conditioned.

In the extensive-intensive treatment, there were some positive correlations ($P < 0.05$) between subcutaneous fat and testicular measurements whereas in the extensive treatment, there were only negative correlations ($P < 0.05$) between these variables. In the intensive treatment there were positive correlations ($P < 0.05$) between subcutaneous fat and semen quality traits whereas, again, in the extensive treatment these correlations were negative ($P < 0.05$). Accumulation of

subcutaneous fat was not as detrimental in the intensive and extensive-intensive treatments compared to the extensive treatment, as the rams in the former two treatments were younger and did not deposit as much subcutaneous fat. Subcutaneous fat is an indicator of maturity, and testicular measurements and semen characteristics improve as rams age. However, there is a threshold for subcutaneous fat, above which possible detrimental effects may be seen in semen parameters.

In terms of testes growth and development, the Döhne Merino rams responded the best to the extensive-intensive treatment compared to the other two breeds, while the SAM rams did the best in the extensive treatment. There was a very clear treatment x breed effect on fat deposition, as well as a clear breed effect on area of fat deposition. Thus, caution needs to be heeded as some breeds accumulate fat in the scrotal neck, with possible adverse effects on thermoregulation. Precautions need to be taken with extensively raised Merino rams, as they showed a negative correlation between scrotal fat and the percentage normal spermatozoa. Although the intensive treatment improved testicular development, precautions would have to be taken if rams were fed intensively for a longer period, especially in the Döhne Merino rams which showed detrimental correlations between semen quality traits and SSNF.

Although no significant correlations were observed between SC and testes measurements in all breeds in all treatments, there were some notable associations. Thus measuring scrotal circumference still gives an accurate measurement of semen volume and fertility.

Seasonal effects: Season influenced a number of testicular variables namely, semen volume and percentage normal spermatozoa, and plasma T_3 concentrations ($P < 0.05$). It did not affect serum testosterone concentrations. This nutritionally induced dissociation between testosterone concentrations, season and testicular growth is characteristic of rams living in regions of inconsistent food supply that is not in phase with photoperiodic responses. This may be a mechanism to ensure that testes are well developed before testosterone-induced behavioural responses occur before the mating season.

Finishing treatment and Merino type effect: The Döhne Merino and SAM rams (dual-purpose breeds), benefitted more from the concentrate diet fed during the second half of the extensive-intensive treatment and were a similar size, and recorded similar testicular dimensions, to the older Döhne Merino and SAM rams of the extensive treatment. Although, caution needs to be heeded as more fat was deposited in the neck of the scrotum of the extensive-intensive treatment rams. None of the feeding systems had particular detrimental effects on semen quality and no pathology was found, but the young rams of the intensive treatment had smaller testicular dimensions and had not yet reached sexual maturity. Farmers following the intensive-like treatment should be made aware of this and be advised to wait another month or two to allow for further testicular growth, before

breeding these rams. The possible reason why semen parameters, in this study, were not poor is because the rams were not fed long enough in order to observe possible detrimental effects of fat accumulation. Poorer semen parameters may possibly only be observed in subsequent spermatogenic waves. The concentrate diet improved gonadal development – had the intensive treatment been longer, those rams would have had better testes development than the rams in the extensive treatment – but, at the same time, precautions would have to be taken as the intensive feeding of young rams for too long may adversely affect fertility. This is especially so for early maturing rams, due to earlier accumulation of excess scrotal fat impairing thermoregulation and increasing the percentage of abnormal sperm. Efficient feeding programs for rams should make provision for physiological maturity types, fattening rate and semen quality.

CHAPTER 5

CRITICAL EVALUATION

- The study was designed to simulate the practises of veld ram clubs even though it made the experimental design more complicated and subsequently complicated data interpretation. Dr Dreyer, a specialist in veld ram clubs and small stock farming, assisted in setting up this study and in selecting the rams which were to be used.

- This study replicated different feeding systems commonly used in South African sheep farming to determine the related effects on growth, gonadal development, fat accumulation and semen quality. A large number of measurements were taken during the course of this study, which already made the scope for this Masters degree very large, but I think measurements such internal body fat weight, scrotal neck fat weight and scrotal body fat weight, would have added value to the interpretation of results in this study.

- The biggest limitation in this study, was that the three treatments were not of the same duration. This meant that rams from different treatments were measured for the last time, slaughtered, and dissected at different chronological ages. The treatment effect is thus partially confounded with physiological age. To overcome these confounding effects, I would have done one of the following:
    - Designed a trial where all the treatments were the same duration.
    - Or, alternatively, I would design a trial where rams are fed until a target weight is achieved.

- Further, the one treatment extended into a different season which, in small stock, may have had an effect on testes size and semen quality as well.

    - The duration of the treatments was also too short, especially the intensive and extensive-intensive treatments. The possible detrimental effects of scrotal fat accumulation, due to poor thermoregulation, on semen quality could not yet be observed. It is possible that poor thermoregulation, due to excess fat accumulation, would have a larger effect on the formation of spermatozoa in subsequent spermatogenic waves than on spermatozoa close to the end of the spermatogenic wave or epididymal spermatozoa.

- I would extend the treatments by two to four months as I believe that greater differences in semen quality may the possibly be observed.

- It would have been beneficial to have feed intake and feed conversion ratio values, but these variables are not generally measured in veld ram clubs. Attempts to determine these variables may compromise ram behaviour and thus feed intake, subsequently affecting growth response.

- The rams used in this study were all from the Vrede district, thus variation between rams was possibly smaller. It also means that the results obtained in this study is only representative of Free State, more specifically the Vrede district, Merino-type rams and not a representation of each Merino breed type as a whole.
    - I would select rams from across South Africa. When the results of each breed are pooled together, it will be representative of each breed as a whole.

- All the rams in this study were the offspring of stud animals and possibly had higher than average genetic potential.
    - I would select rams which were the progeny of stud animals, as well as rams which were not the offspring of stud animals.

- The three Merino breeds used are genetically and physiologically very similar. Thus, within treatments, no great differences were observed between these three breeds.
    - To see the effects of different feeding systems on physiological type, I would use three completely different breeds such as the early maturing Swartkop Persie, the medium maturing Döhne Merino and the later maturing Merino Landskaap.

- As the rams in this study were the progeny of stud animals (and thus possibly had higher than average genetic potential themselves) the absolute statistical minimum number of animals required, was used in this trial.
    - I would increase the number of rams.

- Although this study had a few limitations, the conclusions still stand. If a concentrate diet is fed at a young age, growth is accelerated, and consequently fat deposition occurs earlier. Rams will still benefit (in terms of growth) from a concentrate diet even if they are only fed at slightly older ages, but more fat deposition will occur. If fat accumulation exceeds a certain threshold, it will be detrimental to semen quality.

