Effect of feed composition and sex on feedlot performance, carcass characteristics and profitability of Dorper lambs.

by

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Declaration

By submitting this thesis electronically, I Emma Claire Hanel (SU number 21530483), declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third-party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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Abstract

The Dorper is the most numerous of the meat sheep breeds in South Africa. However, the early maturity of the breed and its tendency to deposit localised fat at an earlier age, typically requires them to be slaughtered at a lower live weight when compared to later maturing breeds. These characteristics tend to be enhanced under favourable environmental conditions, such as intensive feeding systems. Most feedlot operators discriminate against Dorper's and are reluctant to finishing them owing to their slaughtering at a lower live weight or having their grade negatively affected, thereby reducing the income potential.

There is limited literature describing the effect of diet and sex on the performance and profitability of feedlot finished Dorper lambs. The objectives of this two-part study were to determine the effect of treatment (diet) and sex on overall feedlot production parameters of Dorper lambs. Part two considered the effect of diet and sex on carcass characteristics and overall profitability parameters.

Eighty-four Dorper lambs were randomly allocated to one of seven treatment groups (1=control, 2=low-energy, 3=high-protein, 4=high-protein + low-energy, 5=high-fat + low-starch, 6=high-fat + low-starch + high-protein, 7=control + β antagonist), comprising 12 animals each- 6 ram and 6 ewe lambs in a 2 x 7 factorial design.

Treatment yielded a significant ($P \leq 0.05$) effect on performance for most of the measured parameters (dry matter intake, number of feedings, final weight, liveweight gain, average daily gain and feed conversion ratio), while the effect of sex was limited, and the interaction of treatment and sex was significant for feed conversion ratio ($P = 0.01$) only. Findings of this study show the lambs final weight was significantly the highest for Treatment 4. Moreover, these animals yielded superior performance for liveweight gain and ADG across all groups in both ram and ewe lambs ($P \leq 0.05$). Although, not significant, rams on average yielded numerically slightly superior performance compared to ewe lambs across the measured parameters. Treatment 1 yielded the best feed conversion in both rams and ewes, suggesting that the standard feedlot diet resulted in the most efficient growth, while Treatment 7 was shown not effective in improving feedlot performance for all the recorded parameters.

Findings of Part two, investigating the main effects on carcass characteristics, show that Diet yielded a significant ($P \leq 0.05$) effect on most of the measured parameters (final weight, warm and cold carcass weights, warm and cold slaughter percentage, feed cost, carcass value and margin above specified costs) while the effect of sex was limited. The interaction of diet and

sex was significant ($P \leq 0.05$) for the difference in slaughter percentage between warm and cold carcasses and the margin above specified cost only. The highest ($P \leq 0.05$) final weights of Treatment 4 lambs corresponded to the highest carcass weights and thus the highest carcass value/revenue being achieved. Additionally, this group yielded superior performance for these parameters in both ram and ewe lambs ($P \leq 0.05$). Although, not significant, rams on average yielded slightly superior performance compared to ewe lambs across the measured parameters. While Treatment 7 yielded the highest slaughter percentage, with the ewes being the highest of all groups ($P \leq 0.05$), Treatment 1 yielded the highest numeric margins over specified costs (R/head and R/kg), along with the lowest FCR, suggesting the correlation between margin and efficiency of growth. Apart from improving slaughter %, Treatment 7 was shown not effective in improving the recorded parameters.

Results from this study indicate that diet played a significant role in most of the measured parameters on Dorper lambs. Differences were also evident between the sexes. Notable differences and wide variation in the data, indicates that further research is required to reduce individual variation and ensure that all animals, both rams and ewes, yield positive returns from the feedlot finishing.

Opsomming

Die mees algemene vleisskaapras in Suid Afrika is die Dorper. Die vroeë volwassenheid van hierdie ras en die geneigdheid om op ‘n vroeë ouderdom gelokaliseerde vet neer te lê, veroorsaak dat hulle op ‘n laer lewendige massa geslag moet word in vergelyking met ander rasse. Hierdie eienskap is geneig om onder gunstige toestande, soos tydens intensiewe voerkraalsisteme, te vererger. Die meeste voerkraalbestuurders diskrimineer dus teen die Dorper en is huiwerig om hulle te af te rond. Dit is weens die gevolglike_laer slaggewig en swakker gradering wat gewoonlik die inkomste verlaag.

Beperkte literatuur wat die effek van dieët en geslag op prestasie en winsgewindheid van Dorper voerkraallammers beskryf is beskikbaar. Die doelwit van hierdie tweeledige studie was om vas te stel wat die effek van dieët en geslag op voerkraal produksieparameters van Dorper lammers is. Deel twee van die studie het die effek van dieet en geslag op karkaseienskappe en winsgewendheid ondersoek .

Vier-en-tagtig Dorper lammers is ewekansig in een van sewe behandelingsgroepe (1= kontrole, 2= lae energie, 3= hoë proteïen, 4= hoë proteïen + lae energie, 5= hoë vet en lae stysel, 6=hoë vet + lae stysel + hoë proteïen, 7= kontrole groep +β-atagonis) in ‘n 2 x 7 faktoriaal ontwerp ingedeel. Elk van die groepe het uit 12 lammers (waarvan 6 ooi- en 6 ramlammers per groep) bestaan. Hoofeffekte was dieet en geslag.

Dieet het ‘n betekenisvolle effek op die prestasie van die meeste voerkraalparameters insluited DMI, aantal voedings, finale massa, lewendige massatoename, GDT en VOV getoon, terwyl die effek van geslag beperk was. Slegs die interaksie tussen behandeling en geslag was betekenisvol ($P = 0.01$) vir VOV. Die bevindings van die studie toon dat die finale lewenede massa van die lammers die hoogste met behandelingsgoep 4 was. Hierdie groep het ook verbeterde ($P \leq 0.05$) prestasie vir totale lewende massatoename en GDT teenoor alle ander behandelingsgroepe van beide ooie en ramme getoon. Alhoewel nie statisties betekenisvol nie, het ramme numeries ‘n hoër prestasie in groeiparameters teenoor ooie getoon. Behandeling 1 het die beste VOV aangeteken wat daarop dui dat die standaard voerkraaldieet tot die mees effektiewe groei gelei het, terwyl behandeling 7 nie tot verbeterde voerkraalprestasie vir alle groeiparameters gelei het nie.

Die bevindings van deel twee van die studie toon dat dieet ‘n betekenisvolle effek op die meeste meetbare slag- en ekonomiese parameters (finale massa, warm en koue karkasmassas, warm en koue uitslagslagpersentasie, voerkoste, karkaswaarde en marge bo spesifieke koste) gehad het. Die effek van geslag was egter beperk. Dieët en geslagsinteraksie vir uitslagpersentasie was slegs betekenisvol ($P \leq 0.05$) tussen die warm en

koue karkasse sowel as marge bo spesifieke koste. Die hoogste ($P \leq 0.05$) finale massa van behandelingsgroep 4 se lammers korreleer met die hoogste karkasmassa en lei dus ook na die hoogste karkas waarde/ inkomste van hierdie groep. Ten opsgte van hierdie parameters het behandeling 4 ook vir beide geslagte beter ($P \leq 0.05$) prestasie behaal. Alhoewel nie statisties betekenisvol nie, het ramme, in vergelyking met ooie, gemiddeld 'n beter prestatsie oor die meetbare parameters behaal. Behandeling 7 het die hoogste uitslagpersentasie gelewer, met ooie die hoogste ($P \leq 0.05$) van al die groepe. Behandeling 1 het tot die hoogste numeriese marge bo spesifieke koste (R/kop and R/kg) asook die beste VOVgelei, wat daarop dui dat daar 'n korrelasie tussen marge en effektiwiteit van groei is. Benewens vir die verbetering van uitslagpersentasie, was behandeling 7 egter nie suksesvol om slag- en ekonomiese parameters te bevoordeel nie.

Die resultate van die studie dui daarop dat dieët 'n statistiese betekenisvolle rol in die meeste van die meetbare parameters by Dorper voerkraallammers het. Duidelike geslagsverskille is ook bespeur. Wye variasie in die data dui daarop dat verdere navorsing benodig word om individuele variasie te verminder asook om te verseker dat beide vroulike en manlike lammers 'n positiewe opbrengs in die voerkraal lewer.

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Note

The language and style used in this thesis are in accordance with the requirements of the South African Journal of Animal Science. This thesis is presented as a compilation of 5 chapters, where each chapter is introduced separately and some repetition between chapters is therefore unavoidable.

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List of Abbreviations

ADF	Acid detergent fibre
ADG	Average daily gain
ad. lib	Ad libitum
ANOVA	Analysis of variance
Approx.	Approximately
BW	Body weight
CMS	Condensed molasses syrup
CF	Crude fibre
CFI	Cumulative feed intake
cDMI	cumulative dry matter intake
CCW	Cold carcass weight
CP	Crude protein
dDMI	daily dry matter intake
DAFF	Department of Agriculture, Forestry and Fisheries
DAVC	Directly allocatable variable cost
DM	Dry matter
DMI	Dry matter intake
E	Ewes
EC	European Commission
EID	Electronic identification
FAO	Food and Agricultural Organization
FCE	Feed conversion efficiency
FCR	Feed conversion ratio

FIRE	Feed Intake Recording Equipment
g	gram
g/day	gram/day
GIT	Gastro-intestinal tract
GM	Gross margin
GP	Growth promotors
GPA	Growth promoting agent
GPV	Gross production value
HPC	High protein concentrate
kg	kilogram
LSD	Least Significant Difference
LSM	Least square mean
M	Margin (Margin above specified cost)
ME	Metabolizable energy
n	number of animas
NDF	Neutral detergent fibre
NPN	Non-protein nitrogen
NRC	National Research Council
NSSIS	National Small Stock Improvement Scheme
PA	Precision agriculture
PSM	Precision Sheep Management
R	Rams
R	Rand
RFID	Radio frequency identification

RPO	Red Meat Producers Organisation
RUP	Rumen undegradable protein
SAMIC	South African Meat Industry Company
SAMM	South African Mutton Merino
S.D.	Standard deviation
S.E.M	Standard error of mean
TDN	Total digestible nutrients
V	Volts
VID	Visual identification
vs.	Versus
WCW	Warm carcass weight
ZH	Zilpaterol hydrochloride
~	Approximately
°C	Degrees Celsius
β agonist	Beta-adrenergic agonist

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CHAPTER 1

General Introduction

1.1. Background

Sheep, with their various products, contribute significantly to South Africa's livestock industry, the majority coming from meat (Cloete & Olivier, 2010). The importance of sheep to South Africa's livestock sector is represented by them being the most numerous of the livestock species (Abstract of Agricultural Statistics, 2021), suggesting that sheep contribute significantly to food security.

South Africa followed the trend of Australia and New Zealand, traditionally the major sheep producing countries, with a declining national flock. Total commercial sheep numbers which were over 33 million in 1975, are currently below 19 million (Abstract of Agricultural Statistics, 2021). Globally, the South African national sheep flock ranks 8^{th}, with approximately 8000 commercial and 5800 communal sheep farmers in South Africa (Terblanche, 2013; DAFF, 2018). The 3 countries with the highest sheep numbers are China (143 million), Australia (99 million) and India (61 million) (FAO, 2007; Walker, 2008). Despite the declining numbers, sheep remain the most numerous livestock species compared to approximately 12.3 and 1.7 million representing commercial cattle and goat numbers respectively (Abstract of Agricultural Statistics, 2021). These numbers indicating the importance of sheep to South Africa's livestock sector.

Cloete *et al*. (2014) reported the 2010-2011 weaning weight records submitted to the National Small Stock Improvement Scheme (NSSIS). Approximately 50% of the records comprise wool breeds; the Merino and Dohne Merino (dual purpose), contributing roughly 22% and 28% respectively. The Dorper was the largest contributor as meat breed at approximately 19%, followed by the South African Mutton Merino (SAMM) (dual purpose), at 18% (Cloete *et al*., 2014).

The per capita consumption of lamb has also experienced a declining trend. The Abstract of Agricultural Statistics (2021) reported a per capita consumption as 3.1kg in 2020 compared to 6.5kg in 1975, while the total mutton consumption fluctuated over the same period. Throughout this time the demand for lamb exceeded local production; as a result, South Africa is considered a nett importer of lamb (Abstract of Agricultural Statistics, 2021). Declining sheep numbers, rapid population growth and an increasing middle class have resulted in both an increase in demand and shortage in the mutton/lamb supply; this has led to the increase in prices of South African mutton since 2002 (Brester, 2012; DAFF, 2012). The agricultural sector, comprising both producers and professionals within industry are responsible for developing sustainable, efficient and ethically acceptable methods of producing, as well as supplying meat to a growing global population (Webb, 2013; Du Toit, 2017). In order to meet growing demands and ensuring food security, Terblanche (2013) suggests that structural changes of the South African sheep industry towards intensification can be expected.

Production efficiency is a key aspect of intensification. Feedlots, like other intensive systems, improve efficiency with their objectives of increasing output per unit (land and animal) (Terblanche, 2013). This is achieved through the principle of fattening weaned lambs on a high-energy diet, resulting in the highest possible weight gain over the shortest time (Spies, 2011), with the aim to produce A2/3 carcasses, which meet the South African market requirements.

Benefits of feedlotting include, adding the most value to the carcass in the shortest period (Van de Vyver, 2014) as well as allowing producers to maintain production during unfavourable environmental and pasture conditions, ensuring a consistent supply of quality lamb (Duddy *et al*., 2016). Feedlotting also allows better control over challenges facing extensive production systems such as predation and stock theft (Webb, 2013). Additional advantages of feedlot finishing include higher growth rates, more consistent carcass weights and carcass quality with an improved dressing percentage (Cloete *et al*., 2012; Webb & Erasmus, 2013).

There are, however, risks of low margins, owing to the high costs associated with these intensive production systems. Costs comprising both fixed costs (infrastructure and labour) and variable costs (feed and lamb purchase price), where animal performance and the animal's market value represent variable outputs (Bowan *et al*., 2006). Feed is often viewed as the largest input cost to feedlots. Retallick (2012) suggests that feed accounts up to 75% of the variable input cost to feedlots. Given the high cost of feed, it is important that animals utilise feed efficiently, therefore effectively distributing nutrients towards lean muscle growth (Du Toit, 2017).

Carcass value, a function of carcass weight, classification and price, represents revenue achieved, it is therefore a critical factor determining feedlot profitability. Lamb, beef, goat, and pork carcasses intended for retailing in the formal market are all classified according to the South African Red Meat Classification System (SAMIC, 2018). Both lamb and beef carcasses classified as A2 typically receive the highest price (R/kg). The lettering, "A" referring to the age classification is determined by the number of permanent incisors of the animal at slaughter (A equals no permanent incisors) and is an indication of meat tenderness (Van der Westhuizen, 2010). The numbering “2” refers to the fat content of the carcass, fat content is an important characteristic that influence meat quality. A2-3 carcasses are considered most desirable being tender with a lean-to-medium fat content meeting the consumer demands for lean lamb meat and providing eating quality attributes (Van der Merwe, 2020; SAMIC, 2021). Carcasses that are too lean or fat, are considered undesirable and have a reduced market value, while uniform fat distribution is also favoured.

The most common sheep breeds in South African commercial systems and suitable for intensive rearing and finishing in feedlots include the Dohne Merino and SAMM, Dormer and Dorper (Cloete *et al.* 2014; Van der Merwe, 2020). Despite their significant contribution to the NSSIS, a challenge facing producers finishing Dorper lambs intensively, is the risk of them rapidly depositing excess, localised fat at a young age (Brand *et al*., 2017) and therefore often struggling to achieve the optimal A2 carcass classification with uniform fat distribution. To overcome this physiological challenge, Dorper’s are frequently slaughtered at a younger age with lower live weights compared to other later-maturing breeds commonly used in feedlot systems (Cloete *et al*., 2000). Including beta-agonists in the diet of early maturing breeds such as Dorper’s, improves production performance, owing to their ability to repartition nutrients, towards lean meat, while reducing fat deposition (Du Toit, 2017). The use of beta-agonists is however associated with concerns of consumer health that restricts wide use thereof (Centner *et al.,* 2014).

The objectives of the two-part study seek to evaluate animal performance and economy thereof by fattening both female and male Dorper lambs on seven treatment diets by assessing:

- Will Dorper feedlot lambs achieve the desired classification (A2) and sufficient carcass weight fed a standard feedlot diet?
- By decreasing the dietary energy (starch) content, what is the effect on feedlot performance parameters and the economy of fattening Dorper lambs?
- By increasing dietary crude protein content, what is the effect on feedlot performance parameters and the economy of fattening Dorper lambs?
- By increasing dietary protein levels and reducing dietary starch levels, what is the effect on feedlot performance parameters and the economy of fattening Dorper lambs?
- Will substituting (approximately 50%) of the dietary starch for rumen protected fat effective in promoting growth, yielding A2 carcasses and thus economical in the fattening of Dorper lambs?

- Will substituting (approximately 50%) of the dietary starch for fat and increasing dietary protein levels effective in yielding heavier carcasses with optimal classification A2 carcasses and thus economical in the fattening of Dorper's lambs
- Will the inclusion of a beta-agonist to the standard feedlot diet yield the heaviest carcasses with desired classification and therefore result in the best margins?
- Considering all the above objectives, was there a difference between sexes (male and female) in both feedlot performance and economy of feedlot finishing Dorper lambs?
- The overall objective of this two-part study was to determine the most desirable nutritional composition of a diet to fatten Dorper ram and ewe lambs efficiently and sustainably (acceptable to the consumer) in a feedlot.

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CHAPTER 2

Literature Review

2.1. Introduction

A growing global population, particularly from developing countries, with their rapidly growing economies, has led to a surge in the demand for animal-based foods in recent times. This upward trend in consumption and in turn, production of animal products is expected to continue (FAO, 2019). The rise in the global demand of these products is largely met through the increase in the commercial livestock farming (Meissner *et al.,* 2013), which includes intensive production systems and their associated food chains. Focus is required to increasing the efficiency and productivity of the different production systems (communal, commercial, extensive and intensive) to supply the growing demand for animal products (Webb, 2013).

2.1.1. The global sheep industry

The top three countries with the highest sheep numbers are China (143 million), Australia (99 million) and India (61 million) (FAO, 2007). While the global sheep numbers resemble that of the 1960's, there has been a trend of declining numbers in Australia and New Zealand, traditionally the major sheep producing countries. Sheep numbers in the Europe have remained constant over this time, whereas in China, numbers have grown significantly, making them the world's largest producers of lamb (Brester, 2012). Despite the decline in animal numbers, an increase in productivity has led to a 60% rise in the annual global production of lamb since the 1960's (Brester, 2012; Terblanche, 2013). Furthermore, Australia and New Zealand, remain leaders in lamb exports, cumulatively accounting for ~90% of the global lamb exports, despite their decline in animal numbers, they remain major players in the global markets (Walker, 2008).

2.1.2. South African national sheep flock

According to the Abstract of Agricultural Statistics (2021), total commercial sheep numbers, comprising both woollen and non-woollen breeds are currently just below 19 million. These numbers indicate the importance of sheep to the agriculture sector, being South Africa's most numerous livestock species, with approximately 8 and 2 million representing cattle and goat numbers respectively (Abstract of Agricultural Statistics, 2021). The South African national sheep flock ranks 8th globally with approximately 8000 commercial and 5800 communal sheep farmers (DAFF, 2012; Terblanche, 2013). South Africa has followed the trend of the major traditional sheep producing countries, with declining animal numbers in past decades. In 1975, South Africa's total commercial sheep numbers exceeded 33 million (Abstract of Agricultural Statistics, 2018). According to literature cited, many factors account for the trend of declining sheep numbers, including unstable product prices, drought, organised stock theft and predators (DAFF, 2012; Aginfo, 2017). Cloete & Oliver (2010) suggests that sheep farmers are most vulnerable to stock theft when compared to other livestock species, such as cattle.

The significant decline in Merino numbers, from ~25 million (1970) to 10 million (2010), is largely responsible for the decrease in the national flock (Cloete & Oliver, 2010). However, the number of non-woollen sheep increased over this time, from approximately 3.7 million in 1970, peaking at approximately 7.8 million (1999) and then declining again to 5.6 million in 2017. A rise in the Dorper numbers is likely responsible for this increase (Cloete *et al.,* 2000). The Dorper breed has gained popularity owing to its hardiness and adaptability to harsh environmental conditions (Marais and Schoeman, 1990).

Cloete *et al*. (2014) reported the 2010-2011 weaning weight records submitted to the NSSIS, comprising the various breeds and their contribution to the South African small stock genetic resource. The breeds and their relative percentages are shown in Figure 2.1. Approximately 50% of the records, consist of the Merino (major wool breed) and Dohne Merino (dual purpose), contributing ~22% and ~28% respectively. The Dorper was the largest contributor of the meat breeds at ~19%, followed by the SAMM (dual purpose) at 18%. There were however some significant differences in the relative breed contributions stated by Cloete & Oliver (2010) for the period 2005–2008. The proportion of wool breeds (Merino and Dohne Merino) exceeded 55%, with records from Merino's alone contributing 31%. These results indicate a decrease in the contribution from major wool breeds between 2008 and 2010. Despite this, Cloete & Oliver (2010) reported the contribution of Dohne Merino and SAMM as approximately 24% and 6% respectively, indicating that SAMM weaning weight records tripled over the same period. Despite the decreasing contribution of the Dorper from 24.2% (Cloete & Oliver, 2010) to 19.3% for the period 2010-2011 (Cloete *et al.*, 2014), it remains the largest contributor of meat breeds.