REFERENCES

Acocks, J.P.H., 1975. Veld types of South Africa. Mem. Bot. Survey. S. Afr. No. 40. Bot. Res.Inst., Pretoria, South Africa, 1-7, 92-94.

Adams, N.R. & Cronjé, P.B., 2003. A review of the biology linking fibre diameter with fleece weight, live weight, and reproduction in Merino sheep. Aust. J. Agric. Res. 54, 1-10.

Adeel, M., Ijaz, A., Aleem, M., Rehman, H., Yousaf, M.S. & Jabber, M.A., 2009. Improvement of liquid and frozen-thawed semen quality of Nili-Ravi buffalo bulls (*Bubalus bubalis*) through supplementation of fat. Theriogenology. 71, 1220-1225.

AGIS., 2007a. Agricultural Geo-Referenced Information System, accessed from: www.agis.agric.za on 20 March 2017. Annual rainfall – Annual rainfall. Available from: http://www.agis.agric.za/agisweb/nr_atlas?rb=nr_atlas_ann_rainfall.

AGIS., 2007b. Agricultural Geo-Referenced Information System, accessed from: www.agis.agric.za on 20 March 2017. Land Capability – Other land categories. Available from: http://www.agis.agric.za/agisweb/nr_atlas?rb=nr_atlas_land_cap.

Agricultural and Food Research Council (Great Britian), Technical Committee on Responses to Nutrients, 1992. Nutritive requirements of ruminant animals: protein. CAB International, Wallingford, Oxfordshire, UK.

Alexopoulos, K., Karagiannidis, A. & Tsakalof, P., 1991. Development of macroscopic and microscopic characteristics of ejaculates from Chios, Serres and Karaguniki breed lambs. Theriogenology. 36, 667-680.

Al-Haboby, A.H., Alkass, J.E. & Ishak, M.A., 1994. Growth pattern of some sexual organs during pubertal period of docked Awassi and Hamdani rams. IPA J. Agric. Res. 4, 76-85.

Banks, E.M., 1964. Some aspects of sexual behaviour in domestic sheep, *Ovis aries*. Behaviour. 23, 249–278.

Barenton, B., Hochereau-de Reviers, M.T., Perreau, C. & Saumande, J., 1983. Changes in testicular gonadotropin receptors and steroid content through postnatal development until puberty in the lamb. Endocrinol. 112, 1447-1453.

Barrell, G.K. & Lapwood, K.R., 1979. Seasonality of semen production and plasma luteinizing hormone, testosterone and prolactin levels in Romney, Merino and Polled Dorset rams. Anim. Reprod. Sci. 1, 213-228.

Batt, R.A.L., 1980. Influences on animal growth and development. Edward Arnold, London, UK. 1-10.

Bearden, H.J., Fuquay, J.W. & Willard, S.T., 2004. Applied animal reproduction. Pearson Prentice Hall, Upper Saddle River, New Jersey, USA, 57-62, 291-292, 338-340.

Bell, A.W., 1984. Factors controlling placental and fetal growth and their effects on future production. In: Reproduction in sheep. Ed. Lindsay, D.R. & Pearce, D.T., Australian Academy of Science, Canberra, Australia, 144–152.

Bester, N., Schwalbach, L.M.J., Van der Merwe, H.J., Greyling, J.P.C. & Fair, M.D., 2004. The influence of dietary energy concentrations on scrotal, testicular and semen characteristics of young Dorper rams. S. Afr. J. Anim. Sci. 34, 53-55.

Bielli, A., Pérez, R., Pedrana, G., Milton, J.T.B., Lopez, Á., Blackberry, M.A., Duncombe, G., Rodriguez-Martinez, H. & Martin, G.B., 2002. Low maternal nutrition during pregnancy reduces the number of Sertoli cells in the newborn lamb. Reprod. Fertil. Dev. 14, 333-337.

Blache, D., Adam, C.L. & Martin, G.B., 2002. The mature male sheep: a model to study the effects of nutrition on the reproductive axis. Reprod. 59, 219-233.

Blache, D., Zhang, S. & Martin, G.B., 2003. Fertility in male sheep: modulators of the acute effects of nutrition on the reproductive axis of male sheep. Reprod. 61, 387-402.

Blache, D., Chagas, L.M. & Martin, G.B., 2007. Nutritional inputs into the reproductive neuroendocrine control system – a multidimensional perspective. Soc. Reprod. Fertil. 64, 123-139.

Blache, D., Adam, C.L. & Martin, G.B., 2014. The mature male sheep: a model to study the effects of nutrition on the reproductive axis. Reprod. 59, 219-233.

Boland, M.P., Al-Kamali, A.A., Crosby, T.F., Haynes, N.B., Howles, C.M., Kelleher, D.L. & Gordon, I., 1985. The influence of breed, season and photoperiod on semen characteristics, testicular size, libido and plasma hormone concentrations in rams. Anim. Reprod. Sci., 9, 241-252.

Braden, A.W.H., Turnbull, K.E., Mattner, P.E. & Moule, G.R., 1974. Effect of protein and energy content of the diet on the rate of sperm production in rams. Aust. J. Biol. Sci. 27, 67-74.

Brown, C. J., Brown, A. H. & Johnson, Z., 1983. Studies of body dimensions in beef cattle. Arkansas AES. Bull. 863.

Burger, A., Hoffman, L.C., Cloete, J.J.E., Muller, M. & Cloete, S.W.P., 2013. Carcass composition of Namaqua Afrikaner, Dorper and SA Mutton Merino ram lambs reared under extensive conditions. S. Afr. J. Anim. Sci. 43, 27-32.

Cameron, A.W.N., Murphy, P.M. & Oldham, C.M., 1988. Nutrition of rams and output of spermatozoa. P. Aus. Sci. Anim. 17, 162-165.

Chandrasekhar, Y., D'Occhio, M.J. & Setchell, B.P., 1986. Reproductive hormone secretion and spermatogenic function in thyroidectomized rams receiving graded doses of exogenous thyroxine. J. Endocrinol. 111, 245-253.

Chase, D.J., Schanbacher, B.D. & Lunstra, D.D., 1988. Effects of pulsatile and continuous luteinizing hormone (LH) infusions on testosterone responses to LH in rams actively immunized against gonadotropin-releasing hormone. Endocrinol. 123, 816-826.

Chilliard, Y., Delavaud, C. & Bonnet, M., 2005. Leptin expression in ruminants: nutritional and physiological regulations in relation with energy metabolism. Domest. Anim. Endocrinol. 29, 3–22.