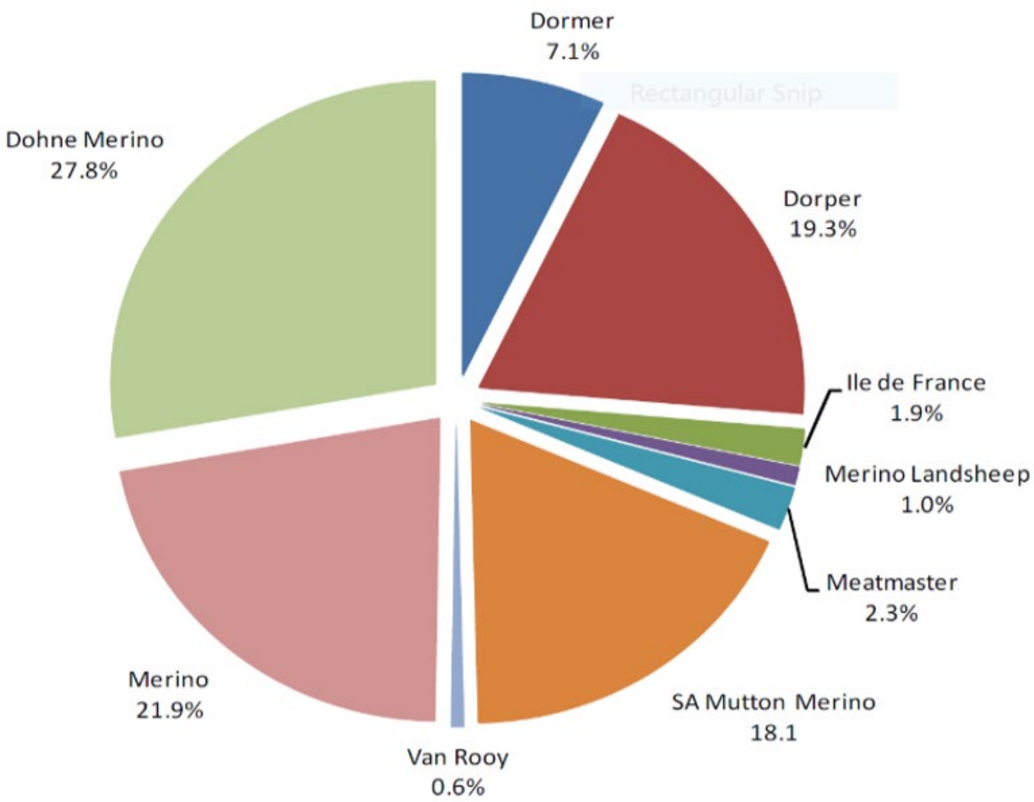

Figure 2.1. The percent contribution of the 2010 - 2011 weaning weights of the various breeds to the National Small Stock Improvement Scheme. Source: Cloete *et al.* (2014) as cited by Olivier (2014).

2.1.3. The South African physical landscape

South Africa is considered relatively dry, classified as having an arid climate and an average annual rainfall of approximately 464 mm (FAO, 2019). Challenges associated with arid conditions limit the agricultural potential (Cloete & Oliver, 2010), leading to a relatively poor environment for livestock production, with low carrying capacity.

As stated in the Abstract of Agricultural Statistics (2018), approximately only 16% of South Africa's 86.2 million hectares of commercial agricultural farmland is considered potentially arable, of which, ~84% is suitable for grazing livestock extensively (Cloete & Oliver, 2010). These areas are typically associated with low carrying capacities, often less than one large stock unit per 12 hectares (Cloete *et al.*, 2014). Cloete (2007) highlighted the advantage of small stock and their ability to survive in these harsh environmental conditions, allowing for sustainable production in extensive regions where farming alternatives are limited. Extensive sheep production therefore represents the dominant livestock industry in these arid regions, predominantly the western and central parts of South Africa. These areas also correspond to the majority of South Africa's commercially produced sheep (Cloete & Oliver, 2010), whereas the wetter Eastern Cape accounts largely for the communal sheep systems. Cloete & Oliver (2010) emphasises the importance of sheep to many rural communities throughout South Africa, with their existence often dependent on sheep and the income from their products, with all participants involved (slaughter, wool processing and tanning) benefitting from the industry.

Livestock production is widely distributed throughout South Africa. As suggested by Meissner *et al*. (2013), the species, breed and animal number are largely dependent on the environment and the available grazing, as well as the type of production system (commercial, small-scale or communal). While intensive production systems such as feedlots, poultry, pigs and dairies are distributed throughout the country, these systems however tend to be concentrated near metropolitan markets and feed suppliers (Meissner *et al*., 2013). In Southern Africa animal production is often based on a combination of both extensive and intensive production systems (Webb, 2013). It is common practice for cattle and sheep to be fattened for a period, to ensure efficient production and carcasses to meet market requirements (Webb & Erasmus, 2013). Although commercial farmers represent the majority compared to the number of communal sheep farmers (DAFF, 2018), it is important that efforts be given to increasing the productivity of all the different production systems (communal, commercial, extensive and intensive) to supply the growing demand for animal products (Webb, 2013).

2.1.4. Demand for lamb

Declining sheep numbers, rapid population growth and an increasing middle class have resulted in both an increase in demand and shortage in the mutton supply (Brester, 2012; DAFF, 2012). Despite the notable decline in South African sheep numbers from approximately 33 million to 20 million (1970 to 2017), total lamb production has remained relatively constant over the same period (Abstract of Agricultural Statistics, 2018). Similarly, there has been a 60% rise in the annual global production of lamb since the 1960's, this despite declining animal numbers (Brester, 2012; Terblanche, 2013). The increased productivity can be attributed to significant improvements in growth and efficiencies of livestock production over time (Webb & Erasmus, 2013). However, during this period, the demand for lamb exceeded production, with imports fluctuating to meet the demand. South Africa is considered a nett importer of lamb, the majority coming from Australia, New Zealand and neighbouring Namibia (Aginfo, 2017).

As reported by the Abstract of Agricultural Statistics (2018), the South African per capita consumption of lamb was 3.3kg (2017) compared to 6.5kg (1975), indicates a declining trend in the per capita consumption of lamb, while the total consumption of mutton fluctuated over the same period. Similarly, Aginfo, (2017) states that over the period 2005/06 to 2014/15, the total mutton consumption increased by 9.7%, however the per capita consumption declined by 5.3%. The rise in consumer awareness and concerns around human health together with a steady increase in lamb prices (DAFF, 2012) as well as fluctuating lamb prices (Oosthuizen, 2016) are likely contributors to the decreasing trend in the per capita consumption of lamb.

As the conventional economic theory suggests, when demand is greater than supply, an increase in price can be expected (Terblanche, 2013). This is true for both producer and consumer prices. DAFF (2018) showed an increase in the prices of mutton for the period 2007 - 2017, while AMT (2021) showed a fluctuating but increasing trend in price for all classifications between July 2018 – January 2021 (Figure 2.2) . Despite the increase in price, there remains a demand for lamb suggesting that lamb is a niche product (Male, 2012) and its demand is reflected by increasing imports (Cloete & Oliver, 2010).

With the growing demand for meat, it is inevitable that animal production systems become more intensive (Webb, 2013). Although most of the lamb and cattle in South Africa are fattened in feedlots prior to slaughter, the current system does not supply the local demand for meat. The agricultural sector possesses the means to address these challenges in terms of technologies as well as the scientific knowledge and expertise (Webb & Erasmus, 2013), however, consumer awareness and concerns regarding the methods of intensive animal production systems are often criticised.

2.2. Carcass classification

Lamb, beef, and pork carcasses intended for retail in the formal market are all graded according to the South African Red Meat Classification System (SAMIC, 2018). Carcass characteristics considered by this classification system include age of the animal, fat content of the carcass, carcass conformation (beef), and the level of carcass damage. Each carcass is inked with its classification, using different colour roller marks (Oosthuizen, 2016).

As suggested by Brand *et al*. (2018), carcass classification systems were developed to inform both processors and consumers on the carcass quality and thus its market value. According to the South African Meat Industry Company (SAMIC) and the Red Meat Producers Organisation (RPO) both beef and lamb carcasses classified as A2 receive the highest market value (R/kg) (SAMIC, 2018; RPO, 2019). The letter (A) refers to the age classification of the animal, which is determined by the animals' number of permanent incisors at slaughter. It is an indication of meat tenderness, with carcasses of younger animals considered more tender (Van der Westhuizen, 2017). An "A grade", refers to an animal having no permanent incisors (in sheep, normally less than 12 months) and is viewed as most tender (Brody, 2017). The number refers to the fat content of the carcass. Fat scores applying to the classification of lamb carcasses range from 0 (extremely lean) to 6 (excessively fat), with either of these extremes considered undesirable thus having a reduced market value. This serves as an important characteristic, influencing the flavour, texture and tenderness of meat. A carcass with a fat grading of 2 is considered lean (Van der Westhuizen, 2017) and is therefore desirable (Brody, 2017), while still providing eating quality attributes (Van der Merwe, 2020; SAMIC, 2021).

The Dorper sheep is an early maturing sheep breed, a challenge associated with finishing these lambs in intensive systems is the risk of rapidly depositing excess, localised fat at a young age (Cloete, 2007; Brand, 2017). Feedlot producers often struggle to achieve the optimal A2 carcass classification with uniform fat distribution. It is expected that early-maturing breeds yield fatter carcasses after a set time on feed, when compared to later-maturing breeds. To overcome this physiological challenge, Dorper's are frequently slaughtered at a younger age (lower live weights) compared to other heavier, later-maturing breeds commonly used in feedlot systems (Cloete *et al.,* 2000; Van der Merwe, 2020). The lower carcass value (lighter carcass) of the Dorper is responsible for the typical discrimination against these animals in feedlot systems (Truter, 2018).

An animal's total fat content as well as the pattern of fat deposition affects carcass classification, in addition influencing the optimal age/weight to slaughter (Brand *et al*., 2018). As carcass weight increases, it is associated with a change in carcass composition, represented by a relative decrease in the proportion of muscle and bone and an increase in the proportion of fat. Given that fat content contributes significant to the carcass classification and its value, the trends of fat deposition across the different animal types should be established (Brand *et al*., 2018). This would assist producers in preventing overfeeding and possible downgrading of their lambs. Further research is required to establish how best to manage and market feedlot Dorper lambs to ensure consistent production of optimal carcasses.

2.3. Feedlots

According to Smith (2011), a feedlot is defined as a feeding operation where animals are arranged in pens to fatten prior to slaughter, with the main objective of rapidly achieving marketable weights by maximising weight gain (Terblanche, 2013). Through intensive feeding, feedlotting aims to add value to animals with a low body weight and poor conformation and produce carcasses with a higher value (Van der Merwe, 2020).

To meet the growing demand for lamb, ensure food security as well as overcoming some of the many challenges facing producers, both economic and environmental, the trend has been towards intensification of sheep production systems (Terblanche, 2013). These factors have led to feedlot finishing of lambs having gained popularity in recent decades (Van der Westhuizen, 2010). Additionally, the societal demand for cheap food is a primary driver towards the intensification of animal production systems (Webb, 2013).

In reference to cattle feedlots, Oosthuizen (2016) suggests that the principle of feedlotting is to buy in weaned calves, feed them a complete, high-energy diet as well administering them with growth promotors. These factors all aid the highest possible weight gain over the shortest time (Spies, 2011). Similar principles apply to the feedlotting of lambs, where animals are typically fattened for a set period with the objectives of these operations to produce carcasses with an A2/3 classification, which meet the South African market requirements and in turn, allow producers to benefit from the highest possible market price.

2.3.3. Benefits to feedlotting

Feedlotting has benefits in allowing lamb producers to maintain production during times of unfavourable environmental and pasture conditions, thereby ensuring they are able to consistently supply quality lamb (Duddy *et al*., 2016). Furthermore, it has been suggested by Webb & Erasmus (2013) that concentrate feeding of feedlot animals tends to yield more consistent carcass composition compared to pasture-fed animals, in turn addressing the need for consistent meat quality and allowing producers to take advantage of the historically high prices for feedlot-finished lamb Male (2012).

Finishing lambs in feedlots allows early weaning of animals as they will be fattened to meet market requirements by exploiting the rapid growth and favourable feed conversion of young animals (Levy *et al.*, 2010). Placing lambs into feedlots also serves to relieve the grazing pressure, thus allowing the producer to carry more productive ewes (Male, 2012), allowing for higher stocking density. In this way, increasing the number of lambs slaughtered per annum and improving output per hectare (Terblanche, 2013; Van Zyl, 2017). Feedlotting also provides producers better control over challenges associated with South African extensive production systems, such as predation and stock theft (Webb, 2013).

When comparing different production systems, Van de Vyver (2014) suggests that feedlot finishing typically adds the most value to the carcass in the shortest possible time. Similarly, Webb (2013) states that intensive systems are known for improved efficiency of production, feed efficiencies and shorter feeding periods. Additional advantages of feedlot finishing include improved management and control over animal performance, which allows for higher growth rates, more consistent carcass weights and carcass quality as well as improved dressing percentage (Cloete *et al*., 2012; Webb & Erasmus, 2013) as well as the reduction in CH_4 production from intensively fed livestock compared to grazing ruminants owing to the lower crude fibre content of their diets (Webb, 2013).

2.4.4. Risks with feedlotting

Feedlots are known to have high capital and input costs and therefore are at risk of low profits (Oosthuizen, 2016). Furthermore, changing markets and price fluctuations in both inputs (feed/purchase price) and output put pressure on profit margins (Oosthuizen, 2016). Effective management and optimisation of all aspects of these systems is crucial in ensuring they remain profitable (Jolly & Wallace, 2007). Along with the risk of high costs and low profit, there are numerous factors influencing feedlot profitability. These include both fixed costs (infrastructure and labour) and variable costs (feed), whereas animal performance and market value represent variable outputs (Bowan *et al*., 2006). Furthermore, many of these influencers affecting feedlot profitability are beyond the control of producers.

Despite the many benefits associated with feedlotting lambs, growing consumer concern is a further challenge facing intensive animal production systems. Criticism towards these systems include concerns, surrounding animal ethics and welfare, risks of environmental damage and sustainability as well as concerns towards human health with the consumption of products from intensively reared animals (Webb, 2013). While it is important that the methods used in animal production systems are challenged (Swan, 2019; Wessels, 2019), the criticism they receive is often based on the general perception that intensive systems are synonymous with confinement and therefore problematic for animal welfare (Fraser, 2005). Intensive systems are vastly different from the traditional, extensive systems, and therefore these perceptions are largely based on the changing nature of these systems rather than the ethics of production (Fraser, 2005; Webb, 2013). While intensification of production systems is necessary to meet future demands, it is important that the livestock industry plans and responds appropriately, ensuring that intensification of these systems are conducted in an ethical and environmentally sustainable manner, in addition to informing consumers on the benefits of these systems.

2.4. Feedlot Profitability

Profit is the primary factor determining the existence of any enterprise (Gardner *et al*., 1996). There are various factors which directly affect the profitability of a production system as well as influence production, which in turn contributes to the profitability of the system. In reference to the beef industry, Retallick (2012) states that many producers focus on improving profitability through improving outputs of the system, such as growth rates, carcass quality and reproductive efficiency. It is however very important to recognise that profitability is a function of both the inputs (costs) and outputs (revenue) of the system (Ahola & Hill, 2012).

While Terblanche (2013) suggests that the common production parameters are the main drivers of profitability for sheep production systems, Van Zyl (2017) suggests that the five most significant drivers of feedlot profitability are animal performance parameters (average daily gain (ADG) and feed conversion ratio (FCR)); carcass characteristics (weight, dressing percentage and classification); meat price; the animal purchase price and the feed costs. This agrees with much of the literature cited however, the order of importance of the specific drivers of profitability may vary between studies.

Factors influencing feedlot profitability can be broadly classified into two categories namely economic or management factors (Spies, 2011). Economic factors refer to those which cannot be controlled by producers and include lamb purchase price, feed price and meat/carcass price. management factors are those factors which can, to some extent, be controlled by producers such as animal performance, ADG and FCR. The instability of feedlot profitability is a significant challenge associated with these systems, owing to fluctuating prices of inputs (feed) and output (meat) (Spies, 2011). In addition, fluctuations in the seasonality of production and the demand for meat also affect profitability.

2.4.1. Economic factors that affect feedlot profitability

The economic factors are those influencers of feedlot profitability which are beyond the control of the producer. These factors include the purchase price for weaners, the feed price (typically a function of the maize price), the carcass price and the interest rate (Spies, 2011). These economic factors are subject to regular price fluctuations which are influenced by a change in supply and demand of each of the products over time (Oosthuizen, 2016) and these price variabilities will have a significant impact on overall feedlot profitability. Increasing input prices (weaner price and feed costs) will have a strong negative correlation with profitability (Maré *et al*., 2010), while output prices (carcass price) are positively correlated.

2.4.1.1. Lamb purchase price

The purchase price of animals to enter the feedlot represent a major input cost and therefore has a significant effect on overall feedlot profitability. Many studies suggesting that the weaned (store) lamb price is the main variable cost to production systems (Van Zyl, 2017). In reference to cattle, Ford (2011), states that the weaner price typically represents (64.4%) of the input costs, followed by the feed costs (23.3%), sentiments shared by Van der Merwe (2020). Like cattle, the store lamb price experiences continuous fluctuations, which are further dependent on annual price trends and external factors, such as drought conditions (Page, 2017).

2.4.1.2. Cost of feed

It is widely accepted that feed prices represent the greatest variable cost to feedlots. Retallick (2012) suggests that feed accounts up to 75% of the variable input cost to feedlots and therefore represents a critical factor determining feedlot profitability. While feed costs are dependent on the cost of the raw materials, total feed costs are however feedlot specific, depending on the operations level of vertical integration. Given the large maize component in feedlot diets (NRC 2007), feed costs are typically a function of the maize price, which is subject to fluctuation, thus feed representing a variable cost to feedlots. Despite the high cost of feed (economic factor), feed (nutrition), is the main management factor providing producers with the greatest control over animal performance (Chappell, 1993; Owens *et al*., 1993).

Feed intake (thus cost of feed) is often expressed as a function of body weight. It is widely accepted that lambs will consume on average, 4% on an as is basis of their live weight daily (Van der Merwe, 2020; Vosloo, 2021). Duddy *et al*. (2016) suggests that the amount of feed lambs require is dependent on an animals' starting weight, the ration quality and type as well as management factors (growth rate and efficiency of feed conversion) which are often related to genotype. The time spent in the feedlot as well as the animals target marketing weight will influence the total feed intake and cost of feed (Koknaroglu *et al.,* 2005).

2.4.1.3. Meat/carcass price

The meat price is dependent on carcass classification, where the carcass value is a function of both weight and classification. Both beef and lamb carcasses graded A2 (and A3) receive the highest market value (R/kg) (RPO, 2021), being lean and tender, from animals with no permanent incisors, these carcasses are considered desirable and meet South African market requirements (Brand *et al*., 2018).

Like store lambs and weaner prices, the prices for both cattle and lamb carcasses experience continuous fluctuations. Market prices are dependent on the annual meat price trends which are driven by supply and demand, for this reason, average monthly prices are used to obtain the annual price trend. External factors such as drought conditions may influence or skew the annual trend of carcass prices (Oosthuizen, 2016). Figure 2.2 shows fluctuating price trends for the different classes of lamb and mutton. The variability in lamb price is a challenge facing industry. At a consumer level, rising prices is partly responsible for the decreasing trend in the per capita consumption of lamb (Oosthuizen, 2019).

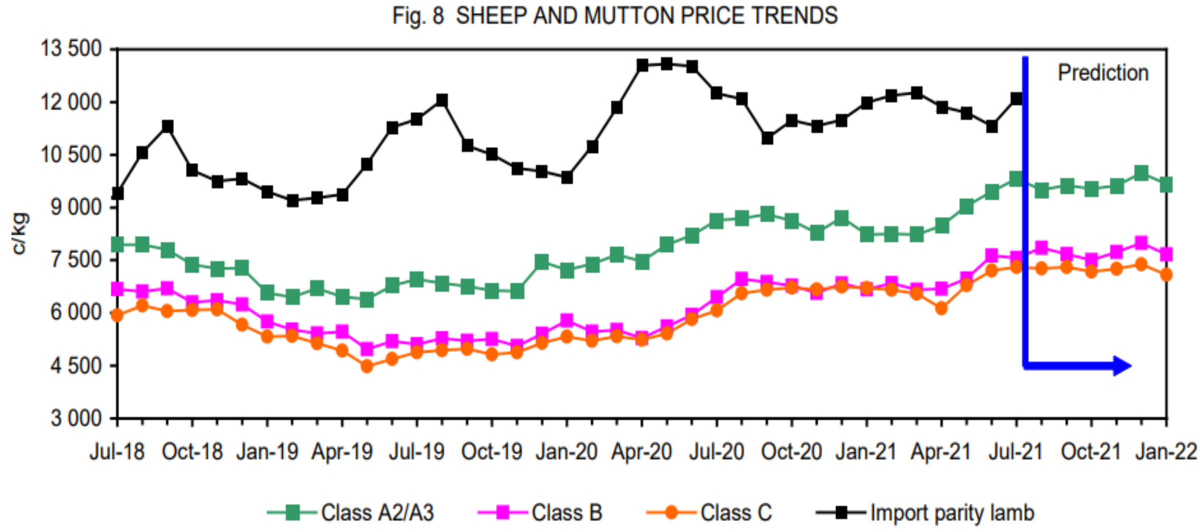

Figure 2.2. The average monthly price trends for lamb and mutton carcass for the period July 2018 – January 2022. Source AMT (2021).

2.4.1.4. Price margin

The price margin refers to the difference between the purchase price of lambs (input) and their expected market value (output) and considers the two important economic factors mentioned above (Esterhuizen, 2008). Fluctuation in the value of weaner lambs relative to the revenue gained from finished lambs poses a significant risk to feedlot profitability. The price margin is therefore important in determining overall feedlot profitability and should be estimated by producers. Animal market values can be assessed by studying long and short-term market trends and meat prices (Duddy *et al.*, 2016) as well as estimating the supply of lamb over the proposed selling period. The importance of a lambs starting value relative to its trading value is emphasised by Page (2017), suggests that it has the greatest influence on feedlot profits. The live purchase price per kg should be a maximum of 86% of the live sale price per kg, in order for feedlot operations to be profitable under Western Australian conditions (Page, 2017). Van Zyl (2021) suggests that under South African conditions, the live purchase price (per kg) should be a maximum of 50% of the carcass price (per kg), for feedlots to remain profitable.

2.4.2. Management factors which affect feedlot profitability

The management factors are those influencers of feedlot profitability which can, or at least to some extent, be managed by the feedlot producers. Management factors typically relate to the animal performance characteristics such as ADG, FCR and dressing percentage as well as mortality rate and time spent on grain. These factors are largely related to intrinsic animal characteristics which include breed, age, weight, sex and health status (Spies, 2011).