Clark, R.T., 1934. Studies on the physiology of reproduction in sheep. I. The ovulation rate of the ewe as affected by the plane of nutrition. Anat. Rec. 60, 125–134.

Cloete, S.W.P. & Olivier, J.J., 2010. South African Sheep and Wool Industry. In: International Sheep and Wool Handbook. Ed. Cottle, D.J., Nottingham University Press, Nottingham UK, 95-112.

Coetzee, J., 2005. The modern Merino in perspective. In: Merino SA focus 2005. 41-43 (in Afrikaans).

Combrink, G.C. & Schoeman, S.J., 1993. The influence of exercising rams on the lambing performance of a Merino ewe flock. S. Afr. J. Anim. Sci. 23, 24–25.

Coulter, G.H., Cook, R.B. & Kastelic, J.P., 1997. Effects of dietary energy on scrotal surface temperature, seminal quality, and sperm production in young beef bulls. J. Anim. Sci. 75, 1048-1052.

Courot, M., 1979. Semen quality and quantity in the ram. In: Sheep breeding. Ed. Tomes, G.J., Robertson, D.E., Lightfoot, R.J. & Haresign, W., Butterworths, London, UK, 495-504.

DAFF, 2016. A profile of the South African wool market value chain. Department of Agriculture, Forestry and Fisheries, South Africa.

DAFF, 2017. A profile of the South African mutton market value chain. Department of Agriculture, Forestry and Fisheries, South Africa.

DAFF, 2018. Trends in the agricultural sector 2017. Department of Agriculture, Forestry and Fisheries, South Africa.

DAFF, 2019. Trends in the agricultural sector 2018. Department of Agriculture, Forestry and Fisheries, South Africa.

Davis, S.J.M., 1996. Measurements of a group of adult female Shetland sheep skeletons from a single flock: a baseline for zooarchaeologists. J. Archaeol. Sci. 23, 593-612.

Dhuyvetter, J., 1995. Beef cattle frame scores. AS-1091.

Dikeman, M. & Devine, C., 2014. Encyclopaedia of Meat Sciences. Academic Press, London, UK, 506-510.

Du Plessis, I., Hoffman, L.C. & Calitz, F.J., 2006. Influence of reproduction traits and pre- weaning growth rate on herd efficiency of different beef breed types in an arid sub- tropical environment. S. Afr. J. Anim. Sci. 36, 89-98.

Echols, A.C., 2011. Relationships among lifetime measures of growth and frame size for commercial beef females in a pasture-based production system in the Appalachian region of the United States. MSc (Agric) dissertation, Virginia Polytechnic Institute and State University, USA.

Elmaz, Ö., Cirit, Ü. & Demir, H., 2007. Relationship of testicular development with age, body weight, semen characteristics and testosterone in Kivircik ram lambs. S. Afr. J. Anim. Sci. 37, 269-274.

Ewing, L.L. & Zirkin, B., 1983. Leydig cell structure and steroidogenic function. In: Proceedings of the 1982 Laurentian hormone conference, Academic Press, 599-635.

Fernandez, M., Giráldez, F.J., Frutos, P., Lavín, P. & Mantecon, A.R., 2004. Effect of undergradable protein supply on testicular size, spermiogram parameters and sexual behaviour of mature Assaf rams. Theriogenology. 62, 299-310.

Fernandez-Abella, D., Becu-Villalobos, D., Lacau-Mengido, I.M., Villegas, N. & Bentancur, O., 1999. Sperm production, testicular size, serum gonadotropins and testosterone levels in Merino and Corriedale breeds. Reprod. Nutr. Dev. 39, 617-624.

Fourie, P.J., Schwalbach, L.M., Neser, F.W.C. & Van der Westhuizen, C., 2004. Scrotal, testicular and semen characteristics of young Dorper rams managed under intensive and extensive conditions. Small Rumin. Res. 54, 53-59.

Fourie, P.J., Schwalbach, L.M., Neser, F.W.C. & Greyling, J.P.C., 2005. Relationship between body measurements and serum testosterone levels of Dorper rams. Small Rumin. Res. 56, 75-80.

Geyer, A.C., 2013. Merino economic overview for the past decade (2003-2013). In: Merino SA focus 2013, 98-99.

Gündoğan, M., 2007. Seasonal variation in serum testosterone, T3 and andrological parameters of two Turkish sheep breeds. Small Rumin. Res. 67, 312-316.

Gupta, P.S.P., Sanwal, P.C. & Varshney, V.P., 1991. Peripheral plasma testosterone levels in hypothyroid-induced male goats. Small Rumin. Res. 6, 185-191.

Hammond, J., 1955. Farm animals: Their breeding, growth and inheritance. Edward Arnold, London, UK.

Hafez, E.S.E., 1952. Studies on the breeding season and reproduction of the ewe. Part I. The breeding season in different environments. Part II. The breeding season in one locality. J. Agr. Sci. 42, 189–231.

Hafez, E.S.E. & Hafez, B., 2000. Reproduction in Farm Animals. Lippincott Williams & Wilkins, Philadelphia, USA, 96-109.

Hossner, K.L., 2005. Hormonal regulation of farm animal growth. CABI, Wallingford, Oxfordshire, UK, 2-10.

Hötzel, M.J., Martin, G.B. & Fisher, J.S., 1994. Comparison of the effect of lupin supplementation during the non-breeding season on reproductive function in Suffolk and Merino rams. P. Aus. Sci. Anim. 20, 425.

Hötzel, M.J., Walkden-Brown, S.W., Blackberry, M.A. & Martin, G.B., 1995. The effect of nutrition on testicular growth in mature Merino rams involves mechanisms that are independent of changes in GnRH pulse frequency. J. Endocrinol. 147, 75–85.

Hötzel, M.J., Markey, C.M., Walkden-Brown, S.W., Blackberry, M.A. & Martin, G.B., 1998. Morphometric and endocrine analysis of the effects of nutrition on the testis of mature Merino rams. Reprod. 113, 217-230.

Hötzel, M.J., Walkden-Brown, S.W., Fisher, J.S. & Martin, G.B., 2003. Determinants of the annual pattern of reproduction in mature male Merino and Suffolk sheep: response to a nutritional stimulus in the breeding and non-breeding season. Reprod. Fertil. Dev. 15, 1-9.

IBM Corp. Released 2015. IBM Statistics for Windows, Version 23.0. Armonk, NY: IMB Corp.

Keinprecht, H., Pichler, M., Pothmann, H., Huber, J., Iwersen, M. & Drillich, M., 2016. Short term repeatability of body fat thickness measurement and body condition scoring in sheep as assessed by a relatively small number of assessors. Small Rumin. Res. 139, 30-38.

Kheradmand, A., Babaei, H. & Ali Batavani, R., 2006. Effect of improved diet on semen quality and scrotal circumference in the ram. Vet. Arhiv. 76, 333-341.

Kleiber, M., 1961. Metabolic rate and food utilization as a function of body size. University of Missouri, College of Agriculture, Agricultural Experiment Station, Missouri, USA, 767.

Knight, T.W., Gherardi, S. & Lindsay, D.R., 1987. Effects of sexual stimulation on testicular size in the ram. Anim. Reprod. Sci. 13, 105–115.

Langford, G.A., Ainsworth, L., Marcus, G.J. & Shrestha, J.N.B., 1987. Photoperiod entrainment of testosterone, luteinizing hormone, follicle-stimulation hormone, and prolactin cycles in rams in relation to testis size and semen quality. Biol. Reprod. 37, 489-499.

Langford. G.A., Shrestha, J.N.B., Sanford, L.M. & Marcus, G.J., 1998. Reproductive hormone levels of early postpubertal ram lambs in relation to breed, adult testis size and semen quality. Small Rumin. Res. 29, 225-231.

Lunstra, D.D. & Schanbacher, B.D., 1988. Testicular function and Leydig cell ultrastructure in long-term bilaterally cryptorchid rams. Biol. Reprod. 38, 211-220.

Lunstra, D.D. & Coulter, G.H., 1997. Relationship between scrotal infrared temperature patterns and natural-mating fertility in beef bulls. J. Anim. Sci. 75, 767-774.

Lui, S.M. & Masters, D.G., 2003. Amino acid utilization for wool productions. Amino acid in animal nutrition. CAB International Publishing. 309-328.

Malejane, C.M., Greyling, J.P.C. & Raito, M.B., 2014. Seasonal variation in semen quality of Dorper rams using different collection techniques. S. Afr. J. Anim. Sci. 44, 26-32.

Martin, G.B., Sutherland, S.R.D. & Lindsay, D.R., 1987. Effects of nutritional supplements on testicular size and the secretion of LH and testosterone in Merino and Booroola rams. Anim. Reprod. Sci. 12, 267-281.

Martin, G.B., Tjondronegoro, S. & Blackberry, M.A., 1994. Effects of nutrition on testicular size and the concentrations of gonadotrophins, testosterone and inhibin in plasma of mature male sheep J. Reprod. Fertil.101, 121-128.

Martin, G.B. & Walkden-Brown, S.W., 1995. Nutritional influences on reproduction in mature male sheep and goats. J. Reprod. Fertil. 49, 437-449. (cited by Selvaraju *et al.*, 2012).

Martin, G.B., Tjondronegoro, S., Boukhliq, R., Blackberry, M.A., Briegel, J.R., Blache, D., Fisher, J.A. & Adams N.R., 1999. Determinants of the annual pattern of reproduction in mature male Merino and Suffolk sheep: modification of endogenous rhythms by photoperiod. Reprod. Fertil. Dev. 11, 355-366.

Martin, G.B., Hötzel, M.J., Blache, D., Walkden-Brown, S.W., Blackberry, M.A., Boukliq, R., Fisher, J.S. & Miller, D.W., 2002. Determinants of the annual pattern of reproduction in mature male Merino and Suffolk sheep: modification of responses to photoperiod by an annual cycle in food supply. Reprod. Fertil. Dev. 14, 165-175.

Martin, G.B., Milton, J.T.B., Davidson, R.H., Hunzicker, G.B., Lindsay, D.R. & Blache, D., 2004. Natural methods for increasing reproductive efficiency in small ruminants. Anim. Reprod. Sci. 82, 231-245.

Martin. G.B., Blache, D., Miller, D.W. & Vercoe, P.E., 2010. Interactions between nutrition and reproduction in the management of the mature male ruminant. Anim. 4, 1214-1226.

Masters, D.G. & Fels, H.E., 1984. Seasonal changes in the testicular size of grazing rams. P. Aus. Sci. Anim. 15, 444-447.

Meat and Livestock Australia, 2017. Market information services: Sheep assessment manual. Meat & Livestock Australia Limited, January 2017.

Meissner, H.H., 1983. Feeding standards of ruminants: A progress report of research under controlled conditions in South Africa. S. Afr. Anim. Sci. 13, 267-276.

Monet-Kuntz, C., Hochereau-de Reviers, M.T. & Terqui, M., 1984. Variations in testicular androgen receptors and histology of the lamb testis from birth to puberty. Reprod. 70, 203-210.

Mori, A., 1959. Studies on the reproductive failure of ram caused by underfeeding. I. On the effects of underfeeding upon the mating potency of ram, and the effects of normal feeding upon its recovery from impotence. Tohoku J. Agric. Res. 10, 263-281.

Moule, G.R., 1963. Postpubertal nutrition and reproduction by the male. Aust. Vet. J. 39, 299– 304.

Mucina, L. & Rutherford, M.C., 2006. The vegetation of South Africa, Lesotho and Swaziland. Strelitzia 19. South African National Biodiversity Institute, Pretoria. 350-352.

NRC, 1985. Nutrient requirements of domestic animals. Nutrient requirements of sheep. 6th revised edition. National Academy of Science, Washington D.C.

Okolski, A., 1975. Effect of different amounts of protein in the diet on sexual behaviour and properties of semen in rams. Acta Agrar. Silvestria Ser. Zootech. 15, 101–121.

Oldham, C.M., Adams, N.R., Gherardi, P.B., Lindsay, D.R. & Macintosh J.B., 1978. The influence of level of feed intake on sperm-producing capacity of testicular tissue in the ram. Aust. J. Agric. Res. 29, 173-179.

Palmer, C.W., Brito, L.F.C., Arteaga, A.A., Soderquist, L., Persson, Y. & Barht, A.D., 2005. Comparison of electroejaculation and transrectal massage for spermatozoal collection in range and yearling feedlot beef bulls. Anim. Reprod. Sci. 87, 25-31.

Palsson, H. & Hammond, J., 1955. Progress in the physiology of farm animals. Butterworths, London, UK, 740.

Parker, G.V. & Thwaites, C.J., 1972. The effects of undernutrition on libido and semen quality in adult Merino rams. Aust. J. Agric. Res. 23, 109–115.

Pelletier, J. & Almeida, G., 1987. Short light cycles induce persistent reproduction activity in Ile-de-France rams. J. Reprod. Fertil. 34, 215–226.