Average daily gain (ADG) represents the daily amount of live weight gained during the fattening period and is calculated by dividing the total live weight gained by the number of days in feedlot and is represented by (g/day) (Reiling, 2011). ADG is traditionally one of the most important production parameters to feedlot producers, in part owing to its ease of calculation. ADG gives an indication of animal performance, growth rate and if calculated frequently, also the pattern of growth. These factors all notably influence the profitability of the enterprise (Spies, 2011). These traits provide feedlot producers with important management tools, allowing them to determine whether animals are growing according to breed/production system standards and adjust management practices if necessary.

Feed conversion ratio (FCR) is defined as the amount of feed required for the animal to gain one kilogram of live weight. The ratio is represented by kilograms of feed to 1 kg live weight gain and is calculated as the mass of the input (feed consumed) divided by the output mass (body weight gained) (Gunsett, 1987; Xu *et al.,* 2014; Yi *et al.,* 2018). Feed conversion efficiency (FCE) is the inverse of FCR, being the output mass divided by the input mass. Both FCR and FCE are important production parameters which describe the efficiency with which animals convert input (feed) to output (live weight).

FCR, like ADG, is dependent on intrinsic animal factors and feed quality. Feed conversion will also differ between breeds and animal types, feed quality influences FCR, with animals receiving high quality, balanced rations having a lower FCR (higher FCE) compared to animals receiving poorer quality feed (Oosthuizen, 2016; Van der Merwe, 2020).

The importance of efficient production for profitability and sustainability within intensive systems is well documented (Terblanche, 2013; Oosthuizen, 2016). However, selection of animals based on feed efficiency with the aim of reducing feed costs has been limited (Retallick, 2012). This in part, owing to the challenges with accurately measuring individual feed intakes of sheep and cattle. However, new technologies like RFID which allow for individual FCR values being determined, will allow for opportunities for advancement within the sheep industry (De Wet, 2018; Muir *et al.,* 2020) and through breeding and management will allow for reducing feed costs and improving feed efficiency.

Carcass weight is directly related to revenue gained as the carcass value is a function of weight and classification. Carcass weight therefore plays a crucial role in determining feedlot profitability. Retallick (2012) showed a linear relationship between weight and value for feedlot cattle. This agrees with Oosthuizen (2016), who found that carcass weight and the animal's value increased in direct proportion (unless there were interactions with additional factors). There are however challenges in producing heavier carcasses, including the increasing cost of gain with age of days in the feedlot, owing to the increased proportion of feed for maintenance rather than live weight gain (Oosthuizen, 2016). A significant limitation in producing heavier carcasses is the deposition of excessive fat with increased days on grain (Van der Merwe, 2020). Excessive fat is both expensive to produce and undesirable as it negatively affects carcass quality and in turn carcass value; a challenge facing producers of early maturing breeds such as Dorper (Cloete et al*.,* 2000). Carcass weight and grade are influenced by the animal type, resulting in different market-ready weights for the different breeds. Therefore, optimal nutrition and feeding period need to be established to maximise profit per individual and animal type.

Dressing percentage refers to the carcass weight as a percentage, relative to the live weight of the animal (Casey *et al.,* 2014). Dressing percentage is directly related to the revenue per lamb and therefore has a significant impact on overall profitability (Coyne *et al.,* 2019). Several factors influence dressing percentage, including whether the hot/cold carcass weight is being considered, the size/animal type (small/medium/large frame), sex and relative carcass composition. These factors vary between breeds/types and are strongly influenced by nutrition and management practices, which include the addition of growth promotors (Spies, 2011).

2.4.2.4. Additional influencers of feedlot profitability

2.4.2.4.1. Selection of Lambs

Importance should be given to the selection of lambs entering the feedlot as not all breeds or sheep types perform equally under feedlot conditions. During selection, factors to consider include breed, age, live weight, sex and sheep type (meat/wool/dual-purpose) and animal history, which includes the animal's background, environmental conditions, past nutritional history and health status (Bowan *et al*., 2006). In reference to cattle, Oosthuizen & Maré (2018) suggest that the various beef breeds differ significantly in terms of their growth rate and pattern of growth (fat, muscle and bone). This is confirmed for sheep by Van der Merwe (2020). To ensure improved feedlot productivity, each breed should be fed according to its genetic growth potential. Breed choice is producer specific however, the dual-purpose Merino-type lambs (Dohne Merino and SAMM) are popular for finishing in intensive feedlot systems due to their favourable growth rates, quality carcasses and the revenue gained from their wool production (Van der Merwe, 2020).

Live weight is also an important factor when selecting starter lambs, with many producers wishing to exploit the rapid growth potential of young lambs. There is however a risk that younger animals struggle to adapt to feedlot conditions. Under Australian conditions, Duddy *et al.* (2016) suggests that finishing heavier lambs is advantageous, owing to the likelihood of predicting the final lamb values, through the availability of price grids and forward contracts for these lambs.

2.4.2.4.2. Management

Sound feedlot management, encompassing every aspect of the production system can have a significant effect on feedlot efficiency and productivity and therefore a positive effect on the overall feedlot profitability. Common commercial practice in feedlots is to manage and market animals on a group basis, according to the group averages and set fattening period. However, the significant variation among animals and the differences in their performance within a group, forms the basis of the trend towards precision sheep management. Through regular measurement and recording of animal performance, objective managing, and marketing decisions based on an individual animal performance, will allow for greater precision and optimisation of sheep feedlots with greater profits being achieved (Precision Pays, 2007).

2.4.2.4.3. Risk

As mentioned, feedlots have risks associated with low profit margins owing to their high capital and input costs. There are several financial risks associated with the feedlot-finishing of lambs, these represent factors that negatively affect feedlot profit margins and include, lamb mortalities, shy feeders, poor growth rates and unexpected changes in feed or market prices (Slusser, 2008). Feedlot profitability is sensitive to the fluctuations in both the price of their inputs and the value of their outputs (Oosthuizen, 2016). Risk to producers can be minimised through sound management of all aspects of the feedlot operation and careful planning, ensuring that forward contracts with abattoirs and/or markets are established (Duddy *et al.*, 2016).

2.5. Nutrition

2.5.1. Introduction

Nutrition is a critical aspect of any production system and is regarded as the factor with which the producer can exert the greatest control (Chappell, 1993) over animal performance characteristics such as ADG and FCR (Chappell, 1993). These represent important feedlot management factors in determining profitability of the enterprise (Chappell, 1993; Owens *et al.*, 1993).

It has been well documented that lambs should be fed according to their nutritional requirements to achieve their genetic productive potential (NRC, 2007). These requirements are dependent on many intrinsic animal factors such as age, weight, breed/animal type and sex as well as the level of production (Van der Merwe & Smith, 1991; NRC, 2007). The nutritional requirements will change with age of lambs and their genetic potential for growth, while the frame size is an indicator of growth potential (Schoenian, 2019). These requirements of the growing lamb in terms of energy, protein, vitamins, minerals, fibre, and water can be met through a variety of feedstuffs. However, with maximum gains in the shortest possible period being the objective of feedlotting, it is common for these lambs to be fattened on high levels of concentrated feed (Van der Merwe & Smith, 1991).

2.5.2. Energy

Energy typically makes up the largest nutritional portion of the diet for intensively finished livestock, with carbohydrates (starch) from cereal grains representing the major dietary source of energy (Feedipedia, 2017). Grains are known to have high levels of digestible energy (DE) compared to roughages; therefore high-grain diets are advantageous for intensive sheep productions (NRC, 2007). Although cereal grains are the most common energy sources in high energy diets, by-products from grain processing are also often utilised as high energy sources (Table 2.1).

Table 2.1. Different feedstuffs commonly used as energy sources in the finishing diets of lambs and their representative %TDN (DM) in descending order.

Feedstuff	% TDN
Whole cottonseed	91
Wheat middling's	90
Maize	89
Wheat	89
Sorghum	89
Barley	84
Rye	81
Soybean hulls	77
Molasses	75
Beet pulp pellets	74
Oats	74

Source: Schoenian (2019).

The specific term used to describe the unit of dietary energy depends on many factors (NRC, 2007). In the South African context, the joule is commonly used, however, energy values for feedstuffs are often expressed in megajoules (1 MJ = 1 000 000 joules). The energy level in a diet may be quantified in various ways. Total digestible nutrients (TDN) is a measure often used to evaluate feedstuffs however, metabolizable energy (ME), which considers the energy loss through methane production, is a more accurate measure of energy in the diets of ruminants.

2.5.2.1. Starch

Starch is defined as a carbohydrate forming the primary stored energy in plants, especially grains like wheat, maize, rice, and potatoes. In addition to providing an important source of nutrition to humans and animals, starch is also used in many other industries (American Heritage, Science Dictionary, 2011). The high DE of starch allows for rapid weight gain (lean tissue) followed by the accumulation of adipose tissue (fat) of feedlot animals. Vasta & Priolo (2006) suggest that grain-based diets induce higher accumulation of branched-chain fatty acids in the meat of feedlot animals compared to production systems, including animals supplemented with fat-enriched diets. The latter, enhancing volatile compounds in meat, which are known to influence flavour.

While high levels of starch may be beneficial in most intensive feeding systems, the resulting accumulation of fat may be detrimental in the fattening of early maturing sheep breeds, well known for depositing excessive fat at an early age (Brand *et al.,* 2018). In these cases, alternative energy sources may be considered.

2.5.2.2. Fat

Fat is known to provide significantly more (2.5 to 4-fold) energy per unit than starch (Huntington, 2011; Van Zyl, 2021) depending on the source of the fat. However, the supplementation of fats in the diets of ruminants yields varying responses on nutrient digestibility, feedlot performance, body and carcass composition (Davila-Ramirez *et al.,* 2015). This variation in response may be attributed to both the inclusion level and or source of fat in the diet, which can directly affect the activity of ruminal microbes (Van der Merwe and Smith, 1991).

High levels of dietary fat may cause coating of fibre in the rumen (Van Zyl, 2021), reducing fibre and organic matter (OM) digestibility. The effects of fat-supplementation on fibre, DM and OM digestibility are well documented (Palmquist, 1994; Zinn *et al.,* 1994; Dutta *et al.,* 2008). Most of the available literature focuses on the effects of dietary fat on milk production and composition in dairy cows and small ruminants, as well as the effects on meat quality and composition. However, studies by Kott *et al.* (2003, Gibb *et al.* (2005) Dutta *et al.* (2008), Davila-Ramirez *et al.* (2014) and Davila-Ramirez *et al.* (2015) showed no detrimental effects on growth parameters of feedlot finished lambs.

2.5.3. Protein

Protein is a crucial nutrient for all animals, particularly high producing animals (Van der Merwe & Smith, 1991). After energy, protein is typically the next largest nutritional constituent in feedlot diets. An animal's protein requirement is dependent on numerous factors; however, requirements are highest for young, rapidly growing animals, depositing lean muscle tissue, such as feedlot lambs (NRC, 2007). Crude protein (CP) is a measurement of the protein content of a substance and a factor of its Nitrogen (N) composition (Van der Merwe & Smith, 1991). Figure 2.2 indicate the protein levels of commonly used feedstuffs in feedlots.

Table 2.2. Different feedstuffs commonly used as protein sources in the finishing diets of lambs and their representative CP content (DM) in descending order

Feedstuff	% CP
Urea	281
Fish meal	62
Soybean meal	48
Whole soybeans	42
Cottonseed meal	41
Linseed meal	34
HPC*	36-40
Poultry litter	26
Distiller's grains	25
Brewer's grains	24
Whole cottonseed	21

*HPC – High protein concentrate (a typical commercially available protein supplement).
Source: Schoenian (2019).

In animal feeds, CP is calculated as N x 6.25 (Krul, 2019). Concentrated protein feeds contain high levels of protein, usually greater than 20% CP (Feedipedia, 2017). Common protein sources in feedlot diets include soya and plant-based oilcakes, which comprise the coarse residues following extraction of oil from various oilseeds (Van der Merwe & Smith, 1991). Oilcakes are high in protein and minerals, depending on the processing method, they typically yield 25-35% CP, with some > 40% CP (Feedipedia, 2017), serving as a valuable protein source to both ruminant and monogastric animal feeds (Mordant, 1981). Animal-based proteins, such as fish, blood and feather meal may also be included in the diets of ruminants, although high costs and ethics are usually a limitation. While urea is not a protein, it is however a source of non-protein nitrogen (NPN) that ruminants can utilise for the synthesis of microbial protein and represents the cheapest source of dietary nitrogen (Van der Merwe & Smith, 1991). Urea comprises 45% N, equating to 281% CP, it needs to be carefully incorporated into the diets of livestock and should not be supplied at more than 30% of the total nitrogen in a diet (Schoenian, 2019).

2.5.4. Minerals and vitamins

Minerals are naturally occurring substances considered as essential nutrients as they are required for cellular activity. According to Schoenian (2019), there are 16 minerals which have been classified as nutritionally essential in the diets of sheep. These comprise macro-minerals, which are required in relatively larger quantities and micro-minerals (trace elements) required in very small amounts. The requirements for mineral supplementation differ according to lambs' diets, both an under and over supply of minerals can be detrimental. Careful attention should be given to balance between calcium (Ca) and Phosphorous (P) in the diet as an imbalance of these minerals can cause urinary calculi in male lambs, especially wethers (Schoenian, 2019). Interactions between minerals further complicates mineral balance in sheep (Van Zyl, 2021).

Vitamins are organic, naturally occurring substances considered as essential nutrients as they are required for cellular activity. While some vitamins are essential in the diet of ruminants, others (B-vitamins) are synthesised by ruminal microorganisms (Van Zyl, 2021).

2.5.5. Growth promoters

Feed additives refer to compounds which are included into rations in addition to supplying the animals with nutrients (EC, 2014). Many livestock producers make use of growth promoters, with the aim of benefitting from the increase in output, through increased weight gain and improved efficiency of production (Hossner, 2005). Various feed additives and their different varieties, have been utilised to improve the health and performance of lambs, including but not limited to antibiotics, hormones, ionophores and beta-agonists.

2.5.5.1. Ionophores

Ionophores refer to a group of carboxylic polyether antimicrobials known to improve feed efficiency in ruminants by altering rumen fermentation. The majority of the ionophore antibiotics are produced by *Streptomyces* species (Benno *et al*., 1988). Since the mid 1970's, ionophores have been used extensively to manipulate rumen fermentation, to improve the efficiency of feed utilisation and to increase weight gain of growing ruminants (Mousa, 1994). Ionophores are primarily used for growth promotion, however they also serve as coccidiostats in preventing the incidence of coccidiosis. These compounds increase efficiency by improving feed utilisation through altering metabolism in several ways. However, an increase in the proportion of propionic acid has been consistently observed with the incorporation of ionophores in animal rations (Ellis *et al.,* 2012; Crossland *et al.,* 2017). This acid is known to improve efficiency of production in ruminants (Al-Dobaib & Mousa, 2009). Several ionophores are either used commercially or have been investigated for use in growing animals (Al-Dobaib & Mousa, 2009).

Despite growing concerns around antibiotic resistance, sub-therapeutic levels of antimicrobial agents including ionophores, remain the most widely used growth promoters in animal production (Partridge, 1991). Several countries, including all European Union countries and Namibia, have however banned the use of antibiotics as growth promoters in livestock, mainly due to consumer concerns to the possible risks of future drug resistance in humans (Al-Dobaib & Mousa, 2009).

2.5.5.2. Hormones

By definition, hormones refer to a class of signalling molecules, produced by glands in multicellular organisms, they are transported by the circulatory system to distant target organs (Mandal, 2019). They act to regulate numerous physiological and behavioural processes, including growth and development. Anabolic hormones comprising both natural or synthetic steroidal hormones, which stimulate growth and development of muscle tissue are those of interest in animal production systems (Dikeman, 2007). Their role in controlling protein deposition and whereby altering growth rate and the body composition of animals, has led to the widespread use of anabolic steroid implants as growth promoting agents in livestock production. As suggested by NRC (1994), these hormones both increase protein accretion and decrease the rate of protein degradation and therefore enhancing growth during the fattening phase. In addition, they are known to increasing ADG and FCR while decreasing carcass fatness (Preston, 1999), however some negative effects on meat tenderness have been reported (Dikeman, 2007).

Many countries, including South Africa have registered use of hormonal implants as growth promoting agents in livestock production. However, since 1998, these have been prohibited in all Western European countries (Preston, 1999)

2.5.5.3. Beta-Agonists

Beta-adrenergic agonists, a group of synthetic compounds often referred to as β-agonists, have a molecular structure similar to the naturally occurring catecholamines; epinephrine and noradrenaline (Hossner, 2005). There are a variety of β-agonists with applications in animal production, these include zilpaterol, clenbuterol, cimaterol, salbutamol and ractopamine (Partridge, 1991). It has been widely reported that β-agonists induce a range of positive effects on muscle tissue and fat deposits (Moody *et al*., 2000). As suggested by Yang & Mc Elligott (1989), β-agonists are potent growth promoters, producing a dramatic increase in skeletal muscle, while a significant decrease in body fat in many species of animals. However, negative effects on meat quality (toughness) have been reported following the use of these growth promotor. (Steenekamp, 2014).

Adrenergic receptors are divided into two main categories, namely Alpha-adrenergic receptors and Beta-adrenergic receptors. The main function of Alpha-receptors is the facilitation of sympathetic nervous system responses and regulation of vasoconstriction as well as smooth muscle contractions (Du Toit, 2017). Beta-receptors control smooth muscle relaxation, they have a higher affinity for Epinephrine than Norepinephrine (Hossner, 2005) and typically have greater response to beta-agonists than alpha-adrenergic receptors.

A β-adrenergic response yields a rapid mobilisation of the body's energy reserves, achieved by the processes of glycogenolysis and gluconeogenesis in the liver and skeletal muscle (Chung *et al*., 2015). Being structurally similar to Epinephrine and Noradrenaline, these compounds significantly influence nutrient metabolism by stimulating lipolysis, increased fat mobilisation and decreased lipogenesis, resulting in a decrease in adipose tissue and its deposition (Chung *et al*., 2015). They are also known to have a positive effect on nitrogen retention and protein turnover, through improved protein accretion and reduced proteolysis (Mersmann, 2002). In this way β-agonists are known as repartitioning agents, with the increase in lean muscle reduced fat deposition responsible for improved feed efficiency with the use of these growth promoters.

β-agonists and other growth promoting agents, known for their overall positive influences on growth patterns, improved efficiency and feed utilisation; whereby yielding heavier animals (Strydom, 2016) with better carcass composition, can have a significant positive influence on profit margins (Du Toit, 2017; Truter, 2018). These substances should therefore be considered by producers, particularly in intensive feedlot systems, where the margins above feed costs are narrow.

2.6. Precision agriculture

Precision agriculture (PA) is a broad concept but can be considered as an all-encompassing term used to describe the various techniques, technologies, and management strategies that address on-farm variability (Maré & Maré, 2015), with the aim of providing producers better control, improved management to make objective management decisions. Bootle (2001) defines PA as "the physical and financial management of farming operations in a site-specific manner, which returns more control, repeatability, and certainty to the farming enterprise; resulting in lower costs and less variable and more predictable returns."

The performance of individual animals can significantly influence the profitability of a feedlot finishing system, Jolly & Wallace, (2007) suggests that the opportunity cost of not identifying and weighing lambs individually should be considered (Atwood *et al.,* 2006). While Oosthuizen (2016) highlights the importance of feedlots producing efficiently, whereby remaining sustainable during unfavourable market conditions, emphasis is also given to the investment cost associated with PA, suggesting that the total fixed cost of conventional farming is lower than with PA. The Australian Sheep Industry Cooperative Research Centre (CRC) has focused on improving profit margins within the Australian sheep industry. This has been achieved by emphasis on greater precision, optimisation and improved efficiency of production systems, as well as focus given to breeding, management and marketing of animals (Jago *et al.,* 2013; Morgan-Davies *et al.,* 2017).The objective of precision farming has been to measure, manage and market animals on their individual merit rather than the traditional group basis, in this way overcoming both the high and low performing animals from being hidden in the averages of the flock (Barnes *et al.,* 2018; De Wet, 2018). The idea of measuring animal performance more intensively and then applying this data in terms of selection and management, forms the basis of Precision Sheep Management (PSM), a concept closely related to PA.

The measurable variation that exists between animals within groups forms the basis of these precision concepts (McLeod, 2019). This variability allows for opportunities to exploit significant gains in animal performance and productivity, through selection and management, whereby leading to increased efficiency and profitability of these systems. Precision Pays

(2007), suggests there is often a difference in performance (both wool and growth parameters) between the top and bottom 25% of animals, equating to a fivefold difference in revenue gained from these two animal groups. As suggested by Oosthuizen (2016), in order for PA to be more profitable than conventional farming systems, there must be sufficient variation between management groups in order to justify the increases in investment costs.

2.7. History and development of the Dorper

2.7.1. Introduction

The Dorper is a synthetic, non-woollen, meat sheep breed, where the Black head Persian and Dorset Horn were combined to produce a robust animal, which has proven highly adapted to the harsh arid environments of South Africa, amongst many other climatic conditions (Schoeman, 2000). This early maturing sheep, though considered indigenous to South Africa, is distributed throughout Africa and abroad (Knights, 2010; Alemseged & Hacker, 2014).

The growing demand for lamb and specifically animals which produce acceptable carcasses and which were suitable for production on veld (Cloete et al., 2000) in the arid and semi-arid regions of South Africa, led to the development of the Dorper breed (Schoeman, 2000).

2.7.2. History

The economic circumstances following World War I, the depression, a surplus of mutton and the drop in wool prices led to the export of lamb gaining interest (Milne, 2000). However, the carcasses of South African indigenous, fat-tailed breeds were unfamiliar to the English market (Nel, 1993). According to their grading system, the carcasses poor confirmation and localised fat deposits (Campbell, 1974; Nel, 1993), were viewed as unacceptable and therefore unable to compete in these markets.