Pénicaud, L., Cousin, B., Leloup, C., Lorsignol, A. & Casteilla, L., 2000. The autonomic nervous system, adipose tissue plasticity, and energy balance. Nutr. 16, 903–908.

Pisselet, C., Perreau, C. & Hochereau-de Reviers, M.T., 1984. Relationship between rete testis fluid secretion and testicular structure in the ram. Reprod. Nutr. Dev. 24, 483-486.

Pomares, C.C., Galloway, D.B., Holmes, J.H.C., Tilbrook, A.J. & Clarke, I.J., 1991. The effects of lupin and cowpea supplements on reproduction characteristics in rams. P. Aus. Sci. Reprod. Biol. Proc. Aus. Soc. Reprod. Biol. 23, 80.

Popkin, P.R.W., Baker, P., Worley, F., Payne, S. & Hammon, A., 2012. The sheep project (1): determining skeletal growth, timing of epiphyseal fusion and morphometric variation in unimproved Shetland sheep of known age, sex, castration status and nutrition. J. Archaeol. Sci. 39, 1775-1792.

Raadsma, H.W. & Edey, T.N., 1985. Mating performance of paddock-mated rams. II. Changes in sexual and general activity during the joining period. Anim. Reprod. Sci. 8, 101–107.

Reece, W.O., 2015. Dukes' physiology of domestic animals. John Wiley & Sons, Inc. Ames, Iowa, USA. 628-631.

Regadas Filho, J.G.L., Pereira, E.S., Villarroel, A.B.S., Pimentel, P.G., Fontenele, R.M., Costa, M.R.G.F., Maia, I.S.G. & Sombra, W.A., 2011. Efficiency of metabolizable energy utilization for maintenance and gain and evaluation of Small Ruminant Nutrition System model in Santa Ines sheep. Rev. Bras. Zootech. 40, 2558-2564.

Rhind, S.M., Archer, Z.A. & Adam, C.L., 2002. Seasonality of food intake in ruminants: recent developments in understanding. Nutr. Res. Rev. 15, 43–65.

Ritar, A.J., Adams, N.R. & Sanders, M.R., 1984. Effect of lupin feeding on LH, testosterone and testes. In: Reproduction in sheep. Ed. Lindsay, D.R. & Pearce, D.T. Australian Academy of Science, Canberra, Australia. 76-78.

Robinson, J.J., Ashworth, C.J., Rooke, J.A., Mitchell, L.M. & McEvoy, T.G., 2006. Nutrition and fertility in ruminant livestock. Anim. Feed Sci. Tech. 126, 259–276.

SA Stud Book, 2015. Guidelines for ram growth and wool tests on the farm.

Saeed, F.F. & Zaid, N.W., 2019. Serum and testicular testosterone levels of ram lamb during puberty. Adv. Anim. Vet. Sci. 7, 92-95.

Salamon, S., 1964. The effect of nutritional regimen on the potential semen production of rams. Aus. J. Agric. Res. 15, 645–656.

Salhab, S.A., Zarkawi, M., Wardeh, M.F., Al-Masri, M.R. & Kassem, R., 2001. Development of testicular dimensions and size, and their relationship to age, body weight and parental size in growing Awassi ram lambs. Small Rumin. Res. 40, 187-191.

Sarlós, P., Egerszegi, I., Balogh, O., Molnár, A., Cseh, S. & Rátky, J., 2013. Seasonal changes of scrotal circumference, blood plasma testosterone concentration and semen characteristics in Racka rams. Small Rumin. Res. 111, 90-95.

Scaramuzzi, R.J., Campbell, B.K., Downing, J.A., Kendall, N.R., Khalid, M., Muñoz-Gutiérrez, M. & Somchit, A., 2006. A review of the effects of supplementary nutrition in the ewe on the concentrations of reproductive and metabolic hormones and the mechanisms that regulate folliculogenesis and ovulation rate. Reprod. Nutr. Dev. 46, 339–354.

Scholtz, M.M., Roux, C.Z. & De Bruin, D.S., 1990. Medium-term responses to and changes in fitness with selection for parameters of the allometric-autoregressive model. S. Afr. J. Anim. Sci. 20, 65-70.

Schoeman, S.J. & Combrink, G.C., 1987. Testicular development in Dorper, Döhne Merino and crossbred rams. S. Afr. J. Anim. Sci. 17, 22-26.

Selvaraju, S., Sivasubramani, T., Raghavendra, B.S., Raju, P., Roa, S.B.N., Dineshkumar, D. & Ravindra, J.P., 2012. Effect of dietary energy on seminal plasma insulin-like growth factor-I (IGF-I), serum IGF-I and testosterone levels, semen quality and fertility in adult rams. Theriogenology. 78, 646-655.

Senger, P.L., 2003. Pathways to pregnancy and parturition. Cadmus Professional Communication, USA, 214-239.

Setchell, B.P., Waites, G.M.H. & Lindner, H.R., 1965. Effect of undernutrition on testicular blood flow and metabolism and the output of testosterone in the ram. Reprod. 9, 149–162.

Setchell, B.P. & Hinks, N.T., 1967. The importance of glucose in the oxidative metabolism of the testis of the conscious ram and the role of the pentose cycle. Biochem. J. 102, 623– 630.

Setchell, B.P., 1986. The movement of fluids and substances in the testis. Aust. J. Biol. Sci. 39, 193–207.

Setchell, B.P., 1990. Local control of testicular fluids. Reprod. Fertil. Dev. p. 2, 291–309.

Sinha Hikim, A.P., Bartke, A. & Russell, L.D., 1988. Morphometric studies on hamster testes in gonadally active and inactive states: light microscope findings. Biol. Reprod. 39, 1225- 1237.

Snyman, M.A., 2014a. South African sheep breeds: Döhne Merino sheep. Info-pack ref. 2014/015. Grootfontein Agricultural Development Institute, South Africa.

Snyman, M.A., 2014b. South African sheep breeds: Merino sheep. Info-pack ref. 2014/022. Grootfontein Agricultural Development Institute, South Africa.

Snyman, M.A., 2014c. South African sheep breeds: SA Mutton Merino sheep. Info-pack ref. 2014/028. Grootfontein Agricultural Development Institute, South Africa.

Souza Júnior, E.L.D., Sousa, W.H.D., Pimenta Filho, E.C., Gonzaga Neto, S., Cartaxo, F.Q., Cezar, M.F., Cunha, M.D.G.G. & Pereira Filho, J.M., 2013. Effect of frame size on performance and carcass traits of Santa Inês lambs finished in a feedlot. Rev. Bras. Zootecn. 42, 284-290.

Starling, J.M.C., Silva, R.G.D., Negrão, J.A., Maia, A.S.C. & Bueno, A.R., 2005. Seasonal variation of thyroid hormones and cortisol of sheep in tropical environment. Rev. Bras. Zootech. 34, 2064–2073.

Swanepoel, J.W., 2006. A genetic evaluation of the Döhne Merino breed in South Africa. MSc (Agric) dissertation, University of the Free State, South Africa.

Swanepoel, F.J.C., Taylor, G.J., Webb, E.C. & Stroebel, A., 2008. Effect of nutrition on testicular traits of tropically adapted yearling beef bulls. Aust. J. Exp. Agr. 48, 950-953.

Swart, D., Olivier, B. & Taylor, R., 2009. The National Merino flock: A true success story 20 years of performance recording and BLUP breeding. In: Merino SA focus 2009, 76.

Talebi, M.A., 2012. Feed intake, feed efficiency, growth and their relationship with Kleiber ratio in Lori-Bakhtiari lambs. Arch. Zootech. 15, 33-39.

Tarulli, G.A., Stanton, P.G., Lerchl, A. & Meachem, S.J., 2006. Adult Sertoli cells are not terminally differentiated in the Djungarian hamster: effect of FSH on proliferation and junction protein organization. Biol. Reprod. 74, 798–806.

Tatum, J.D., Dolezal, H.G., Williams Jr, F.L., Bowling, R.A. & Taylor, R.E., 1986. Effects of feeder-cattle frame size and muscle thickness on subsequent growth and carcass development. II. Absolute growth and associated changes in carcass composition. J. Anim. Sci. 62, 121-131.

Tatum, J.D., DeWalt, M.S., LeValley, S.B., Savell, J.W. & Williams, F.L., 1998. Relationship of feeder lamb frame size to feedlot gain and carcass yield and quality grades. J. Anim. Sci. 76, 435-440.

Terblanche, E., 1979. Know our small stock breeds. Human & Rousseau, Cape Town, South Africa, 38-44, 84-93,103-109. (in Afrikaans)

Thwaites, C.J., 1995. The comparative effects of undernutrition, exercise and frequency of ejaculation on the size and tone of the testes and on semen quality in the ram. Anim. Reprod. Sci. 37, 299–309.

Tilbrook, A.J. & Cameron, A.W.N., 1990. The contribution of the sexual behaviour of rams to successful mating of ewes under field conditions. In: Reproductive physiology of Merino sheep – concepts and consequences. Ed. Oldham, C.M., Martin, G.B. & Purvis, I.W., School of Agriculture (Animal Science), The University of Western Australia, Perth, Australia, 143-160.

Todini, L., 2007. Thyroid hormones in small ruminants: effects of endogenous, environmental and nutritional factors. Animal. 1, 997-1008.

Tufarelli, V., Lacalandra, G.M., Aiudi, G., Binetti, F. & Laudadio, V., 2011. Influence of feeding level on live body weight and semen characteristics of Sardinian rams reared under intensive conditions. Trop. Anim. Health Pro. 43, 339-345.

Valle, L.B.S., Oliveira-Filho, R.M., Romaldini, J.H. and Lara, P.F., 1985. Pituitary-testicular axis abnormalities in immature male hypothyroid rats. J. Steroid Biochem. 23, 253- 257.

Valtorta, S., Hahn, L. & Johnson, H.D., 1982. Effect of high ambient temperature (35 degrees), and feed intake on plasma T4 levels in sheep. P. Soc. Exp. Biol. Med. 169, 260–265.

Van Oudtshoorn, F., 1992. Guide to grasses of South Africa. Briza Publikasies Bk, Nasionale Boekdrukkery, Cape Town, 38-40. (In Afrikaans).

Venter, C., 2017. Merino of old versus modern Merino. In: Merino SA focus 2017, 36-39. (In Afrikaans).

Vermorel, M. & Bickel, H., 1980. Utilisation of feed energy by growing ruminants. Ann. Zootech. 29, 127-143.

Vilakazi, D.M. & Webb, E.C., 2004. Effect of age and season on sperm morphology of Friesland bulls at an artificial insemination centre in South Africa. S. Afr. J. Anim. Sci. 34, 62-69.

Walkden-Brown, S.W., Restall, B.J. & Taylor, W.A., 1994. Testicular and epididymal sperm content in grazing Cashmere bucks: seasonal variation and prediction from measurements *in vivo*. Reprod. Fertil. Dev. 6, 727-736.

Warren, G.H., 1979. Growth of dissectible fat in the Merino. In: Sheep breeding. Ed. Tomes, G.J., Robertson, D.E., Lightfoot, R.J. & Haresign, W., Butterworths, London, UK, 195- 202.

Webb, E.C., Dombo, M.H. & Roets, M., 2004. Seasonal variation in semen quality of Gorno Altai cashmere goats and South African indigenous goats. S. Afr. J. Anim. Sci. 34, 240-243.

Webster, J.R., Moenter, S.M., Woodfill, C.J.I. & Karsh, F.J., 1991. Role of the thyroid gland in seasonal reproduction. II. Thyroxine allows a season-specific suppression of gonadotropin secretion in sheep. Endocrinol. 129, 176–183.

Wiemer, K.E. & Ruttle, J.L., 1987. Semen characteristics, scrotal circumference and bacterial isolates of fine wool range rams. Theriogenology. 28, 625-637.

Yarney, T.A. & Sanford, L.M., 1990. Pubertal development of ram lambs: reproductive hormone concentrations as indices of postpubertal reproductive function. Can. J. Anim. Sci. 70, 149-157.

Zhang, S., Blache, D., Blackberry, M.A. & Martin, G.B., 2004. Dynamics of the responses in secretion of luteinising hormone, leptin and insulin following an acute increase in nutrition in mature male sheep. Reprod. Fertil. Dev. 16, 823–829.