During the development of the Dorper breed, emphasis was given to improving the carcass quality of indigenous fat-tailed sheep, with the aim that they could replace the export of local animals (De Waal & Combrinck, 2000), allowing South Africa to produce carcasses more acceptable to European markets. In an attempt to overcome the limitations of the indigenous breeds, the sire-line was specifically selected for traits associated with carcass quality, while the dam-line focused on hardiness and mothering ability (De Waal & Combrinck, 2000). The Dorset Horn, a British breed, was the paternal breed of choice owing to its desirable carcass conformation and uniform fat distribution (De Waal & Combrinck, 2000), these traits aimed at improving carcass composition. Another benefit of the Dorset Horn was its longer breeding season when compared to other British mutton breeds (Milne, 2000). Additionally, the breed has a tendency for multiple births and high milk production, ensuring rapid growth rates of lambs (Nel, 1993).

For the sheep to meet the requirement of being suitable for extensive production in arid regions, it was important that the maternal line be adapted to these conditions. Emphasis was given to traits such as hardiness and adaptability, with tolerance to heat stress and drought conditions (Nel, 1993; Milne, 2000). It was necessary to ensure that animals were able both to survive and to produce lambs in the harsh, arid environments, typical of extensive sheep farming in South Africa. The good performance of the Blackhead Persian in the harsh local environmental conditions, lead to its selection as the maternal breed during development of the Dorper (Milne, 2000). The Blackhead Persian, known for its ability to lamb year-round (De Waal & Combrinck, 2000), complimented the long breeding season of the Dorset Horn, allowing for mating in spring and lambing in autumn; an important trait for the Western parts of South Africa (Nel, 1993). In addition to the growing demand for lamb and the forementioned objectives of the breed, the novel breed had to be a low maintenance sheep (Milne, 2000) which under extensive conditions, could produce fast growing lambs with quality carcasses (Dorper Breeders society, 2019). In the Western Cape, being a winter rainfall region, it was important for ewes to lamb from April onwards.

2.7.3. Development of the Dorper

2.7.3.1. Background and motivation

The increase in demand for lamb and the objectives for the novel breed stated above - a sheep producing acceptable carcasses and suitable for extensive production in arid conditions were among the factors which led to the development of the Dorper breed.

Results from various crossbreeding programs taking place at Grootfontein Agricultural Collage between rams of different British mutton breeds and indigenous fat-tailed breeds, concluded that the progeny from Dorset Horn x Blackhead Persian, showed the longest period of sexual activity (De Waal & Combrinck, 2000). This, together with the Blackhead Persian's performance under harsh environmental conditions, led to its selection as the maternal breed (De Waal & Combrinck, 2000). The Dorset Horn, was selected as the paternal breed, owing to its favourable carcass characteristics and extended breeding season (Milne, 2000).

Throughout the process of creating and developing the breed, a series of experiments were conducted at the Grootfontein Agricultural College, in conjunction with a group of farmers in the Karoo area (Milne, 2000). All parties were co-operating under the supervision of the

Department of Agriculture (Dorper Breeders society, 2019) and the guidance of D. J. Engela, who played a key role in the development of the Dorper breed.

Crossing the Blackhead Persian and Dorset Horn allowed for rapid improvements in the carcass quality of the F1 crossbred progeny (Blackhead Persian x Dorset Horn), compared to those from indigenous animals. The breeding program during the Dorper's development, was however not without its challenges (De Waal & Combrinck, 2000).

2.7.3.2. Limitations

A limitation of the crossbreeding program was the active practice and continued management required for the operation. Producing the F1 progeny required that the two parental breeds be maintained in separate flocks and then further separated by sex (De Waal & Combrinck, 2000). This system was costly in terms of labour, management and capital output for infrastructure such as fencing. A second disadvantage of a terminal F1 production system is that breeding stock is not typically generated, with all the F1 progeny generally being sold. The high prices for British breeds, which proved poorly adapted to the local conditions, having high mortality rates and poor mating ability, ultimately lead to the failure of the purebred British mutton breeds (Milne, 2000). For these reasons, a more practical and permanent solution was required for the crossbreeding program used during the development of the Dorper (De Waal & Combrinck, 2000).

2.7.3.3. Methodology

In response to the high prices and poor adaptability of British breeds, in 1941, it was decided that the Dorset Horn rams be upgraded to the half-cross Dorset Horn x Blackhead Persian by mating Dorset Horn x Blackhead Persian rams to indigenous fat-tail breeds (Milne, 2000). A benefit of this breed modification is the opportunity to rapidly introduce animals to novel environments (FAO, 2019); owing to the progeny's adaptability, inherited from the indigenous parent, giving these crossbred animals their ability to overcome the limitations of the exotic parental breed.

In 1942, following establishment of the F1 half-cross and the improvements in its carcass characteristics acknowledged, it was decided that the next phase in the development of the Dorper breed be initiated. This stage, conducted by a limited number of co-operating farmers, consisted of a rotational F2 crossbreeding system, known as the half-cross Rani scheme (Dorper Breeders Society, 2019). It involved controlled mating among F1 progeny (F1 x F1) producing an F2 half-cross, Blackhead Persian x Dorset Horn. Benefits of this crossbreeding system and further developing the Dorper, include the ability to increase the limited number of

F1 progeny (De Waal & Combrinck, 2000) and reduce the level of management and infrastructure required when compared to the F1 crossbreeding system. Another significant benefit of the F2 breeding system is that it allows for the selection of superior F1 animals used to produce the F2 progeny. This, together with the system's inherent ability to exploit three levels of hybrid vigour (heterosis from crossbreeding as well as both the maternal and paternal heterosis) owed to the rapid gains observed in the crossbred animals (Dzama, 2017).

As suggested by De Waal & Combrinck (2000), during its development, the Dorper underwent upgrading through the back mating of Dorper rams with both Blackhead Persian ewes, their crosses as well as other indigenous fat-tailed breeds. Through this process of continued back-mating of Dorper rams, the resulting progeny was eventually considered close enough and registered as the Dorper (FAO, 2019).

2.7.4. The Dorper

On 19 July 1950, at the Grootfontein Agricultural College, the Dorper Breeders Society (consisting of 28 farmers and 11 officials) was founded and the new mutton breed was officially named the Dorper (a combination of the names DOR-set Horn and Black Head PER-sian) (De Waal & Combrinck, 2000; Milne, 2000). In addition to crossing these two breeds, during its creation, the Dorper underwent further development and upgrading (De Waal & Combrinck, 2000), resulting in the animal representative of the breed today.

Traits of hardiness and adaptability, particularity to undesirable conditions, led to the Dorper's rapid gain in popularity (Cloete *et al.,* 2000). Marais & Schoeman (1990) showed the significant rise in South African Dorper numbers by 48.7% from 1963/64 to 1976 and a further 21.8% increase from 1976 to 1987. The appeal of the Dorper to producers in Western Australia lies in the breed's low maintenance requirements and reputation as a hardy, fertile sheep suitable to extensive grazing systems in hot, arid climates (Butler *et al.,* 2001). Additionally, their carcass conformation and quality are suitable for both the domestic and export markets (Butler *et al.,* 2001).

When reporting the weaning weight records submitted to the NSSIS for the period 2005-2008, Cloete & Oliver (2010) stated that the Dorper at 24.2%, was the largest contributor of the exclusive mutton breeds to the South African small stock genetic resource. Within the breed, the majority (20.3%), of the records comprising Black-headed Dorper's and the remaining 3.9% derived from White Dorper flocks (Cloete *et al.,* 2014).

2.8. Sex effect in feedlotting lambs

Within the feedlot industry, it is common practice that young weaned male animals are those which will typically be sold to / placed in the feedlot. Additionally, the female lambs which are not selected as replacement animals may be fattened in feedlots, alternatively sold as maiden ewe lambs (Truter, 2018).

While there is much literature describing the trend of high fertility rates of Dorper ewes, there are limited publications on the performance and profitability of feedlot finished Dorper ewe lambs, particularly those fed varying diets within the South African context. Studies by Miranda de Vargas *et al.* (2014); Hoffman *et al.* (2020) and Van der Merwe (2020) looking at the effect of sex and genotype, production systems and breed on carcass characteristics respectively, all reported that no significant interactions between the main effect of sex on all the other respective main effects were found. Miranda de Vargas *et al.* (2014) did however report that for the growth performance parameters (final body weight, days on feed, ADG, FCR and intakes) that the male animals showed significantly superior values than the female animals. These findings agree with much of the literature cited.

When evaluating the effect of sex, Arnold & Meyer (1988) found that sex, intact ram lambs vs. castrated lambs (wethers) at different stages, yielded significant differences in growth rates, while there was no significant difference between ewe lambs vs. castrated lambs (wethers) at different stages. The same trend was observed for feed efficiency, where the ram lambs were more efficient than wethers, while there was no difference between wethers (time of castration) and ewe lambs (Arnold & Meyer, 1988). These results agreed with a study by Du Toit (2017) showing that ram lambs had superior values for production parameters (ADG and FCR) when compared to wethers, while no difference between ewes and wethers were observed for ADG, FCR and dry matter intake (DMI). Pommier *et al.* (1989), Okeudo & Moss, (2008) and Rodríguez *et al.* (2011), suggest that the sex of the animal plays a major role on its production efficiency, while Seideman *et al.* (1982) emphasises that intact ram lambs grow more rapidly (superior rate of gain), utilise feed more efficiently and yield leaner carcasses compared to wethers and ewes, although the specific values differ between the studies cited. This agrees with much of the reviewed literature, which concludes that rams yield the leanest carcasses followed by wethers and the fattest are typically from ewes (Pommier *et al.,* 1989; Dransfield et al., 1990; Cloete *et al.,* 2007, 2012a).

There is a large body of literature suggesting that sex yields significant differences within meat quality characteristics (Pommier *et al.,* 1989; Hoffman et al., 2020). While production parameters of rams are widely described as superior when compared to ewes, there are some disadvantages of fattening intact male lambs with respect to meat characteristics undesirable odour's/colours/flavours and meat tenderness (Seideman *et al.,* 1982). Additionally, when considering slaughter characteristics, ewes have been widely shown to have higher dressing percentages, followed by wethers and rams yielding the lowest (Vergara *et al.,* 1999; Rodríguez *et al.,* 2011; Van der Merwe 2020).

The characteristic of early maturity together with relatively early fat deposition, is typically enhanced in female animals, thus can be viewed as disadvantageous in the feedlot finishing of these lambs. While certain growth promoting agents (GPA) are known to be effective to improve performance in early maturing breeds, owing to their ability to repartition nutrients towards growth and thereby delaying fat deposition (Steenekamp, 2014), it is however important to consider the consumer specifications and not only has there been a health conscious shift towards leaner meat in recent times (Du Toit, 2017) but also a shift away from GPA's in animal production (Montossi *et al.,* 2013; Hirpessa *et al.,* 2020).

2.9. Conclusion

The growing global population and the accompanying increase in demand for food is well documented (Fukase & Martin, 2020). Africa, with its developing countries, is expected to contribute significantly to the predicted growing population (FAO, 2017). Livestock and their various products contribute 40% of the world's total agricultural output (FAO, 2019). In addition, they support the livelihoods and food security of almost a 1.3 billion people, with livestock contributing 25% of the total global food protein (FAO, 2019). The relevance of livestock to the agricultural sector and food security is therefore significant, additionally, the livestock sector is one of the most rapidly growing aspects of the agricultural economy. The responsibility ultimately lies with primary producers to supply the worlds growing food demands (FAO, 2017) however, the growth and transformation of the livestock sector offers significant opportunities for agricultural development.

The intensification of animal production systems, with emphasis on Precision Agriculture (PA), are likely the only means the livestock and agricultural sectors will meet the growing demands for increased food supply (FAO, 2017; Cole *et al.,* 2018). PA is a broad concept but considering the realities of a growing global population, which include the need to produce more food with fewer resources and therefore the need to optimise resource usage and increase the efficiency of production (NRC 1997). In addition, aspects such as marketing, branding, differentiating and value adding need to be considered (Oosthuizen, 2019). These factors along with the appropriate knowledge, research, skills, management and innovative thinking are essential in the concept of PA.

Several studies have been conducted on animal performance parameters for the breeds commonly used in feedlot systems. However, there is very limited literature published on the Dorper breed, with emphasis on nutrition to overcome the physiological challenge of these lambs depositing excessive fat. With climatic conditions expected to become hotter and drier, focus should be given to improve production parameters of this hardy, adaptable sheep (FAO, 2015).

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CHAPTER 3

Effect of feed composition and sex on feedlot performance of Dorper lambs.

3.1. Abstract

The objective of this chapter was to determine the effect of treatment (diet) and sex on overall feedlot production parameters of Dorper lambs. Eighty-four Dorper lambs were randomly allocated to one of the seven treatment groups (1=control, 2=low-energy, 3=high-protein, 4=high-protein + low-energy, 5=high-fat + low-starch, 6=high-fat + low-starch + high-protein, 7=control + β antagonist), comprising 12 animals each- 6 ram and 6 ewe lambs in a 2 x 7 factorial design. Treatment yielded a significant ($P \leq 0.05$) effect on performance for most of the measured parameters (intake, number of feedings, final weight, liveweight gain, ADG and FCR), while the effect of sex was limited, and the interaction of treatment and sex was significant for FCR (P = 0.01) only. Findings of this study show the lambs final weight was significantly highest for Treatment 4 (high protein, low energy). Moreover, Treatment 4 yielded superior performance for liveweight gain and ADG across all groups in both ram and ewe lambs ($P \leq 0.05$). Although, not significant, rams on average yielded numerically superior performance compared to ewe lambs across the measured parameters. Treatment 1 (control) yielded the best (lowest) FCR, suggesting that the standard feedlot diet resulted in the most efficient growth, while Treatment 7 (control + β antagonist) was shown not effective in improving feedlot performance for all the recorded parameters.

3.2. Introduction

3.2.1 South African landscape

Only 12.5% of South Africa's agricultural land is considered arable and therefore suitable for the cultivation of crops (FAO, 2019). This implies that the majority of agricultural land is suitable only for livestock production or wildlife ranching. While beef and dairy productions systems utilise large areas of pastoral land (Van der Merwe, 2020), a significant portion of South Africa is considered arid and semi-arid, and these regions are best utilised by hardier small ruminants (Brand, 2000). Sheep production is often also incorporated into mixed agriculture systems, where the sheep utilise cultivated cereal stubbles, increasing producer income per hectare from both grain and lamb. The South African national flock is currently estimated at 19.9 million head of sheep (DAFF, 2019) and globally this ranks 8th, with approximately 8000 commercial and 5800 communal sheep farmers in South Africa (DAFF, 2018).

It is predicted that global warming will lead to climates becoming hotter and drier with drought conditions becoming more frequent and severe, causing the composition and quality of the natural veld to change, leading to less forage being available for livestock (Rust and Rust, 2013). The limited forage resource will cause increased competition for grazing, in turn amplifying the pressure on producers to not only maintain production levels, but also increase production in order to meet the growing consumer demands for meat (lamb). Many producers have implemented strategies of more intensive management to increase production including feedlots to finish weaned lambs to benefit from the marketing of higher value slaughter ready lambs and their high-quality carcasses.

3.2.2. The Dorper

The Dorper breed was derived from crosses between the Dorset Horn (sire line) and the Blackhead Persian (dam line) (Milne, 2000). The Dorper is an early maturing breed and is well known for its adaptability to produce and growth under harsh conditions (Cloete *et al*., 2000). Schoeman (2000) suggests that the Dorper has excellent potential for growth under both extensive and intensive feeding systems, whereby yielding fast growing lambs with good carcass quality characteristics. The early maturity of the breed and therefore its tendency to deposit more localised fat at an earlier age, requiring that they be slaughtered at a lighter live weight compared to later maturing breeds has been well documented (Van der Merwe, 2020). These characteristics of early maturity are often viewed as unfavourable and a limitation of the Dorper, where some producers are reluctant to feedlot finish these breeds (Truter, 2021) owing to their slaughtering at a lower live weight, thereby reducing the income generated per carcass.

Despite this, the Dorper remains the most numerous of the meat sheep breeds in South Africa, contributing approximately 19% to the 2010-2011 weaning weight records submitted to the National Small Stock Improvement Scheme (Cloete *et al*., 2014).

3.2.3. Feedlot finishing

Feedlot finishing refers to an intensive feeding operation which fattens large numbers of animals for slaughter within a confined space (McDonald, 2020). Typically young, weaned animals will be subjected to high energy diets, with the aim of achieving market weight in the shortest possible time. As described by Van der Merwe (2020), feedlotting adds value to animals with low body weight and poor conformation through intensive feeding in order to produce carcasses with improved musculature and more desirable fat cover. It is also known to take advantage of compensatory growth in lambs which received suboptimal nutrition prior to weaning (Addah *et al*., 2017).

Increases in the prices meat, both lamb and mutton (A and C grade respectively) along with the increased pressure to intensify production systems (DAFF, 2019), are drivers for many producers choosing to intensively finish lambs. Declining sheep numbers (DAFF, 2019) means that this intensification of lamb production is essential to meet the growing demand for lamb. South African domestic demand for lamb and mutton increased by 7.2% from 2011 to 2020 (Cornelius, 2020). The objectives of the feedlot system are to take advantage of the superior growth rates and feeding efficiencies of young animals (Van der Merwe, 2020), by rapidly rearing them to optimal market weights and ensuring maximum revenue. Another benefit to producers is that the practice of feedlotting weaned animals ensures fewer grazing animals on the veld. This reduces grazing pressure and preserves grazing, thus allowing for more breeding ewes to be maintained, therefore further increasing producer productivity per hectare (Van der Merwe, 2020).

There are, however, numerous challenges facing feedlot producers. These include but are not limited to, the high input costs associated with intensive systems, changing markets and price fluctuations of inputs (commodities/feed) and output (lamb) (Oosthuizen, 2016). These factors lend themselves to the narrow price margins associated with feedlot enterprises (Truter, 2020). Despite these, profitability remains the main driver in all feedlot finishing operations.

3.2.4. Nutritional / feed considerations

In order to meet the high energy and protein demands for rapidly growing lambs, raw materials high in starch, quality protein and relatively low fibre are typically included in feedlot diets (NRC, 2007). Rios-Rincon *et al.* (2014) suggests that the level of tissue deposition for the carcass components is largely determined by the level of protein intake and the energy available for retention in muscle tissue. Feeding high protein and energy diets are known to improve the performance of feedlot animals (Sultan *et al.,* 2010). These authors further suggesting that potential benefits on intake and performance have been established in feedlot finished steers fed varying levels of these nutrients. The nutritional composition of a ration has been reported to influence dry matter intake (DMI). DMI is considered a major factor determining the amount of nutrients available to the lamb (Pulina *et al*., 2013), therefore affecting production parameters and ultimately determining whether the animal achieves optimal growth. Sultan *et al.* (1991), Sultan *et al.* (2010), Rios-Rincon *et al.* (2014) and Bello *et al.* (2016) all showed significantly lower feed DMI of lambs fed high-energy diets. Furthermore, the latter authors stated that lambs on high-protein diets tend to have higher DMI and final weight compared to lambs on low-protein diets.

3.2.4.1. Growth promoting agents

Growth promotors (GP) can be considered as feed additives/dietary factors known to influence growth parameters and efficiencies in feedlot lambs when included in feedlot diets (Herago and Agonafir, 2017). While there are a wide array of growth promoting agents, the GP of concern in the present study is a beta-agonist (Zilpaterol hydrochloride), sold under the trademark name of Zilmax® (MSD) since 1995. Today Zilmax is one of the most widely utilised beta-agonists in feedlot systems (Du Toit, 2017). Other products like Grofactor® (Virbac) contains similar active components (Avendaño-Reyes *et al.,* 2016).

The improvement in efficiencies associated with this GP are achieved through the agent's ability to repartition nutrients towards muscle growth, through effective utilisation of the nutrients provided in the diet, ensuring that heavier animals can be marketed for slaughter at a younger age (Brooks *et al.,* 2009; Strydom, 2016). The use of these GP agents can be seen of particular benefit in the finishing of early maturing breeds, such as the Dorper through improved production performance owing to the repartitioning of nutrients away from fat synthesis whereby delaying the effect on early fat deposition (Steenekamp, 2014) which is typical of the breed. A further advantage of growth promoting agents and their repartitioning effects, is the possibility of the producer to alter product quality according to consumer/market specifications, in particular reference, to carcass variation owing to sex, maturity and the different types of sheep breeds finished in South African feedlots.

While beta-agonists has been widely described as advantageous to feedlot systems through improved production parameters (ADG, FCR, dressing percentage and higher yields in protein: fat ratio) (Du Toit, 2017; Webb *et al.,* 2018), there is however negativity surrounding it's use in production systems. There are some reports of perceived reduction in meat quality (increased toughness), implications in animal health (increased heart rate) and possible residues in the meat, however many reports are inconsistent (Mersmann, 1998; Strydom *et al.,* 2009).

It is also important to consider consumer perception of lamb, which is complex and dependent on several interrelated variables (Köster, 2003) and many intrinsic and extrinsic characteristics of the meat (Cunha de Andradeet., 2016). A study by Font-i-Furnols and Guerrero (2014) showed that for some consumers, meat origin was the most important factor in determining purchase decisions while for others, the feeding system was the most important factor in choosing any particular meat amongst others, grass-fed being the most preferred. Surprisingly, the lamb price showed a minor role in determining consumer's purchasing decisions (Font-i-Furnols and Guerrero, 2014). There is an increasing trend in society's concerns towards the consumption of animal products and the sustainability of their production, with intensification of animal industries often viewed as potentially damaging to the environment, animal welfare and human health (Montossi *et al.,* 2013). These growing consumer awareness on not only where the livestock was raised (product origin), but how they were raised (general production practices and animal welfare. (Montossi *et al.,* 2013)

These concerns can be extrapolated to the use of growth promoting agents (GPA's) in animal production systems. Where β-agonists are registered for commercial use in 13 countries but have never been permitted in Europe (Du Toit, 2017). Kuiper and Noordam (1998) stated that no beta-agonists have been permitted in the European Community for growth-promoting purposes in farm animals and there is strict monitoring of the presence of residues in livestock and meat, with specific guidelines for sampling procedures on farms and in abattoirs, regulated by the Directive 86/469/EEC (EC, 2014). Furthermore, stating that the use of highly active beta-agonists as growth promoters is not appropriate owing to the potential hazard for human and animal health. It can be expected that the restriction on the use of these agents in animal production are likely to intensify (Stampa *et al.,* 2020).

3.2.5. Production parameters

The two most common production parameters considered in finishing systems are average daily gain (ADG) and feed conversion ratio (FCR), which are respectively defined as the average daily live weight the animal gains throughout the feeding period, and the amount of feed required for the animal to gain one kilogram of liveweight. Feed intake is another important parameter to consider, it is used to determine both FCR and feed efficiency, which is the inverse of FCR and defined as the amount of live weight gain from one kilogram feed consumed.

Furthermore, the cost of feed is described as a major cost to intensive systems (Lima *et al*., 2017). Therefore, feed intake is an important parameter to be considered, more so, determining feed intake as a measure of efficiency in growing feedlot lambs would be highly valuable to producers. Growth rate and feed conversion ratio during the post-weaning feeding phase are economically important production traits (Yeaman *et al.,* 2013). While feed intake is influenced by several factors pertaining to the diet itself as well numerous intrinsic animal factors (Pulina *et al*., 2013), determining intake on an individual animal basis, in commercial feedlot systems, is mostly not possible but is rather based on the groups average. This study aims to evaluate individual animal intake and its effect on the major production parameters, while considering the effect of diet on Dorper lambs.

3.2.6. Animal growth

Animal growth is defined as an increase in bodyweight achieved through the processes of hypertrophy and hyperplasia until a mature size is reached, with the accompanying changes in body conformation known as development (Lawrie, 1998; Brand *et al*., 2017). Mature size (maturity) is generally considered as the point where the animal has undergone puberty, reached maximum muscle mass and fat deposition increases (Owens *et al*., 1993). At this mature weight, the animal reaches its physiological limits to growth, which are also associated with increased maintenance requirements of body tissues and the animal as a whole (Webb & Casey, 2010).

Genotype is the main factor determining the potential of the animal for growth however, as Aberle *et al*. (2001) suggests, the growth rate and development of tissues can be manipulated through environment and nutrition. The nutritionally dense, high energy and relatively low fibre content of feedlot diets (Brand *et al*., 2017) are designed to maximise growth rate and minimize the number of days on feed (Notter *et al*., 1991). The Dorper are often viewed as less profitable in feedlot finishing operations owing to their relatively smaller carcasses due to their early maturity and slaughter at lower live weights when compared to larger, later maturing commercial breeds (Truter, 2021).

3.2.7. Objectives

The overall objective is to evaluate the effects of treatment (diet) and sex on feedlot performance.

- Will lambs achieve optimal growth on a standard feedlot diet.
- What is the effect of decreasing the dietary energy (starch) content, on feedlot performance parameters.
- Will heavier final weight be achieved by increasing dietary crude protein content
- By increasing dietary protein levels and reducing dietary starch levels, what is the effect on feedlot performance parameters of fattening Dorper's.
- Will substituting (approximately 50%) of the dietary starch for rumen protected fat effective in promoting growth.
- Will substituting (approximately 50%) of the dietary starch for fat and increasing dietary protein levels effective in yielding heavier final weights.

- Will the inclusion of a beta-agonist to the standard feedlot diet yield superior feedlot performance.
- Considering all the above objectives, was there a difference between sexes (male and female) in both feedlot performance of feedlot finishing Dorper's.
- The overall objective of this two-part study was to determine the most desirable nutritional composition of a diet to fatten Dorper's efficiently and sustainably (acceptable to the consumer) in a feedlot.

Through measuring individual intake, live weight gains and the common production parameters, the objective of this study is to see whether nutrition can be used as a tool to improve performance, in feedlot finished Dorper lambs.

3.3. Materials and methods

3.3.1. Overview

Ethical clearance for this study was obtained from Stellenbosch University Research Ethics Committee: Animal Care and Use (Ref: ACU-2018-7938). For this study, all lambs were obtained from a stud flock from the Northern Cape Province of South Africa, ensuring that all animals were subject to the same conditions. At weaning, all lambs were dosed for internal parasites and multimineral and received a multi-clostridial vaccine. The lambs were then transported to the University of Stellenbosch experimental farm, (Welgevallen Experimental sheep Unit), where they were housed in door on wooden slatted floors under feedlot conditions for the trial period.

Upon arrival the lambs received both an electronic RFID tag (EID) and visual tag (VID), one in each ear. The eighty-four Dorper lambs were randomly allocated to the seven treatment groups, comprising 12 animals each- 6 ram and 6 ewe lambs. Lambs were provided a pelleted adaption diet for 10 days along with decreasing amounts of available roughage, allowing time for the lambs to be accustomed to the pelleted feed and feeders. Following this, the lambs were adapted onto their specific treatment diets over 5 days. Lambs were weighed at the start of the trial (start weight - the average start weight was 26.9 kg) and weekly thereafter at the same time, on a full-belly basis using an RFID scale. Throughout the adaption and trial phase the lambs had *ad. lib* access to feed and fresh water. After a 32-day trial period, the lambs were weighed (final weight - the average final weight for the lambs was 38.6kg). Lambs were then transported to a commercial abattoir, where they stood in lairage for approximately 20 hours. At slaughter, lambs were rendered unconscious by electrical stunning and slaughtered using standard South African techniques as described by Cloete *et al*. (2007).

The three macronutrients of consideration were energy, protein and fat. The seven treatment diets were formulated, such that only the specific macronutrient in question was present at the altered level, while all the others were as close as possible held constant, a representative of the control (Treatment 1), a standard balanced feedlot ration. A proximate analysis on each of the seven treatment diets was conducted in duplicate, with the relative findings summarised in Table 3.1.

Table 3.1 Formulated feed ingredients and nutrient composition of the seven treatment diets.

Item	Treatment#						
	1	**2**	**3**	**4**	**5**	**6**	**7**
Ingredient (kg/ton)							
Bergafat®					65	65	
CMS[1]	30	30	30	30	30	30	30
Kalori 3000[2]	25	25	25	25	25	25	25
Maize	530	285	500	280	275	275	530
Soya oilcake	50	30	75	75	50	75	50
Fishmeal			40	40		50	
Oat hay	225	225	225	225	225	225	225
Lucerne	75	75	75	75	75	75	75
Soya hulls	30	300		223	223	153	30
Acid Buff®	5	5	5	5	5	5	5
Salt	3	3	3	3	3	3	3
Feed lime	8	4	3		5		8
HPC[3]	19	19	19	19	19	19	
HPC[4] + Zilpaterol							19
Total	1000	1000	1000	1000	1000	1000	1000
Nutrient (DM)							
Moisture (g/kg)	111.6	96	98.2	96.5	93.8	100.6	105.9
DM (g/kg)	888.4	904	901.8	903.5	906.2	899.4	894.1
Ash (g/kg)	48.1	68.8	68.9	73.3	66.6	62.6	63.5
Fat (g/kg)	24.8	20.4	30.8	19.9	64.7	70.6	22
Starch (g/kg)	32.2	24.7	36.9	26.1	30.1	27.9	34.2
Protein (g/kg)	128.5	133.6	172.4	172.9	136.8	187.3	135.3
CF (g/kg)	63.9	70.6	67.4	148.8	151.8	113.7	69.2
NDF (g/kg)	192.3	355.8	195.3	302.4	323.8	263.1	215.3
ADF (g/kg)	103.5	233.4	111.8	189.8	222	182	119.7

[#] 1: control – standard feedlot ration; 2: low-energy; 3: high-protein; 4: high-protein, low-energy; 5: high-fat, low-starch; 6: high-fat, low-starch, high-protein; 7: control + β antagonist.
[1] Condensed molasses syrup
[2] Dehydrated molasses powder
[3] Commercial HPC, Feedtek Mutton Gainer 125

[4] Commercial HPC, Feedtek Mutton Gainer 125 with the inclusion of β-antagonist (Zilmax, 70 ppm in final diet).
[3,4] DM = 894 g/kg, CP = 329.2 g/kg, NDF = 239 g/kg.

The carcass classification was determined by an independent, experienced carcass classifier soon after slaughter, while the carcass was on the slaughter line. The carcass weight and class for each animal was recorded and the cold carcass weight was extrapolated as the warm carcass weight less 3%.

3.3.2. Housing and data

The trial was conducted in a specifically designed shed with an elevated, slattered floor and open sides for ventilation at the University of Stellenbosch Welgevallen experimental farm. The trial pens were 6m x 6m, allowing 3m^2 per lamb. Each pen had an automatic water supply as well as an RFID-Experts electronic Automated Radio Frequency Identification (RFID) feeder (RFID Experts Africa, Durbanville South Africa), used to determine individual intake in the seven different treatment groups. The feeding system was very similar to the Feed Intake Recording Equipment (FIRE) as described by Yeaman *et al.* (2013). Feeders were checked twice daily to ensure that lambs had *ad. lib* access to feed and the water troughs and pens were cleaned 3 times weekly.

Eighty-four Dorper lambs were used in the study. Six ram and six ewe lambs were randomly allocated to each of the seven treatment groups, housing 12 animals each. Table 3.2 indicates the assignment of the animals to the various treatment groups, yielding a 2 x 7 experimental design with treatment and sex as the main effects.

Table 3.2. Experimental design and allocation of animals to the various groups.

		Treatment						
		1	**2**	**3**	**4**	**5**	**6**	**7**
Sex	**Rams**	n = 6	n = 6	n = 6	n = 6	n = 6	n = 6	n = 6
	Ewes	n = 6	n = 6	n = 6	n = 6	n = 6	n = 6	n = 6

n = number of animas

Figure 3.1 shows the electronic RFID scale (Tru-test XR5000, RFID Experts Africa, Durbanville, South Africa) that was used throughout the trial, for the weighing of all animals. The individual animal intake data recorded from the electronic feeders, together with the data recorded by the electronic scale was used to calculate production parameters, average daily gain (ADG) and feed conversion ratio (FCR).

Figure 3.1 RFID scale (Tru-test XR5000) used for weighing sheep.

3.3.3. Statistical analysis

Statistica version 14 (TIBCO Software Inc., 2020) was used to analyse the recorded data and generate the statistical analysis. The data set was first tested for normality and homogeneity after which appropriate multiple analysis of variance (ANOVA) were performed. In the two-way ANOVA, the relationships between continuous response variables (the various production parameters) and nominal input variables (the different treatments (1 – 7) and sexes (rams, ewes)) were analysed, as well as the interactions between the two main effects (treatment and sex).

Fisher's LSD (Least Significant Difference), an appropriate multiple comparison of LS Means were done as the post hoc test to determine where significant differences occurred. The Bonferroni multiple comparison test was used to interpret which interaction means were significantly different. Significance was declared at 5% ($P < 0.05$) and tendencies at ($P < 0.10$).

3.4. Results and discussion

No significant interaction between the main effects of treatment and sex for all the measured parameters besides FCR (P = 0.01) were observed. The two main effects are therefore largely interpreted separately.

3.4.1. Intake data

Considering treatment as a main effect, Table 3.3 shows clear differences between the parameters of cumulative dry matter intake (cDMI) (kg), daily dry matter intake (dDMI) (kg) and dry matter intake as a percentage of body weight (BW) across the seven treatment groups. However, when considering the effect of sex, no significant differences across the measured parameters were observed (Table 3.4). These differences observed for the intake data across the seven treatment groups can be attributed to significant differences in diet composition.

Table 3.3. Means and standard error of the means of intake data; cumulative DMI (cDMI), daily DMI (dDMI) and DMI as % body weight throughout the trail period across the treatment groups.

Item	Treatment[#]							SEM	P-value
	1	2	3	4	5	6	7		
cDMI (kg)	49.90[bc]	74.36[a]	68.58[a]	66.86[a]	68.97[a]	55.91[b]	43.31[c]	3.19	< 0.01
dDMI (kg)	1.56[bc]	2.32[a]	2.14[a]	2.09[a]	2.16[a]	1.75[b]	1.35[c]	0.10	< 0.01
DMI % BW (%)	4.77[ef]	7.39[a]	6.51[bc]	5.81[cd]	6.88[ab]	5.44[de]	4.16[f]	0.27	< 0.01

Table 3.3 shows that cDMI was similar for Treatments 2 - 5 and while Treatment 1 differed from these (P < 0.05) and did not differ from Treatment 6 and 7. However, the latter two differed from each other (P < 0.05). This pattern was the same for the parameter dDMI but differed for DMI as percentage of BW.

Considering the varying energy levels, the significant increase in intake of Treatment 2 lambs compared to Treatment 1 (control) was expected. It has been widely documented that lower dietary energy levels are associated with elevated intakes as the animals aims to compensate for the lower energy. Studies by Sultan *et al.* (2010) and Rios-Rincon *et al.* (2014)

showed that dry matter intake (DMI) was significantly lower on the lambs fed high-energy diets. Additionally, the increased ($P < 0.05$) cDMI of Treatments 3 and 4, relative to the control, can be explained by their higher dietary protein levels. These findings are in agreement to the results of Ebrahimi *et al.* (2007); Sultan *et al.* (2010) and Shahid *et al.* (2019). This however is not true for Treatment 6, where a numerical marginal increase in cDMI was recorded relative to the control for all 3 parameters measured. This agrees with results of Rios-Rincon *et al.* (2014) and Yerradoddi *et al.* (2015), who suggest that DMI was not significantly affected by dietary protein levels. Moreover, this can be explained by Treatment 6 also being considered a high-fat diet. Martinez *et al.* (2013) showed a decrease in DMI in both dairy cows and goats following fat supplementation, owing to its negative effect on digestibility. This however does not explain the significant increase in cDMI recorded for Treatment 5 lambs compared to those in Treatment 6. While these differences were not expected, a possible suggestion could be the inclusion of fishmeal in Treatment 6 compared to Treatment 5. Fishmeal is known to have a strong scent and may have negatively influenced palatability explaining the lower intake of Treatment 6 when compared to Treatment 5

The parameter dry matter intake as percentage of BW yielded a very different pattern from the parameters cDMI and dDMI. Table 3.3 shows that DMI % BW was numerically the highest for Treatments 2 but similar to Treatment 5. While Treatment 1 differed from these ($P < 0.05$) it did not differ from Treatment 6 and 7. However, the latter two differed from each other ($P < 0.05$) but Treatment 6 did not differ from Treatment 4, which in turn did not differ from Treatment 3. The highest numeric intake (cDMI and dDMI) recorded for Treatment 2, yielded the elevated ($P < 0.05$) DMI as a % BW for this group (7.39%) when compared to the other treatments across the 32-day trial period. In comparison, the lowest intake (cDMI and dDMI) was recorded for Treatment 7, with the lowest corresponding DMI as a % BW (4.16%). Feedlot finished lambs are widely known to consume approximately 4.5% DMI as percentage of BW (Farmers Handbook, 2013). Table 3.3 shows that only the Treatment 1 (control) and Treatment 7 (control + β antagonist) represent this standard, and the findings show that any variation in treatment (diet) from the control, a standard feedlot ration, resulted in an elevated dry matter intake as percentage of BW.

While not significant, Table 3.4 shows that the effect of sex did yield numeric differences for all the feed intake parameters within treatments, with rams averaging higher intakes than ewes for all the parameters.

Considering the raw data generated from the study, the largest difference in cumulative DMI between ram and ewe lambs was recorded for Treatment 6 (high fat, low starch, high protein) where rams had an average cDMI of 62.4kg and ewes 49.5kg. While higher intakes were typically associated with ram lambs within treatment groups, the exception was treatment 5 (high fat, low starch), where ewes had notably higher intake than rams, with an average cDMI of 71.6kg vs. 66.3kg respectively.

Table 3.4. Means and standard error of means of intake data, cumulative DMI (cDMI), daily DMI (dDMI) and DMI as % body weight throughout the trail period between the sexes.

Item	Sex		SEM	P-value
	Ram	Ewe		
cDMI (kg)	62.80	59.45	1.71	0.17
dDMI (kg)	1.96	1.86	0.05	0.17
DMI % BW (%)	6.01	5.7	0.15	0.14

The dDMI averages of 1.96kg and 1.86kg for rams and ewes respectively, are similar to the findings of Du Toit (2017), who reported DMI means (kg/day) of 1.76, 1.65 ,1.61 for ram, wether and ewe Dorper lambs. The findings also agree with those DMI's of Brand *et al.* (2017), whose Dorper lambs had an average of 1.87 (kg/day) on an as-is basis, across the 105-day trial period. The trend of higher intake of ram lambs compared to ewe lambs agrees with much of the literature cited, Du Toit (2017) suggesting this is likely behavioural owing to the rams more aggressive nature. However, the results for dDMI averages are significantly higher than the values reported by Miranda de Vargas *et al.* (2014), who showed DMI of 0.98, 0.91 (kg/day), for their feedlot finished ram and ewe lambs respectively. Similarly, the studies by Davila-Ramirez *et al.* (2014) and Davila-Ramirez *et al.* (2015), reported DMI's of 1.12 and 1.03 (kg/day) for feedlot finished ram and ewe lambs. These differences can be attributed to breed differences and environment, where those studies were performed under conditions of high heat stress.

When considering the parameter DMI as percentage of BW, with averages 6.0% and 5.7% for rams and ewes, these were also notably higher than the values reported by Miranda de Vargas *et al.* (2014) of 3.98% and 3.83%, for their feedlot finished ram and ewe lambs respectively. Reasons for the elevated DMI as percentage of BW both across the treatments and between the sexes are likely due to environmental and breed reasons.

3.4.2. Feeding data

Table 3.5 describes the effect of treatment on the feeding data parameters, showing significant differences (P < 0.01) in the total and daily number of feedings across the seven treatment groups, while there was a tendency of difference (P = 0.08) for average DMI per feeding.

Table 3.5. Means of feeding data, total and daily number of feedings, the average DMI per feeding and average duration per feeding throughout the trail period across the treatment groups.

Item	Treatment#							SEM	P-value
	1	2	3	4	5	6	7		
Total feedings	420^{c}	597^{ab}	510^{bc}	655^{a}	619^{a}	470^{c}	643^{a}	36.25	< 0.01
Daily feedings	13.14^{c}	18.66^{ab}	15.93^{bc}	20.47^{a}	19.33^{a}	14.68^{c}	20.08^{a}	1.13	< 0.01
Ave. DMI/feed (kg)	0.121^{b}	0.128^{b}	0.156^{ab}	0.116^{b}	0.127^{b}	0.209^{a}	0.079^{b}	0.03	0.08
Ave. duration (min)	5.08	4.59	5.04	4.68	5.32	5.56	4.89	0.45	0.75

[abc] Means within rows with different superscripts differ significantly (P < 0.05)
[#] 1: control – standard feedlot ration; 2: low-energy; 3: high-protein; 4: high-protein, low-energy; 5: high-fat, low-starch; 6: high-fat, low-starch, high-protein; 7: control + β agonist.

Table 3.5 shows that total number of feedings was similar for Treatments 2, 4, 5, and 7 and while Treatment 1 differed from these (P < 0.05), it did not differ from Treatments 3 and 6. Furthermore Treatment 2 and 3 were similar in their total number of feedings. This trend was the same for the parameter daily number of feedings but differed marginally from the average DMI per feeding. Table 3.5 shows that Treatments 1, 2, 3, 4, 5 and 7 were similar in average DMI per feeding, while Treatment 6 differed from all of these besides Treatment 3. No difference was recorded for the parameter average duration (min) per feeding across the Treatment groups.

The number of feedings (both total and daily) yielded the same pattern with Treatment 4 showing the highest (655 and 20) and Treatment 1 the lowest (410 and 13) respectively. While the high number of feedings associated with Treatment 4 agrees with the higher intakes recorded for this group, it also suggests that there may be other factors including possible improved palatability and/or energy requirement, contributing to the frequent number of visits to the feeding station. Opposing this is the high number of feedings recorded for Treatment 7 along with it having the lowest intake and therefore the lowest DMI per feeding, the highest

DMI per feeding was recorded for Treatment 6. Again, low palatability may explain this finding of Treatment 6 animals consuming fewer but larger meals, suggesting that animals only ate when they were very hungry. There is limited literature describing feeding behaviour in lambs, a study by Yeaman *et al. (*2014), who used a similar feeding system as the one in the present study, did not report these parameters.

Table 3.6 shows significant difference (P = 0.02) for the parameter of the average feed duration when considering sex as the main effect. Table 3.6 shows that there was no significant difference in the number of feedings (total or daily) and DMI per feeding between the sexes within treatment groups. However, rams showed a significantly longer (5.4 minutes) average feed duration compared to the ewes (4.6 minutes) (P = 0.02). Again, the more aggressive nature of rams and possible dominance at the feeding station suggests an explanation for this behavioural finding (Du Toit, 2017).

Table 3.6. Means of feeding data, total and daily number of feedings, the average DMI per feeding and average duration per feeding throughout the trail period between the sexes.

Item	**Sex**		**SEM**	**P-value**
	Ram	**Ewe**		
Total feedings	559	560	19.37	0.97
Daily feedings	17.46	17.48	0.61	0.97
Ave. DMI/feed(kg)	0.127	0.141	0.02	0.50
Ave. duration (min)	5.43	4.62	0.24	0.02

The parameters displayed in Table 3.5 and Table 3.6 can be considered as feedlot behavioural parameters rather than standard production parameters. The feeding systems used in the present study allowed for these to be recorded. While typical feedlot operations do not make use of these systems and thus cannot determine these parameters, this data as well the additional data recorded (time of feeding and environmental temperature at feeding) can be useful to feedlot operations in identifying problem lambs (shy feeders), optimal feeding times, the effect of temperature on intake and more.

3.4.3. Bodyweight data

Table 3.7 describes treatment as a main effect on bodyweight data parameters, showing clear differences (P < 0.01) for the final weight of the lambs and weight gain throughout the trial, while there is no difference for the lambs start weight, which is explained by the lambs being randomly allocated to treatments. However, when considering the effect of sex, Table 3.8 shows a tendency for difference (P = 0.07) in live weight gain between the sexes.