Addendum A

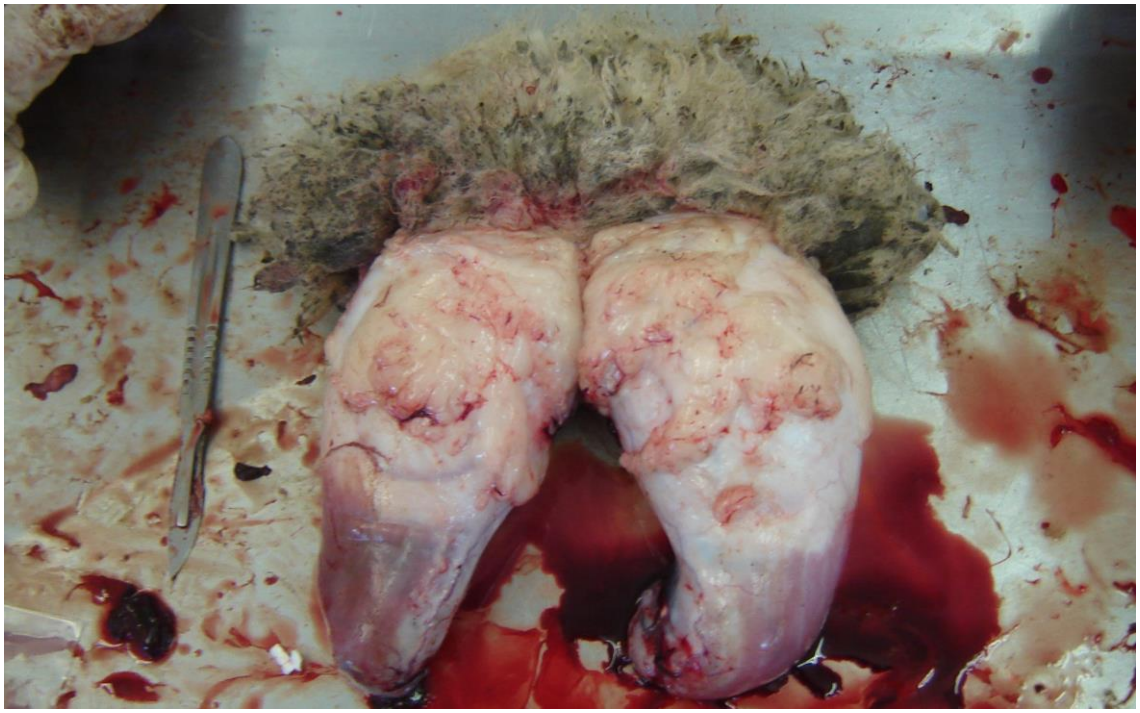
Analysis of variance of growth results of Döhne Merino, Merino and South African Mutton Merino in extensive, extensive and intensive, or intensive production systems.

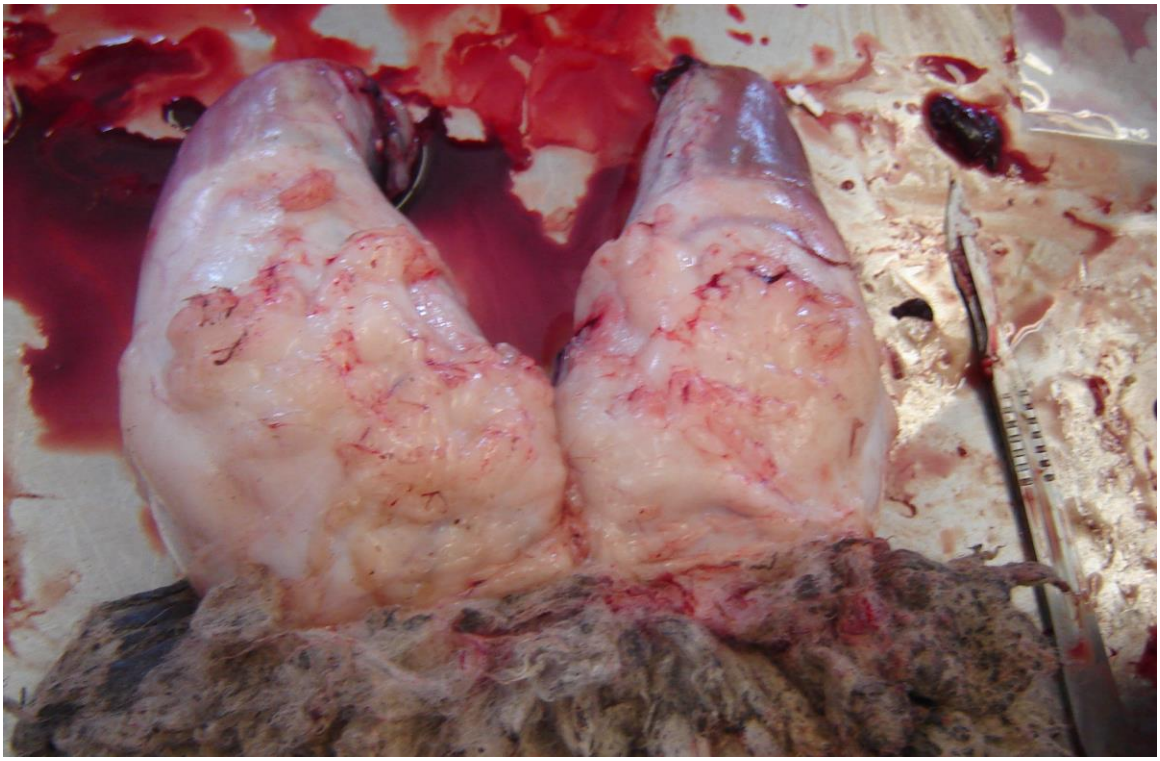
Source	Dependent Variable	Type III Sum of Squares	Mean Square	F	Sig. Level (P=F)
Finishing treatment	BCS_I	2.311	1.155	2.216	0.116
	BCS_F	111.245	55.622	83.525	0.000
	$Weight_I$ (kg)	18.215	9.107	0.666	0.517
	$Weight_F$ (kg)	7450.417	3725.208	137.113	0.000
	$Weight_G$ (kg)	8190.615	4095.308	256.416	0.000
	ADG (kg)	0.078	0.039	36.830	0.000
	MetWeight ($MJ/kgW^{0.75}$)	524.516	262.258	136.652	0.000
	Kleiber index	41593.552	20796.776	234.458	0.000
Breed	BCS_I	0.923	0.461	0.885	0.417
	BCS_F	15.924	7.962	11.956	0.000
	$Weight_I$ (kg)	1230.774	615.387	45.009	0.000
	$Weight_F$ (kg)	1182.930	591.465	21.770	0.000
	$Weight_G$ (kg)	0.487	0.243	0.015	0.985
	ADG (kg)	0.000	0.000	0.097	0.908
	MetWeight ($MJ/kgW^{0.75}$)	82.333	41.166	21.450	0.000
	Kleiber index	1969.574	984.787	11.102	0.000
Finishing treatment x breed	BCS_I	1.259	0.315	0.604	0.661
	BCS_F	28.492	7.123	10.696	0.000
	$Weight_I$ (kg)	158.244	39.561	2.893	0.027
	$Weight_F$ (kg)	280.938	70.234	2.585	0.043
	$Weight_G$ (kg)	283.011	70.753	4.430	0.003
	ADG (kg)	0.009	0.002	2.085	0.090
	MetWeight ($MJ/kgW^{0.75}$)	19.413	4.853	2.529	0.047
	Kleiber index	477.657	119.414	1.346	0.260

BCS_I – Initial body condition score; BCS_F – Final body condition score; $Weight_I$ – Initial weight; $Weight_F$ – Final weight; $Weight_G$ – Weight gained; ADG – Average daily gain; MetWeight – Metabolic weight

Addendum B

Photos of dissected testes illustrating testes with scrotal fat accumulation.





Addendum C

Plenary paper presented at the 50th SASAS conference, held in Port Elizabeth, and published in the proceedings of the conference.

Effects of Extensive and intensive conditioning on growth and gonadal characteristics in South African mutton Merino rams

A.M. du Preez[1#], E.C. Webb[1], W.A. van Niekerk[1]

[1]Department of Animal Science, University of Pretoria, Pretoria 0002, South Africa

[#]Corresponding author: amelia.may.dp@gmail.com

Background: Different practices for rearing and conditioning breeding rams for auction are used. Rams either enter veld ram clubs after weaning (e.g. on extensive pasture for 130 days, followed by intensive feeding for ca. 50 days), or intensive feeding until auction (usually 12 months of age). A previous study reported irreversible pathology of seminiferous tubules in bulls fed at a too young age. These histological changes decreased the fertility of bulls. Little is known about the effects of intensive feeding of young rams on their fertility and reproductive performance.

Aim: The present study investigated the effects of different feeding systems during the growing phase (five to 12 months of age) on gonadal development and fertility of South African Mutton Merino rams.

Methodologies: Three dietary treatments representing different production systems were evaluated, namely a control (rams kept on pasture only), treatment one (feeding in typical veld ram clubs) and treatment two (intensive system, where rams were fed a concentrate diet from the beginning of the trial). All growth, anthropometric and scrotal parameters were measured and semen quality was assessed. After the animals were slaughtered, the testes were dissected followed by histopathology.

Results: There were significant differences between the three conditioning groups in terms of final growth and anthropometric measurements. Subcutaneous fat and carcass fat differed (P=0.000) between the three conditioning groups, with extensively fed rams containing most fat. Final scrotal circumference differed (P=0.02) between the intensive treatment (32.7 ± 2.49cm) and extensive treatment (34.6 ± 2.81cm). Scrotal mass and scrotal fat mass differed between the conditioning groups (P=0.000). Rams in the extensive group had the heaviest scrotal mass, but the extensive-intensive combination group contained most scrotal fat. Scanned scrotal fat differed (P=0.000) between the conditioning groups and showed that the extensive-intensive combination group had the most fat. The volume of semen produced differed (P=0.013) between the extensive-intensive combination group (2.27 ± 1.02ml) and the extensive group (1.63 ± 0.70ml). Percentage normal sperm differed (P=0.000) between the intensive group (69.0 ± 20.04%) and both the extensive-intensive combination group (81.7 ± 9.88%) and the extensive group (83.0 ± 10.09%). Initial scrotal circumference (SC_I) correlated negatively with the percentage normal sperm of the extensive group (P=0.045, r=-0.766), while the intensive group showed a positive correlation (P=0.007, r=0.820). In extensively fed rams, subcutaneous fat (which closely reflects body fat content) correlated negatively with semen volume (P=0.009, r=-0.882).

Discussion: In accordance with other studies the present results show that hypernutrition, especially from a younger age, improves the animal growth, but with possible adverse effects on semen quality and hence fertility. The different correlations between SC_I and percentage normal sperm for the extensive and intensive groups suggest that the growth hormone cascade may have an influence on the gonadal axis.

Conclusions and recommendations: Intensive feeding of young rams benefits growth and fertility, provided that rams are not overfed from a young age. Feeding programs should monitor semen quality, scrotal fat accretion and carcass fat accretion.

Addendum D

Plenary paper presented at the 69th EAAP conference, held in Dubrovnik, and published in the proceedings of the conference.

Effects of feeding systems and maturity type on gonadal development and semen quality of rams

A.M. du Preez[1#], E.C. Webb[1], W.A. van Niekerk[1]

[1]Dept. of Animal Science, University of Pretoria, Pretoria 0002, South Africa

[#]Corresponding author: amelia.may.dp@gmail.com

This study investigated the effects of feeding systems during the growing phase (five to 12 months old) on gonadal development and semen quality of rams of different maturity types.

The effects of rangeland feeding (C), rangeland followed by intensive feeding (TR1) and intensive feeding (TR2) were evaluated in early (Merino; M), medium (Dohne Merino; DM) and later maturity type (SA Mutton Merino; SAM) rams. Growth, size, scrotal measurements, semen quality and post mortem gonadal measurements were recorded. Data was analyzed by GLM ANOVA procedures, using IBM SPSS V 23. Differences between treatment means for breeds, feeding systems and interactions were tested by Bonferroni's multiple range test at $P<0.05$.

Final growth and size differed between breeds and feeding systems ($P<0.05$). Treatment-breed interactions were significant for final mass, ADG, body length and subcutaneous fat (SCF), with highest growth for M-rams fed diet C. SAM in C had the heaviest scrotal mass (SM; 905.6 +- 120.9g), but DM and M had the heaviest SM in TR1 (880.8 +- 142.8g and 815.4 +- 114.8g respectively). All breeds deposited most scrotal fat in TR1. M fed TR1 had the least scrotal neck fat (SNF; 1.4 +- 0.08cm) while DM and SAM had similar SNF (1.7 +- 0.19cm and 1.8 +- 0.17cm respectively), and in C M had most SNF (1.7 +- 0.46cm). Correlations between percentage normal sperm (PNS) and scrotal fat mass ($P<0.05$, $r=-0.71$) was negative in M in C and between PNS and SCF ($P<0.05$, $r=-0.81$) in TR2. In SAM fed C, SCF and semen volume (SV; $P<0.01$, $r=-0.88$) correlated. In DM fed TR2, SV and SNF correlated ($P<0.05$, $r=0.75$), as well as PNS and SNF ($P<0.05$, $r=-0.79$), and SV and PNS ($P<0.05$, $r=-0.71$). SV and PNS ($P<0.05$, $r=-0.76$) correlated in DM fed C, while PNS and final scrotal circumference ($P<0.05$, $r=-0.87$) and PNS and scrotal mass ($P<0.05$, $r=-0.69$) correlated for DM in TR1.

Intensive feeding of young rams improved growth and gonadal development, but could adversely affect fertility of early maturing rams due to earlier accumulation of excess scrotal fat, impairing thermoregulation and increasing the percentage abnormal sperm. Efficient feeding programs should make provision for maturity types, fattening rate and semen quality.