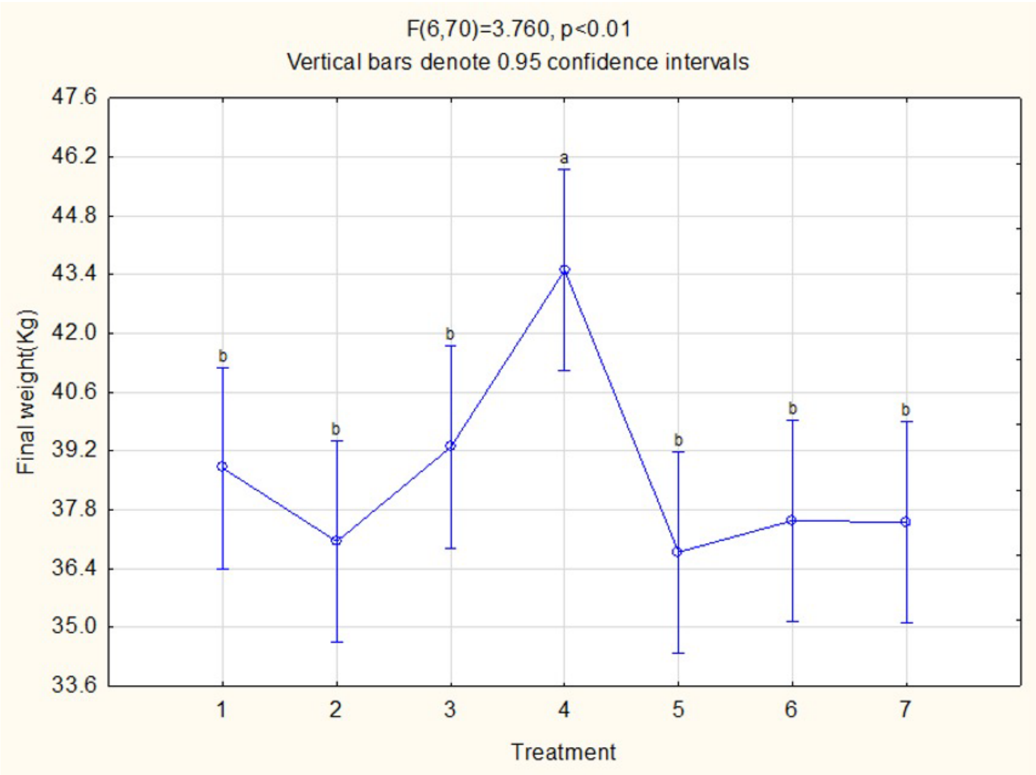
Table 3.7 shows that the start weight of Treatment 4 differed from Treatments 2 and 5, but was similar to Treatments 1, 3, 6 and 7 and Treatment 1 was similar to all the treatments. This similarity between treatment groups was expected owing to random allocation of animals to groups, with animals having an average start weight of 26.9kg across the groups. This is in line with the statement by Van der Merwe (2020), that lambs entering a feedlot typically weigh 25kg - 35kg, depending on the breed. It is however lower that that reported by Yeaman *et al.* (2014) with lamb's average weight of 31.4 ± 3.7 kg at the start of the trial at an average age of 92.7 ± 9.2 d and Du Toit, (2017) with an average live weight of 31.5kg at 100-110 days respectively. These differences could be attributed to availability of lambs, breed and country in which the trials were conducted.

Table 3.7. Means of the bodyweight data, start weight, final weight, and weight gain throughout the trail period across the treatment groups.

Item	Treatment#							SEM	P-value
	1	2	3	4	5	6	7		
Start (kg)	26.63^{ab}	26.08^{b}	26.50^{ab}	28.92^{a}	25.88^{b}	26.54^{ab}	27.96^{ab}	0.90	0.20
Final (kg)	38.72^{b}	37.04^{b}	39.29^{b}	43.5^{a}	36.79^{b}	37.54^{b}	37.5^{b}	1.20	< 0.01
Gain (kg)	12.16^{b}	10.96^{bc}	12.79^{ab}	14.58^{a}	10.92^{bc}	11.0^{bc}	9.54^{c}	0.82	< 0.01

^{abc} Means within rows with different superscripts differ significantly (P < 0.05)
$^{\#}$ 1: control – standard feedlot ration; 2: low-energy; 3: high-protein; 4: high-protein, low-energy; 5: high-fat, low-starch; 6: high-fat, low-starch, high-protein; 7: control + β agonist.

Figure 3.2 shows that Treatment as a main effect significant influenced the lamb's final weight, clearly showing that all treatments were similar in final weight, apart from Treatment 4, which yielded a significantly higher (P < 0.01) final weight (43.5kg), while the remaining groups averaged 37.8kg and the overall average final weight was 38.6kg across the seven treatments.



[ab] Means with different superscripts differ significantly (P < 0.05).

Figure 3.2. The effect of treatment on lamb final weight.

These results of the lamb's final weight agree with Van der Merwe (2020) who suggested when considering back-fat depth, that the ideal slaughter weight for dorper's was 38 kg. Opposing this, Brand *et al.* (2018) found that 36kg is the optimal slaughter weight for dorper's, while Brand *et al.* (2017) suggests that 43kg was the ideal market weight, after 42 days in the feedlot. The higher weight recommendation of the latter could be owing to the high (36.6kg) start weight, but closely resembles the high final weights of Treatment 4 lambs (43.5kg). This difference could be attributed to lamb availability and breed differences.

Higher intakes were recorded for the three high-protein groups when compared to the control, where significantly elevated cumulative DMI was recorded for Treatment 3 and 4 (P > 0.05), while Treatment 6 was numerically higher than the control (Table 3.3). This finding of increased DMI accompanied by improved performance (higher final weight), with increased dietary protein is a common trend amongst the literature cited. Studies by Ebrahimi *et al.*

(2007) and Ayele *et al.* (2019) reported significantly heavier warm and cold carcasses from lambs supplemented with higher dietary CP levels compared to those on lower CP levels. It can be extrapolated that these heavier carcasses from these studies were associated with the lambs having heavier final weights.

Considering the parameter of liveweight gain, Table 3.7 shows a different pattern, with no significant difference between Treatments 3 and 4 and gain was similar for Treatments 1, 2, 3, 5 and 6, additionally there was no difference in gain between Treatments 2, 5, 6 and 7. While Treatment 4 yielded largest numeric weight gain (14.6kg) across the treatments, accompanied with it also yielding the highest average final weights (43.5kg), Treatment 7 yielded the lowest gain (9.5kg) which is explained by this group having the lowest cumulative DMI.

Considering sex as the main effect, Table 3.8 shows that there was no difference in both the start and final weights between the sexes however, there was a tendency for differences in weight gain within treatment groups, with rams on average numerically gaining more liveweight compared to ewes. The most significant ($P < 0.05$) difference between the sexes was recorded for Treatment 6, with an average of 12.8kg gain for ram and 9.3kg for ewe lambs respectively. While rams typically gained more weight than ewes, the exception was Treatment 2 where ewes on average gained more than the rams 12kg vs. 9.9kg respectively ($P < 0.05$), Treatment 1 also yielded marginal numerical higher gains in the ewes compared to the rams 12.4kg vs 11.9 respectively. The trend of rams outperforming ewes in growth/gain and final weight/carcass weight agrees with much of the literature cited. Miranda de Vargas *et al.* (2014) reported that for the growth performance parameters including final body weight, that male animals showed significantly superior values than females. Although not significant, in the latter study considering the differences between start and final weight between the sexes, ewe lambs were on average heavier at the start of the trial (27.1kg) compared to ram lambs (26.1kg), whereas final weights showed ram lambs (39.0kg) to be heavier than ewe lambs (38.3kg).

Table 3.8. Means of the bodyweight data, start weight, final weight and weight gain throughout the trail period between the sexes.

Item	Sex		SEM	P-value
	Ram	Ewe		
Start weight (kg)	26.73	27.13	0.48	0.55
Final weight (kg)	39.01	38.26	0.64	0.41
Weight gain (kg)	12.19	11.13	0.44	0.07

The significant differences reported in the current study for the lambs' final weight and weight gain (Table 3.7) across the treatment groups can be attributed to diet differences between treatments. Considering the raw data generated from the study, Treatment 4 yielded the highest cumulative liveweight gain, which corresponded to the highest average as well as the highest average for both sexes. In comparison, the lowest cumulative live weight gain was recorded for Treatment 7, corresponding to the lowest average and the lowest average gain recorded for rams (9.6kg) across the treatments, the average gain for the ewes (9.5kg) was marginally higher than reported for Treatment 6 (9.3kg) respectively. This observation was not expected and could not be explained.

Animal growth/liveweight gain is a parameter of utmost importance to producers, where the aim of feedlot finishing, through intensive feeding, is to add value to animals with low body weight and poor conformation and produce heavier animals (carcasses) with improved musculature and more desirable fat cover, so that maximum revenue can be achieved (Van der Merwe, 2020).

3.4.4. Performance data

Tables 3.9 and 3.10 show the performance data of average daily gain (ADG) and feed conversion ratio (FCR) considering treatment and sex as main effects respectively. While the effect of treatment yielded significant differences for both ADG and FCR ($P < 0.01$), the effect of sex resulted in a tendency for difference for ADG ($P = 0.07$). However, Table 3.11 shows that an interaction between the main effects of treatment and sex ($P = 0.01$) was detected for FCR.

Table 3.9. Means of the performance data, average daily gain (ADG) and feed conversion ratio (FCR) throughout the trail period across the treatment groups.

Item	Treatment[#]							SEM	P-value
	1	2	3	4	5	6	7		
ADG	380[b]	342[bc]	400[ab]	456[a]	341[bc]	344[bc]	298[c]	0.03	< 0.01
FCR	4.19[d]	7.12[a]	5.53[bc]	4.67[cd]	6.49[ab]	5.32[c]	5.29[c]	0.04	< 0.01

[abcd] Means within rows with different superscripts differ significantly ($P < 0.05$).
[#] 1: control – standard feedlot ration; 2: low-energy; 3: high-protein; 4: high-protein, low-energy; 5: high-fat, low-starch; 6: high-fat, low-starch, high-protein; 7: control + β agonist.

Considering treatment as the main effect and the parameter ADG, Table 3.9 shows that there was no significant difference between Treatments 3 and 4. Average daily gain was similar for Treatments 1, 2, 3, 5 and 6, additionally there was no difference in ADG between Treatments 2, 5, 6 and 7. This pattern is similar as for the parameter weight gain (Table 3.7), confirming the link between overall liveweight gain and ADG (growth rate). Treatment 4 yielded the largest numeric ADG (456 g/day) across all treatments, accompanied by the largest numeric liveweight gain and highest final weight. Alternatively, Treatment 7 yielded the lowest numeric ADG (298 g/day), accompanied by the lowest numeric liveweight gain over the 32-day trial period. Again, the relatively poor performance of this group can be explained by it having the lowest cumulative DMI across the treatments (Table 3.3).

When considering the effect of increased protein levels in the rations and the effect on ADG, the four groups Treatment 1 (control), Treatment 3, 4 and 6 are to be compared. While Treatment 4 had the highest numeric ADG, it was similar to Treatment 3, which in turn did not differ from Treatments 1 and 6. The three high-protein rations all yielded elevated intakes relative to the control, Treatment 3 and 4 lambs had significantly higher cumulative DMI and Treatment 6 a numeric increase respectively. This finding of increased DMI accompanied by improved performance (i.e., higher ADG), with increased dietary protein levels is a common trend amongst literature (Ebrahimi *et al.* (2007). Similarly, Shahid *et al.* (2019) describes a linear increase in DMI and ADG with the crude protein (CP) level of the diet, stating that feeding higher levels of CP linearly increased the growth, feed intake and feed efficiency of growing male Beetal goats. Sultan *et al.* (2010) showed higher DMI in ram lambs on higher-protein diets across varying energy levels, also ADG was higher for animals on the higher-protein diets. Contradictory findings were reported by Beauchemin *et al.* (1995); Rios-Rincon *et al.* (2014) and Yerradoddi *et al.* (2015), suggesting that dietary CP level (and protein degradability) has limited/no effect on growth, performance and carcass characteristics. The latter recommending a low-protein and high-energy diet for better performance, nitrogen retention and better returns from Deccani ram lambs.

Table 3.9 shows that the parameter FCR resulted in a different pattern from ADG, Treatment 2 and 5 yielding similar FCR values, with Treatment 5 also similar to Treatment 3, which did not differ from Treatments 4, 6 and 7. While Treatment 1 was similar to Treatment 4, it differed from 6 and 7, with these having the same FCR. Treatment 2 yielded the largest (worst) numeric FCR (7.12) across the treatments, the reason for this can be attributed to the elevated feed intake (cumulative DMI) for animals in this group, accompanied with a relatively low liveweight gain throughout the trial period. Alternatively, Treatment 1 yielded the lowest (best) numeric FCR (4.19), as a result of its relatively low cumulative DMI with relatively high liveweight gain throughout the 32-day trial period, suggesting that the standard feedlot ration resulted in the most efficient growth. The increased weight gain of Treatment 4 was offset by elevated DMI resulting in a numerically poorer FCR compared to Treatment 1. Given that FCR is a function of the feed consumed and liveweight gain, thus, the lower the FCR value the more advantageous, indicating efficient growth.**Table 3.10.** Means of the performance data, average daily gain (ADG) and feed conversion ratio (FCR) throughout the trail period between the sexes.

Item	Sex		SEM	P-value
	Ram	Ewe		
ADG	384	348	0.01	0.07
FCR	5.45	5.58	0.20	0.64

Considering sex as the main effect, Table 3.10 shows that there is a tendency for differences in ADG within treatment groups, with rams on average having a higher ADG/growth rate (g/day) than ewes. The largest difference (109 g/day) between the sexes was recorded for Treatment 6, with an average ADG of 398 g/day vs. 289 g/day for ram and ewe lambs respectively. Similar was the difference (107 g/day) between sexes recorded for Treatment 3, with an average ADG of 453 g/day for ram and 346 g/day for ewe lambs respectively. While rams typically had higher growth rates than ewes, the exception was Treatment 2, where ewes on average had higher ADG than rams 375 g/day vs.310 g/day respectively. Treatment 1 also yielded marginal higher ADG in the ewes compared to the rams 388 g/day vs. 372g/day respectively. This result agrees with the pattern of liveweight gain between the sexes, with Treatment 2 being the exception to rams on average gaining more liveweight that ewes, as well as Treatment 1 ewes also yielded marginally higher gains compared to rams.

Although results from the present study are not significant, the trend of rams outperforming ewes in ADG, agrees with much of the literature cited, which typically suggest that rams significantly outperform both ewes and wethers (castrated rams). In addition, the results differ in that the ADG values are mostly superior (higher), in particular the ewe lambs, compared to many of the studies cited. Du Toit (2017), reported higher ADG for the Dorper ram lambs (400 g/day), while the ewes were significantly lower, Miranda de Vargas *et al.* (2014) noticeably lower values for both the sexes 209 vs. 161 (g/day) for rams and ewes respectively. These differences can be attributed to breed and diet used. Studies by Brand *et al.* (2017) and Van der Merwe (2020) also showed a lower average ADG of 245.0 and 327.3 (g/day) for their Dorper lambs respectively due to lower nutrient density diets. While Brand *et al.* (2017) did not specify the sex, the latter was the average ADG across the sexes. In the study by Brand *et al.* (2017), the lack of an adaptation period prior to commencement of the trial, in addition with the long (105-day) trial period, could possibly explain the lower ADG observed compared to the current study.

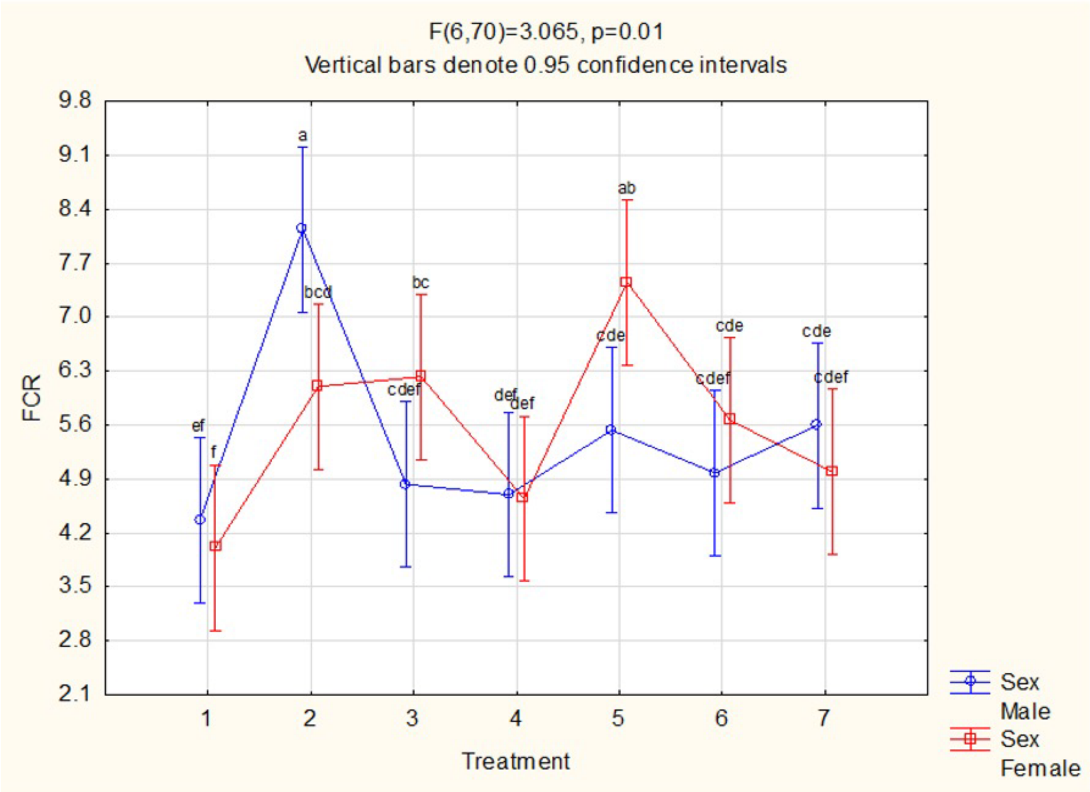
Although not significant, Table 3.10 shows that on average rams showed numerically improved FCR compared to ewes (5.45 vs. 5.58), suggesting improved growth efficiency for rams. These FCR values agree with Miranda de Vargas *et al.* (2014) and Du Toit (2017), who reported similar values for their studies, along with the trend of better (lower) FCR values for rams compared to ewes and wethers. Brand *et al.* (2017) however, reported notably higher FCR values for the Dorper lambs in their study, with an average of 7.54 across the 105-day trial. The significantly longer trial period could provide an explanation for this as it is well known that animal growth rate and efficiency of production decreases with time. Van der Merwe (2020) describes the typical growth curve of feedlot lambs which is characterised by an accelerating phase followed by a decelerating phase and a plateau in growth as the individual nears mature weight.

While Table 3.11 shows no difference in FCR within treatment groups when considering sex as the main effect, Table 3.11 however, shows that the interaction of treatment and sex is significant (P = 0.01) for the parameter FCR.

Table 3.11. The interaction of the main effects of treatment and sex on performance data, average daily gain (ADG) and feed conversion ratio (FCR) throughout the trail period.

Item	Treatment# 1		2		3		4		5		6		7		SEM	P-value
	Ram	Ewe	Ram	Ewe	Ram	Ewe	Ram	Ewe	Ram	Ewe	Ram	Ewe	Ram	Ewe		
ADG	372^{bcde}	388^{abcde}	310de	375^{bcde}	453^{ab}	346^{cde}	479^{a}	432^{abc}	375^{bcde}	307de	398^{abcd}	289^{e}	299de	297de	0.04	0.16
FCR	4.37^{ef}	4.01^{f}	8.14^{a}	6.10^{bcd}	4.83^{cdef}	6.23^{bc}	4.70^{def}	4.64^{def}	5.53^{cde}	7.45^{ab}	4.98^{cdef}	5.66^{cde}	5.60^{cde}	4.99^{cdef}	0.54	0.01

^{abcdef} Means within rows with different superscripts differ significantly (P < 0.05).
$^{\#}$ 1: control – standard feedlot ration; 2: low-energy; 3: high-protein; 4: high-protein, low-energy; 5: high-fat, low-starch; 6: high-fat, low-starch, high-protein; 7: control + β agonist.



abcdef Means with different superscripts differ significantly (P < 0.05).

Figure 3.3. Interaction between main effects treatment and sex for the parameter FCR.

Figure 3.3 clearly shows that FCR is significantly (P < 0.05) higher for rams in Treatment 2, while ewes had significantly (P < 0.05) higher FCR in Treatment 5. Table 3.11 confirms this result, showing that Treatments 2 and 5 are the only groups within the study, where there was significant difference between the sexes for the parameter FCR, with Treatment 2 rams having the highest recorded FCR (8.14), followed by Treatment 5 ewes (7.45).

Given that FCR is a function of intake and liveweight gain, the high numeric FCR values for Treatment 2 (Table 3.9) can be attributed to the elevated feed intake for animals in this group, associated with a relatively low liveweight gain throughout the trial period (Table 3.7). The elevated intakes were recorded on both the individual animal and on a group basis, owing to the diet's low energy density. Although the cumulative DMI of ewes was lower than ram lambs for Treatment 2 (71.8kg vs. 76.8kg), the ewe lambs had surprisingly higher liveweight gains (12.0kg vs. 9.9kg) and therefore improved ADG (375 g/day vs. 310 g/day) and lower FCR (6.10 vs. 8.14) respectively. This difference between sexes of Treatment 2 was not expected. While higher intakes were typically associated with ram lambs within treatment groups, Treatment 5, however, yielded notably higher intakes for ewes compared to rams (71.6kg vs. 66.3kg) respectively. The higher intake by the ewes was accompanied by relatively low total live weight gain (9.8kg vs. 12.0kg) and therefore lower ADG compared to the rams (307 g/day vs. 375 g/day) was responsible for the significant higher FCR of ewes in Treatment 5 observed in Figure 3.2.

While the reason for the ewes having higher intakes in Treatment 5 is unclear, it can however be suggested that the nature of the pellets may be a contributing factor. The high fat content of Treatment 5 and 6 resulted in crumbling and therefore a poorer pellet quality when compared to the other treatments. A possible suggestion could be, while the rams may have been more aggressive in selecting and therefore consuming the larger pellets, perhaps the ewes were less selective and therefore had more 'fines' available to them.

Furthermore, Table 3.11 shows that the elevated FCR of Treatment 2 rams differs significantly from all other groups besides Treatment 5 ewes, which in turn did not differ from Treatment 2 and 3 ewes. Treatment 1 ram and ewe lambs, with the lowest numeric FCR values, were similar to both Treatment 4 ram and ewe lambs, owing to the rapid growth (highest ADG) and largest recorded liveweight gain of these animals. Treatment 1 rams and ewes are also similar to the rams of Treatments 3 and 6, while treatment 1 rams did not differ from rams in Treatments 5 and 7 and ewes of Treatment 6. Additionally, the FCR values of Treatment 1 rams did not differ from those of Treatment 7 rams and ewes, while Treatment 1 ewes were similar to Treatment 7 ewes. This finding is in partial agreement with Du Toit (2017), who found that the inclusion of R-salbutamol (although not the same GP used in the present study), did improve FCR in ram lambs but had no effect in ewe lambs.

While FCR differed significantly ($P < 0.05$) between Treatment 2 rams and ewes, Treatment 2 ewes did not differ from both ewes and rams of Treatments 3, 4, 5, 6 and 7 but did differ significantly ($P < 0.05$) from rams and ewes in Treatment 1 for the parameter FCR. Feed conversion ratio is unique from the other parameters in study, given that it is influenced by different variables, being a function of both feed intake (cDMI) and liveweight gain, which in turn is associated with ADG, multiple factors therefore influence FCR. For this reason, the differences reported within these individual parameters may be masked by those which also influence FCR, explaining the similarities for FCR when looking at the interaction of the main effects, Treatment and Sex.

Considering fat supplementation in this interaction of the main effects, rams and ewes from Treatments 1 (Control), 5 and 6 are to be compared. While Treatment 1 rams and ewes don't differ, Treatment 1 rams are similar to both ewes and rams of Treatment 6 and the rams of Treatment 5. Treatment 1 ewes, however, differ significantly ($P < 0.05$) from both the rams and ewes of Treatment 5 and the ewes of Treatment 6. This finding suggests that supplementing fat has a greater effect on FCR in ewes than rams, yielding higher FCR's and therefore poorer efficiency of gain in ewe lambs, this trend was also observed in rams, with Treatment 1 animals having numerically the lowest FCR of all groups (Table 3.11). Opposing this, Davila-Ramirez *et al*. (2015) reported that a 6% soybean oil supplementation did affect the gain, resulting in a significantly ($P < 0.05$) improved FCR in fat supplemented ewes. However, Davila-Ramirez *et al.* 2014 however, found that 6% soybean oil supplementation had only a marginal effect in increasing FCR in ram lambs, which agrees with the results form present study. Differences between the study of Davila-Ramirez *et al*. (2015) and the present study can be attributed to differences in breed and dietary fat type.

3.4.5. Nutritional Considerations

3.4.5.1. Energy

When considering energy levels, only two treatments will be compared for the measured parameters, Treatment 1 (control – standard feedlot diet) and Treatment 2 (low energy diet). Treatment 2 resulted in significantly ($P < 0.05$) elevated feed intake cDMI, dDMI and DM as % BW) compared to the control. An elevated intake was expected for Treatment 2 as the animals try to compensate for the lower energy level. This finding agrees with studies by Sultan *et al.* (1991); Sultan *et al.* (2010) and Rios-Rincon *et al.* (2014).

Considering final weight, liveweight gain and ADG, the two treatments yielded relatively similar findings, with Treatment 1 lambs performing numerically better. However, FCR was significantly higher (poor efficiency of gain) for Treatment 2 lambs due to the significantly elevated intake of this group. It is to be noted that ewes in Treatment 2 had notably lower FCR compared to the rams, corresponding with superior performance, higher weight gain and ADG. Treatment 1 ewes also showed slight improved performance compared to the rams, where rams outperformed ewes in all other treatment groups. The reason for the superior performance of ewe lambs in Treatment 2 is unknown and was not expected.

Considering the rams only, due to the skewed group mean as a result of the high performing Treatment 2 ewe lambs, Treatment 1 yielded better feedlot performance over Treatment 2, for all the measured parameters, specifically FCR. Much of the literature cited agrees with these findings, suggesting improved performance with higher energy diet, alternatively demonstrating poorer performance being associated with low energy diets (Sultan *et al.* 1991; Beauchemin *et al.* 1995; Ebrahimi *et al.* 2007; Sultan *et al.* 2010; Yerradoddi *et al.* 2015). In contrast Rios-Rincon *et al.* (2014) found that energy levels did not affect final weight nor ADG, but owing to lower intake on high energy rations, it consequently resulted higher efficiency of gain (lower FCR values) in intact male lambs.

3.4.5.2. Protein

When considering the effect of increased protein levels in the diets, the four treatments that will be compared for the measured parameters, Treatment 1 (control), Treatment 3 (high-protein diet), Treatment 4 (high-protein, low-energy) and Treatment 6 (high-fat, low-starch, high-protein). Protein levels were increased in Treatments 3, 4 and 6 through the ~5% inclusion of fishmeal to the diets (Table 3.1). Fishmeal is considered a high-quality bypass rumen undegraded protein (RUD) protein source for livestock, with 76.2% crude protein and a rumen degradability of 15.2% (Beauchemin *et al.,* 1995).

The three high-protein diets all yielded elevated intakes relative to the control, Treatment 3 and 4 lambs had significantly higher ($P < 0.05$) cumulative DMI and Treatment 6 a numeric increase respectively. Considering final weight, liveweight gain and ADG, Treatment 4 yielded significantly ($P < 0.05$) improved performance compared to the control, whereas Treatments 3 and 6 did not differ from the control for these parameters. Moreover, Treatments 3 and 4 were similar in their gain and ADG, whereas Treatment 3 did not differ Treatments 1 and 6. Feed conversion ratio yielded a different pattern, with Treatment 1 having the numeric lowest (best) FCR of all the Treatment groups.

This finding of increased DMI accompanied by improved performance, with increased dietary protein is a common trend amongst the literature cited. Ebrahimi *et al.* (2007) showed similar findings. Shahid *et al.* (2019) describes a linear increase in DMI and ADG with the crude protein (CP) level of the diet, stating that feeding higher levels of CP linearly increased the growth, feed intake and feed efficiency of growing male Beetal goats. Sultan *et al.* (2010) showed higher DMI in ram lambs on higher-protein diets across varying energy levels. Average daily gain also was higher for animals on the higher-protein diet, furthermore, showing a significant interaction between dietary energy and protein levels and the effect on FCR (Sultan *et al.*, 2010). Contradictory findings were reported by Beauchemin *et al.* (1995); Rios-Rincon *et al.* (2014) and Yerradoddi *et al.* (2015), suggesting that dietary CP level (and protein degradability) has limited/no effect on growth, performance and carcass characteristics. The latter recommending a low-protein and high-energy diet for better performance, nitrogen retention and better returns from Deccani ram lambs.

The exact reasons for the marked improvement in performance of Treatment 4 lambs relative to the other high-protein groups and to the control is unknown. But these lambs benefitted from the high protein for increased muscle growth. Furthermore, the lower energy level of the diet, relative to the other three groups, was also beneficial to these lambs. It can be speculated that the adaptability of the Dorper breed to harsh, arid conditions and therefore poorer quality feed, with typically a low nutritional value, may provide an explanation. Despite some contradictory results, it can be concluded that elevated CP diets could be beneficial to feedlot Dorper lamb performance.

3.4.5.3. Fat

In ruminants, the supplementation of fats in their diets yield varying effects on nutrient digestibility, feedlot performance, body and carcass composition (Davila-Ramirez *et al.,* 2015). The widely varying response to fat supplementation may be attributed to both the inclusion level and or source of fat in the diet, which can directly affect the activity of ruminal microbes (Van der Merwe and Smith, 1991).

When considering varying fat levels, the three treatments to be compared for the measured parameters are Treatment 1 (control - standard feedlot diet), Treatment 5 (high-fat, low starch), and Treatment 6 (high-fat, low-starch, high-protein). Fat levels were increased in Treatments 5 and 6 through the 6.5% inclusion of Bergafat® (a processed palm oil powder) to the diets (Table 3.1). Despite being considered high fat, these two treatments had normal ME levels, given that the 6.5% inclusion of fat was approximately 50% substitute for the conventional maize (starch) component of these diets.

The parameters final weight, liveweight gain and ADG were similar between the three groups, however both high-fat groups had increased intake (cDMI, dDMI and DM as % BW) relative to the control, with Treatment 5 being significantly ($P < 0.05$) higher. These elevated intakes yielded higher FCR's relative to the control, with Treatment 5 again being significantly ($P < 0.05$) the highest.

The differences observed between Treatments 5 and 6 can be attributed to the different protein levels. Moreover, these treatments yielded differences in performance between ram and ewes, with rams exclusively outperforming the ewes. It is to be noted, that treatment 5 was the only treatment group of the study where ewes had cumulatively higher intakes than rams, which is responsible to their poor (high) FCR value. Weight gain and ADG was numerically superior for the control compared to Treatment 5 and 6. This trend of reduced performance in animals with fat supplementation agrees with a study by Zinn *et al.* (1994), who reported depressed ADG and dry matter conversion in feedlot cattle supplemented with fat. The latter authors however noted that these depressions were more notable at 12% level of fat supplementation. Furthermore, suggesting that the detrimental effects of excessive supplemental fat can be attributed to the ruminal indigestibility of dietary fat. Palatability issues due to poorer pellet quality (high fat) may can explain the differences between the current study and that of Zinn *et al.* (1994). Gibb *et al.* (2005) however reported opposing findings showing that feeding full-fat hemp seed did not affect DMI, ADG, FCR and carcass traits on feedlot cattle. Furthermore, suggesting that feeding up to 14% of dietary DM full-fat hemp seed had no detrimental effect on growth or efficiency of growth compared to cattle fed a standard barley-based finishing diet. This finding agreed with studies by Kim *et al.* (2007); Davila-Ramirez *et al.* (2014) and Davila-Ramirez *et al.* (2015), who reported that the inclusion of soybean oil at 4-6% (DM basis) in finishing diets did not affect performance of feedlot lambs. Studies conducted by Kott *et al.* (2003) and Dutta *et al.* (2008) however, reported an improvement in performance (growth rate and efficiency of growth), while carcass composition and meat quality remained unaffected, in male lambs supplemented with a diet containing 6% oil from safflower seeds and 5% palm oil supplementation respectively, while efficiency of gain (FCR) decreased at greater than 5% supplementation with palm oil.

While no obvious detrimental effects were detected in lambs on the high-fat diets, the poor efficiency of gain of these animals when compared to the control and in particular the ewe lambs in treatment 5, suggests that substituting approximately 50% maize from the diet for processed palm oil as an alternative energy source, has no beneficial effects on performance.

3.4.5.1.4. Growth Promotors

Although not a nutritional component, growth promotors (GP) can be considered as feed additives. Even though all diets in the current study contained similar levels of ionophores, the GP of interest used in the present study was a beta-agonist called Zilpaterol hydrochloride, under the trademark name of Zilmax® (MSD). Today Zilmax is one of the most widely utilised beta-agonists in feedlot systems (Du Toit, 2017). When considering the effects of including this growth promotor on feedlot performance, only two treatments will be compared for the measured parameters, Treatment 1 (control – standard feedlot ration) and Treatment 7 (control + GP).

Treatment 1 yielded significantly superior performance compared to Treatment 7 for the parameters liveweight gain, ADG and FCR, this was both on a group basis and an average of the sexes. Cumulative intake was marginally lower for Treatment 7 which may contribute to its relatively lower liveweight gain but does not explain the poorer efficiency of gain (higher FCR). The intake data recorded for these two groups was lower than all other treatments and the effects of sex was negligible between them. These findings are in partial agreement with the studies of Davila-Ramirez *et al.* (2014) and Davila-Ramirez *et al.* (2015), who noted that while Zilpaterol hydrochloride (ZH) did improve performance during periods of the trials, but it did not affect feedlot performance (total gain, ADG and efficiency of growth) of ram and ewe lambs throughout the overall feeding period of their studies. Moreover, they reported that Zilpaterol hydrochloride supplementation did not affect DMI. A study by Du Toit (2017) on

Dorper's reported that dietary R-salbutamol inclusion did improve FCR in ram lambs only, while there was no influence DMI and ADG.

Results from this study suggest that the growth promotor Zilmax was not effective in improving feedlot performance for lambs for the measured parameters. This finding implies that the use of Zilmax is not warranted for the feedlot finishing of ram and ewe Dorper lambs.

3.5. Conclusion

The overall objective of this two-part study was to determine whether the final weight (carcasses) of the Dorper lambs can be increased without increasing their fat deposition. Establishing whether altering nutritional compositions of different treatment diets, would yield improved performance and result in higher final weights. These nutritional differences were specifically emphasised over the use of growth promotors (GP) to achieve these results. While many studies have proved growth promoting agents to be effective in improving feedlot performance by enhancing production parameters, results from the current study disagree. This, together with growing consumer awareness and the increasing global shift away from these products, lends to the secondary objective for the trial, which aims to explore and establish alternatives to these feed additives through nutrition.

Furthermore, the Dorper was selected as the breed of choice for this two-part study with the vision of its sustainability in future. The breed is well known for adaptability to harsh semi-arid and arid conditions and many extensive producers are forced to farm with this animal type. Additionally, climate change and its associated hotter and drier environmental conditions are likely to further increase utilisation of the Dorper by producers and thereby increasing its supply to feedlot finishing systems. Most feedlots discriminate against Dorper lambs due to poor feedlot performance.

It can be concluded from this study that Treatment 4 (high protein, low energy) yielded improved performances in liveweight weight gain and ADG, and significantly higher final bodyweights across all treatment groups in both ram and ewe lambs. Although Treatment 1 (control – standard feedlot ration) resulted in the most efficient gain, with the lowest average FCR across the sexes. Reducing the starch level in Treatment 2 – low energy, in an attempt to reduce fat deposition, proved inappropriate owing to the excessive feed intake and consequently poor efficiency of gain (elevated FCR) of lambs in this group. Substituting 50% of the maize (starch) from the diet for 6.5% processed palm oil as an alternative energy source had no beneficial effects on performance and given the higher associated costs, it therefore is not recommended for feedlot finishing of Dorper lambs. Disregarding carcass quality, the inclusion of the Zilpaterol hydrochloride to the diet showed to be detrimental to all the measured parameters (weight gain, ADG and FCR) for both rams and ewes when compared to the control, suggesting that this growth promotor should be excluded from the finishing diets of Dorper lambs.

These results indicate that diet played a significant role in the performance parameters of Dorper lambs under feedlot conditions. Differences were also evident between the sexes. While not significant, rams on average outperformed the ewes. There were however certain exceptions and these variations in performance indicate that further research is required before a “designer Dorper diet” can be established for the feedlot finishing of ram and ewe lambs. Additionally, it is important that the economics are considered (part two of the study) when performing these comparisons to establish whether the improvements in performance are enough to justify the potential increased costs associated with the optimal Dorper feedlot finishing diet.

The RFID feeder system used in the study meant that the lambs were not required to be housed in individual pens nor was the weighing back of feed refusals required to determine the animals feed intake. When compared to many of the studies cited, this technology is advantageous, allowing for the recording of individual animal feed intake while animals can be housed in a group. This is considered particularly beneficial when considering dorper’s, which are highly adapted to extensive systems, it can therefore be extrapolated that they are particularly prone to stress when housed individually which it likely to affect their feed intake and overall performance.

Limitations of the study included the fixed slaughter date owing to the festive season. Additionally, given the early maturity of the Dorper breed, the start weight of the animals was higher than optimal, meaning that animals were relatively closer to their mature weight prior to commencement of the study. This would likely have affected overall performance and time on feed for the various treatments in order to achieve optimal final bodyweights for Dorper ram and ewe lambs, as feeding lambs from a different start and endpoint may have resulted in an alternative conclusion.

3.6. References

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CHAPTER 4

Effect of feed composition and sex on carcass characteristics and profitability of Dorper lambs.

4.1. Abstract

The objective of this study was to determine the effect of diet and sex on carcass characteristics and overall profitability parameters of Dorper lambs. Eighty-four Dorper lambs were randomly allocated to one of seven diet treatment groups (1=control, 2=low-energy, 3=high-protein, 4=high-protein + low-energy, 5=high-fat + low-starch, 6=high-fat + low-starch + high-protein; 7=control + β antagonist), comprising 12 animals each- 6 ram and 6 ewe lambs in a 2 x 7 factorial design. Diet treatment yielded a significant ($P \leq 0.05$) effect on most of the measured parameters (final weight, carcass weights- warm and cold, slaughter percentage-warm and cold, feed cost, carcass value (R/head) and margin above specified costs (R/head and R/kg)), while the effect of sex was limited. The interaction of diet and sex was significant ($P \leq 0.05$) for the difference in slaughter percentage between warm and cold carcasses and the margin above specified cost only. Findings of this study show the lambs final weight was significantly ($P \leq 0.05$) highest for Treatment 4 (high protein, low energy), resulting in the highest carcass weights and thus the highest carcass value/revenue being achieved. Moreover, Treatment 4 yielded superior performance for these parameters in both ram and ewe lambs ($P \leq 0.05$). Although, not significant, rams on average yielded numerically superior performance compared to ewe lambs across the measured parameters. While Treatment 7 (control + β antagonist) yielded the highest slaughter %, with the ewes being the highest of all groups (both ram and ewe lambs) ($P \leq 0.05$), Treatment 1 (control) yielded the highest numeric margins over specified costs (R/head and R/kg), along with the lowest FCR, suggesting the correlation between margin and efficiency of growth, apart from improving slaughter %, Treatment 7 was shown not effective in improving the recorded parameters.

4.2. Introduction

4.2.1. South African landscape

The majority (~87.5%) of South Africa's agricultural land is not arable and considered suitable only for animal production and game. While beef and dairy productions systems utilise large areas of pastoral land (Van der Merwe, 2020), a significant portion of South Africa is considered arid and semi-arid, and these regions can only be utilised by hardier small ruminants (Brand, 2000). Sheep production is also incorporated into mixed agriculture systems, where the sheep utilize cultivated cereal stubble, increasing producer income per hectare from both grain and lamb (Brand, 2000). It is predicted that global warming will lead to climates becoming hotter and drier with drought conditions becoming more frequent and severe, causing the composition and quality of the natural veld to change, leading to less forage being available for livestock (Rust and Rust, 2013). The limited forage resource will cause increased competition for grazing, in turn amplifying the pressure on producers to not only maintain production levels but also increase production to meet the growing consumer demand for meat (lamb). These pressures highlight the importance of more efficient production (Meissner *et al.,* 2013) and the need for producers to intensify their operations to maintain productivity. Many producers have value-added through implementing strategies of more intensive management to increase production, including feedlots to finish weaned lambs and benefit from the marketing of higher value slaughter ready lambs (Landman, 2013).

The South African national flock is currently estimated just below 19 million head of sheep (Abstract of Agricultural Statistics, 2021), globally this ranks 8th, with approximately 8000 commercial and 5800 communal sheep farmers in South Africa (Walker, 2008; Terblanche, 2013: DAFF, 2018). The national flock comprises different breeds and sheep types, according to weaning weights records from the National Small Stock Improvement Scheme (NSSIS), contributions of the various types are Wool (Merino, Dohne Merino and SA Mutton Merino) approximately 68%; haired, meat breeds (Dorper, Meatmaster and Van Rooy) 22% and terminal sire breeds (Dormer, Il de France, Sufflok and Merino landsheep) 10% (Cloete *et al.,* 2014).

The South African industry produces approximately 177 000 tonnes of lamb and mutton per annum (DAFF, 2019) and according to the Red Meat Producers Organisation (RPO) trend in slaughter statistics, the majority (~70%) of lambs slaughtered at commercial abattoirs are classified as A2, with an average carcass weight of 20.14kg (RPO, 2021). This meets market specifications and allows producers to benefit from their higher market value.

4.2.2. Conventional economic theory

This principle suggests that while the trend in the demand for a product (lamb) exceeds its supply, then increases in price can be expected, in this case, incentivising producers to increase their supply of lamb (Dibb *et al.,* 2005). Both the producer and consumer prices for lamb have followed this trend, showing an increase for all grades from 2007 to 2017 (DAFF, 2018).

Despite these increases in the prices of lamb, the South African national sheep flock however declined by ~12 % during the period 2010 to 2020 (Abstract of Agricultural Statistics. 2021) Various factors have been cited as responsible for this countertrend in the traditional relationship of supply and demand within the South African sheep industry (Terblanche, 2013). These factors include stock theft, drought conditions, predation, and diversification of extensive livestock production into systems such as game farming (DAFF, 2012). Furthermore, stating that these factors have been reported to have a significant negative impact on sheep production, particularly in extensive areas, such that the annual proportion of marketable animals in these flocks are declining (Van Niekerk *et al.,* 2009).

While this decline in animal numbers affects the supply of lamb to market, producer revenues and farm-level economics are also negatively affected (Terblanche, 2013), suggesting that structural changes within the sheep industry can be expected. While the supply of lamb from the traditional extensive sheep production systems is declining, production is likely to shift to more intensive systems. A trend of increasing prices for both lamb and mutton along with the increased pressure to intensify production systems (DAFF, 2019), are drivers for many producers choosing to feedlot finish their lambs. Moreover, the decline in sheep numbers means that this intensification of production is essential, to meet the growing demand for lamb.

4.2.3. Feedlotting

Feedlotting refers to an intensive feeding operation which fattens large numbers of animals for slaughter (Terblanche, 2013). Typically young, weaned animals will be subjected to high energy diets, with the aim of achieving market weight in the shortest possible time. As described by Van der Merwe (2020), feedlotting adds value to animals with low body weights (small, low valued carcasses) and poor conformation through intensive feeding to produce carcasses with improved musculature and more desirable fat cover. Feedlotting is also known to take advantage of compensatory growth in lambs which received suboptimal nutrition prior to weaning (Addah *et al.,* 2017). The objective of this intensive feeding system is to take advantage of the superior growth rates and feeding efficiencies of young animals (Van der Merwe, 2020), whereby rapidly rearing them to optimal market weights, ensuring that maximum revenue is achieved.

Feedlot finishing plays a fundamental role in preparing lambs for slaughter in the intensification of sheep production systems, which is becoming more common within the sheep industry. As suggested by Terblanche (2013), only a small percentage of lambs achieve marketable weights by the time of weaning. Feedlot finishing is common practice, allowing weaned lambs to reach desirable weights and classification for slaughter. In addition, it serves to relieve the grazing pressure on pasture and natural veld, allowing the producer to carry more productive ewes, whereby improving output per hectare (Van Zyl, 2017). This enhanced output is necessary for producers to overcome the higher input cost associated with intensifying sheep production (Stephanie *et al.,* 2020).

4.2.4. Challenges and risks in feedlotting

Despite the many advantages of intensively finishing lambs, there are however numerous challenges facing feedlot producers, these include but are not limited to, the high input costs associated with intensive systems (Stephanie *et al.,* 2020), changing markets and price fluctuations in inputs (feed/purchase price) and output (lamb) (Oosthuizen, 2016), moreover, these factors are mostly beyond the control of producer (Spies, 2011).

The cost of feed has been widely described as a major input, representing approximately 70% of the variable costs for intensive systems (Lima *et al.,* 2017). Feed intake of animals is therefore an important parameter to be considered, along with diet costs; Chiba (2009) emphasises the importance of providing animals with quality feed at the lowest possible cost.

The purchase price of the weaned lambs also represents a major portion of the input costs to feedlot operations (Van der Merwe, 2020). Typically, feedlot operators will purchase store lambs (R/kg, live weight) and after the fattening period, will market them through abattoirs at the current meat/carcass price (R/kg, carcass weight). Producers are price takers, and therefore are not able to control the price of their product which they market (Truter, 2021). In addition, feedlot operations purchasing lambs for finishing are also price takers in the price of weaned lambs (Oosthuizen, 2016). However, producers fattening their own lambs should also consider the initial value of their lambs entering the feedlot to determine their overall profitability more accurately without capitalising on opportunity cost (Van der Merwe, 2020). The same is true for feed costs for any feedstuffs produced on farm to be used for the finishing of lambs (Van der Merwe, 2020). These lamb and feed inputs should be valued on the day they are moved into the intensive system, considering the opportunity cost the producer would receive for selling them.

Fluctuations in both the purchase price of lamb and meat/carcass price is a real challenge to feedlot operators and the ratio between the purchase and selling prices is subject to fluctuation on a weekly basis, throughout the year, according to the supply and demand of weaned lambs and carcasses (Spies, 2011). The consumers demand for lamb is also influenced by number of factors such as economy (purchasing power), seasonality (higher demand of lamb during summer) and religious ceremonies.

A significant challenge facing feedlot producers and the sheep industry in general, are small and varying profit margins (Oosthuizen, 2016). This owing to the high input and capital costs, placing pressure on the profit margins (Stephanie *et al.,* 2020) and therefore risk of low profitability (Morris, 2009), associated with intensive systems. Despite these risks, there has been a growing trend of intensifying animal production systems, to meet the increasing demand for meat and overcoming some of the many forementioned challenges facing farmers.

Intensive feedlot finishing of lambs can be a high-risk enterprise, with high turnover and low margins (Jolly & Wallace, 2007). A significant risk associated with feedlotting is that the availability of weaned lambs fluctuates due to seasonality of production, and this can negatively influence the throughput (Terblanche, 2013) of the feedlot and therefore affect profitability. However, the risk to the feedlot operator not able to supply contracts, can be more detrimental than running at a loss (McKenzie, 2021; Van Zyl, 2021). Producers emphasising that it is of greater importance that the operation is stocked with animals over the profitability of the operation (Truter, 2021), as producers are often obliged to deliver a specific number of carcasses. Failing to meet these contracts can result in losing the client and thus the producer's market (Van Zyl, 2021).

Duddy (2016) suggests that the animals themselves can be a risk including lamb mortalities, non-feeders/shy-feeders and poor performers pose a financial risk. According to Duddy (2016) underperforming lambs are costly and may bring little or no return.

With the risk of small and varying profit margins, the producer needs to ultimately weigh the cost of capital against the additional gain by the feedlotting enterprise when deciding on whether to proceed with fattening lambs or not.

4.2.5. Influencers of feedlot profitability

Profit is considered as the difference between the value of the products/services produced on the farm and the costs of resources used in their production and profitability is the farm/operations income/revenue as a fraction of the average total capital used (Van Zyl *et al*., 2013). As with all operations, profitability of the system is key to sustainable production, with various factors influencing production and thus contributing to overall profitability. Profit is the primary factor determining the existence of any enterprise and this is true for the feedlotting of lambs (Gardner *et al.,* 1996).

Feedlot profitability is dependent on many factors, the fixed costs (infrastructure and labour), variable costs (feed), animal performance and the market value of the animals (Bowan *et al*., 2006). However, the five main drivers or influencers of feedlot profitability according to (Van Zyl, 2017), include the lamb purchase price (R/kg live weight), carcass/meat price (R/kg carcass), carcass characteristics (weight, dressing %), production parameters (ADG & FCR) and feed price. While feed costs typically represent the largest variable cost (70%) in feedlots

(Ford, 2011; Lima *et al.,* 2017), it tends to have a relatively small effect on overall profitability, due to the slower growth rates (ADG) often associated with poor quality feeds, which outweigh the saving of the cheaper feed (Van Zyl, 2017). According to Van Zyl (2021) feedlot profitability is normally more sensitive to animal buying cost, income, growth performance.

The forementioned, feed costs and the purchase price of lambs represent the two major inputs into feedlot systems, while revenue is achieved through the marketing of carcasses, therefore any unexpected changes in feed or market prices can affect feedlot profitability (Duddy, 2016). The value of the carcass is dependent on its weight and classification, with the highest price (R/kg) being achieved for carcasses classified as A2/3 (RPO, 2021). Meeting the markets specifications of optimal weight and fat cover for lamb carcasses is critical for producers in achieving maximum revenue and increasing profitability of feedlot systems.

Carcass weight is a major driver of revenue and feeding animals to heavier weights is usually beneficial (Hyer *et al.,* 1986). The longer rearing periods, allows for greater gains (larger carcasses) and therefore greater profit margins. For this reason, feedlot operators typically favour larger breeds over smaller, early maturing breeds, like the Dorper, which typically have a shorter rearing period to slaughter weight. However, this shorter fattening period of these breeds can be advantageous (Brand *et al.,* 2018) as these early maturing animals consume less feed and therefore have lower feed costs. Furthermore, the increasing FCR with age implies there is a point where marginal revenue is lower than marginal cost. In reference to beef feedlotting, Oosthuizen & Maré (2018) describes additional limitations with producing heavier carcasses over a longer period, including undesirably large carcasses/muscle cuts. With increasing age there is also an increased cost of gain associated with increased maintenance requirements. Furthermore, an increase in fat deposition with time may lead to carcass classified as over fat, which will affect the grade and decrease carcass value (Van der Merwe, 2020).

Fluctuations for both the weaner and carcass price have been well documented in significantly influencing feedlot profitability (Langemeier *et al.,* 1992; Amer *et al.,* 1994, Williams and Bennett, 1995; Maré *et al.,* 2010). However, as suggested by Duddy (2016), there are historically strong seasonal price patterns and these can be used to estimate market prices from known weaner lamb prices, allowing for approximate profitability to be determined. The price margin, the difference between the purchase price paid for lambs entering the finishing system and the theoretical market price for the unfinished animal at that stage (Eksteen, 2016) also influences profitability. A general rule under South African conditions, is that the meat/carcass price (R/kg) needs to be at least two times the purchase/store lamb price (R/kg) to ensure that the operation is profitable (Van Zyl, 2021). In agreement to this was the comparison of the ratio between the lamb purchase price and the meat/carcass price

(A2/A3 carcass) on the ABSA weekly reports, this ratio was typically reported as ~49%, (RPO, 2021).

Production parameters including average daily gain (ADG) an indication of growth rate and feed conversion ratio (FCR) which indicates the efficiency of production are important drivers of profitability in sheep production systems (Terblanche, 2013). Average daily gain is expressed in grams per day, and it is suggested that lambs generally need to be growing in excess of 300g/day to be profitable (Jolly & Wallace, 2007; Terblanche, 2013; Van Zyl, 2021). Feed conversion ratio is expressed as a ratio of the liveweight gain/feed consumed (De Wet, 2018). With feed being a significant cost in feedlot operations, the efficiency of growth or the efficiency with which lambs convert feed to live weight gain is important.

Additional factors that influence feedlot margins include the 5th quarter and other revenue opportunities from the animal (wool, hide, head) (Van der Merwe, 2020). According to Spies (2011) 5th quarter income generally remunerates the slaughtering process and is not regarded as a pure income to the operator. Economies of scale which spread the fixed costs over a larger number of animals, if the facility can accommodate them, thereby reducing the costs per head (Porter & Jones, 2005). Time on feed refers to the time lambs spend in the finishing system; with high feed costs this plays an important role in feedlot profitability (Hannon & Murphy, 2019). The type of animal influences the time on feed, generally the larger, later maturing breeds tend to be fattened for longer than smaller, early maturing breeds.

Costs associated with running feedlot operations to be considered (Jolly & Wallace, 2007) include:

- Infrastructure maintenance
- labour
- veterinary
- transport cost includes that of transporting lambs to and from the feedlot to the market/abattoir.
- processing
    - dosing
    - dipping
    - hormonal implantation
    - shearing
- Agent commission- costs associated with the purchasing or selling lambs through an agent
- Slaughter fee- the levy per animal for using the slaughter facility

Many of these factors can be considered as fixed costs and through economies of scale, by increasing the size of the operation and throughput in the number of lambs fattened in the operation, these costs can be reduced by spreading over a larger number of animals. As suggested by Van der Merwe (2017), narrow profit margins mean that feedlot producers are often reliant on economies of scale to generate a sufficient income.

Strict management in the intensive rearing of lambs is required to minimise input costs and wastage and to produce animals with ideal slaughter weights is needed to obtain premium carcass prices. Management can therefore have a significant effect on feedlot efficiency and productivity in turn affecting the overall feedlot profitability either positively or negatively.

4.2.6. Factors enhancing feedlot profitability

Like all industries, profitability is the main driver in all feedlot finishing operations. Many of the major factors influencing feedlot profitability, both the inputs (feed costs and lamb purchase price) and outputs (market lamb/carcass price) are beyond the control of the producer and known as Economic factors (Spies, 2011). While the factors which can, or at least to some extent, be managed by the feedlot producers are known as Management factors. These typically relate to the animal performance such as ADG, FCR, dressing percentage and time on feed. These factors are largely related to intrinsic animal characteristics which include breed, age, weight, sex, and health status (Spies, 2011).

To enhance feedlot profitability, it is critical that variables which are subject to the producer's control (nutrition and management strategies) are strictly managed to improve the efficiency, achieve optimal performance of lambs and overall profitability of feedlot operations (Raineri *et al.,* 2015). Nutrition is often regarded as the main factor (Owens *et al.,* 1993) over which the producer can exert the highest level of control (Chappell, 1993).

Common practice within the industry is to manage and market animals on a group basis, according to the group averages and a set fattening period, with the aim that the majority achieve market specifications. However, the significant variation among animals and the differences in their performance (growth and efficiency of growth) within a group (Burns & Calver, 2020), forms the basis of the trend towards precision sheep management. As stated by Precision Pays (2007), regular measurement and recording of animal performance, allows objective managing and marketing decisions based on an individual animal performance, in turn ensuring greater precision and optimisation of sheep feedlots with greater profits being achieved (De Wet, 2018). When lambs are considered as groups rather than individuals, many poor performing lambs are concealed by the group's averages, while negatively effecting feedlot profitability (De Wet, 2018).

Considering the numerous factors influencing feedlot profitability, it is evident that profit margins in intensive lamb finishing systems are narrow. However, the value of a weaner lamb is significantly lower than that of the market lamb, owing to the smaller carcass not meeting the consumer/market requirements with respect to size and tissue composition. Profitability of a lamb feedlot system is therefore dependent on adding value to the carcasses in the form of tissue growth to obtain a more desirable product (Van der Merwe, 2020), which meets market specifications with a higher economic value.

4.2.7. Carcass Classification

In South Africa, since 1992, red meat carcasses (beef, lamb and mutton) have been described using a classification system, prior to this (1944 – 1992), a carcass grading system was employed (Webb, 2015). The classification and marking of meat intended for sale in South Africa is regulated by the Agricultural product standards act, 1990 (act no. 119 of 1990) (Samic, 2021). The classification system is based on physical and compositional attributes (Webb, 2015) comprising age of the animal (A, AB, B, C), carcass fat content (1-6) based on subcutaneous back fat thickness, carcass conformation (1-5) and damage (1-3) (Oosthuizen, 2016). There are numerous factors both extrinsic and intrinsic which affect carcass and meat quality, and this forms the basis of the carcass classification in South Africa, which serves to classify carcasses to ensure more consistent meat quality, composition, and consumer satisfaction (Webb, 2015).

The value of the carcass is dependent on its weight and class, with the highest price per kilogram normally being achieved for carcasses classified as A2/3 (RPO, 2021). These carcasses are considered most desirable, being tender and fat score of 2 or 3 representing a lean-to-medium fat content which meets the consumer demands for lean lamb meat while still having sufficient fat to provide desired eating quality attributes (Van der Merwe, 2020; SAMIC, 2021). Age and fat content have the biggest influence on the carcass price and therefore the greatest influence on feedlot profitability (Langemeier *et al.,* 1992; Amer *et al.,* 1994; Williams and Bennett, 1995). Meeting the markets specifications of optimal weight and fat cover for lamb carcasses is critical for producers in achieving maximum revenue and increasing profitability of feedlot systems. According to the RPO slaughter statistics, the majority (70%) of lambs slaughtered in South Africa are classified as A2 and therefore meet market specifications, allowing producers to benefit from the higher market value (Van der Merwe, 2020).

4.2.8. Objectives

The study seeks to determine whether the effect of treatment (diet) and sex yields a difference in carcass data and the revenue achieved for feedlot fed Dorper lambs, while evaluating typical profitability parameters by assessing:

- Will Dorper feedlot lambs achieve the desired classification (A2), and sufficient carcass weight fed a standard feedlot diet?
- By decreasing the dietary energy (starch) content, what is the effect the economy of fattening Dorper's?
- Will increasing dietary crude protein content increase carcass weights and improve the economy of fattening Dorper's?
- By increasing dietary protein levels and reducing dietary starch levels, what is the effect on the economy of fattening Dorper's?
- Will substituting (approximately 50%) of the dietary starch for rumen protected fat effective in yielding heavier, A2 carcasses and thus economical in the fattening of Dorper's?
- Will substituting (approximately 50%) of the dietary starch for fat and increasing dietary protein levels be effective improving the economy of fattening Dorper's?
- Will the inclusion of a beta-agonist to the standard feedlot diet yield the heaviest carcasses with desired classification and therefore result in the best margins.
- Considering all the above objectives, was there a difference between sexes (male and female) in economy of feedlot finishing Dorper's.
- The overall objective of this two-part study was to determine the most desirable nutritional composition of a diet to fatten Dorper's efficiently and sustainably (acceptable to the consumer) in a feedlot.

4.3. Materials and methods

Ethical clearance for this study was obtained from Stellenbosch University Research Ethics Committee: Animal Care and Use (Ref: ACU-2018-7938). Trial animals were subject to the same conditions as described in Section 3.1.1.

4.3.1. Overview Part 1: Trial / Feedlot production

Upon arrival the lambs received both an electronic RFID tag (EID) and visual tag (VID) and were weighed, corresponded to the lambs' start weight (average start weight was 26.9kg). The eighty-four Dorper lambs were randomly allocated to the seven treatment groups, comprising 12 animals each- 6 ram and 6 ewe lambs, yielding a 2 x 7 experimental design with treatment and sex as the main effects.

All lambs were adapted, fed and weighed as previously described in Section 3.3.1.

4.3.2. Overview Part 2: Slaughter

After the 32-day trial period, the lambs were transported to a commercial abattoir, where they were kept in lairage for approximately 20 hours, allowing them sufficient rest time. At slaughter, lambs were rendered unconscious by electrical stunning (200 V for 4 seconds) and slaughtered using standard South African techniques as described by Cloete (2007). Following stunning the lambs were immediately exsanguinated and the carcasses were suspended to assist with rapid bleeding out. The slaughter line comprised a moving rail, no electrical stimulation was applied to the carcasses. After bleeding out, the skin was mechanically removed followed by the remaining offal components (head, trotters, testes, gastrointestinal tract, red offal as well as abdominal fat) then being removed in sequence. While still on the slighter line, the warm carcass, containing kidneys and kidney fat, were visually inspected, and classed by an independent trained and experienced red meat carcass classifier. Carcass classification was performed according to the description of (Government Notice No. R. 863, 2006) (Van der Merwe, 2020). Thereafter, while still on the slaughter line, the carcass was automatically weighed (warm weight) and the cold weight was extrapolated as the warm carcass weight less 3% (Anonymous, 2003; Schweihofer, 2011). At this point, the carcass weights (warm and cold) and class were recorded through automatic generation of individual tags fixed to each carcass. Thereafter carcasses were chilled at 3°C for 24 hours.

4.3.3. Overview Part 3: Profitability

Various parameters were considered when determining the revenue generated and the margins achieved on an individual basis. Factors influencing the lamb purchase price factors include the store lamb price (at the time of purchase, week of 16 November 2020) and the start weight of the lambs. Total feed costs considered the specific cost of each of the seven different diets and the total intake (cDMI) throughout the 32-day trial period. Animal growth parameters, average daily gain (ADG) and feed conversion ratio (FCR) which are known to influence profitability were also considered. Carcass characteristics: (warm and cold) carcass weights, classification, as well as carcass prices at the time of slaughter (week of the 7 January 2021) were used to determine the overall revenue achieved on an individual animal basis. The economic evaluation was done to the point of margin above specified cost, with current market prices being used for the calculation.

Table 4.1 summarises the costs each of the treatment diets (R/ton) as formulated and indicated in Table 3.1

Table 4.1 The price (R/ton) of each of the seven treatment diets.

Item	Treatment						
	1	**2**	**3**	**4**	**5**	**6**	**7**
Cost (R/ton)	3285	2891	3905	3644	3827	4613	4009

4.3.4. Statistical analysis

Version 14 of Statistica (TIBCO Software Inc., 2020; Data Science Workbench, http://tibco.com) was used to analyse the recorded data and generate the statistical analysis.

The data set was first tested for normality and homogeneity after which appropriate multiple analysis of variance (ANOVA) were performed. Relationships between continuous response variables (the various recorded parameters) and nominal input variables (the different treatments (1 – 7) and sexes (rams, ewes)) as well as the interactions between the two main effects (treatment and sex) were analysed by means of a two-way ANOVA.

Fisher's LSD (Least Significant Difference), as an appropriate multiple comparison of LS Means were done as the post hoc test to determine where significant differences occurred. The Bonferroni multiple comparison test was used to interpret which interaction means were significantly different. Significance was declared at 5% ($P \leq 0.05$) and tendencies at ($P \leq 0.10$).

4.4. Results and discussion

Interactions and tendencies of interactions between the main effects of treatment and sex were observed for parameters of the revenue data. For these the interaction mean differences will be describe apart while the two main effects will be interpreted separately.

4.4.1. Weight data

Considering diet treatment as a main effect, Table 4.12 shows differences between the parameters of the final live weight (kg), the warm carcass weight (WCW) (kg) and the cold carcass weight (CCW) (kg) across the seven treatment groups. However, when considering the effect of sex, no significant differences across these measured parameters were observed (Table 4.2).

Table 4.2 compares the animals final liveweight along with both warm and cold carcass weights. Treatments were similar in final weight apart from Treatment 4, which yielded a significantly higher (P < 0.01) final weight (43.5kg), while the overall average final weight across the seven treatments was 38.6kg. This agrees with Van der Merwe (2020) who suggested, when considering back-fat depth, that the ideal slaughter weight for Dorper's was 38 kg. An important consideration is that these final weights, like all the weight recordings throughout the trial phase, were performed on a 'full-gut' basis and therefore are not a true representation of the actual liveweight at slaughter, which are likely to have been notably lower. This owing to the losses associated with transportation and the gut emptying during the period the lambs stood in lairage prior to slaughter.

Table 4.2. Means and standard error of the means for the weight data; lamb final liveweight (kg), warm carcass weight (kg) and the cold carcass weight (kg) following the trial period across the seven treatment groups.

Item	Treatment[#]							SEM	P-value
	1	2	3	4	5	6	7		
Final (kg)	38.72	37.04	39.29	43.5^{a}	36.79	37.54	37.5	1.20	< 0.01
WCW[1] (kg)	18.60^{b}	16.83^{c}	18.17^{bc}	20.38^{a}	17.02^{bc}	17.85^{bc}	18.37^{bc}	0.60	< 0.01
CCW[2] (kg)	18.04	16.32	17.61	19.78^{a}	16.51	17.32	17.82	0.59	< 0.01

[abc] Means within rows with different superscripts differ significantly (P < 0.05)
[#] 1: control – standard feedlot ration; 2: low-energy; 3: high-protein; 4: high-protein, low-energy; 5: high-fat, low-starch; 6: high-fat, low-starch, high-protein; 7: control + β agonist.
[1] Warm carcass weight
[2] Cold carcass weight

The warm carcass weights followed a similar pattern to the animals' final live weight, Treatment 4, which yielded a significantly ($P < 0.05$) heavier warm carcass (20.38 kg), while the overall average weight of the warm carcasses across the seven treatments was 18.17 kg. The lowest was recorded for Treatment 2 (16.83kg) which differed ($P < 0.05$) from Treatment 1, however Treatments 3, 5 ,6 and 7 were similar to both Treatments 1 and 2.

The parameter cold carcass weights yielded the same pattern as the lamb's final weight. All treatments were similar in their cold carcass weights apart from Treatment 4, which yielded a significantly ($P < 0.05$) heavier cold carcass (19.78 kg), while the overall average across the groups were 17.60 kg. The similar patterns between final live weight and carcass weights were expected. Zonabend König *et al.* (2017), suggests that live weight is the best measure in predicting carcass weight and this agrees with Van der Merwe (2020), who states that the cold carcass weights followed similar trends to that of slaughter weight. The literature cited typically reports cold carcass weights rather than the warm carcass weights and findings from this study differ marginally from those reported. Van der Merwe (2020) and Van der Merwe *et al.* (2020) found that the optimal slaughter weight (final weight) for Dorper lambs was 37.9 kg, with a corresponding cold carcass weight of 18.9 kg, which is higher than the average of the present study. The optimal Dorper slaughter weights as suggested by Brand *et al.* (2018) of 36kg yielded a cold carcass weight of 17.2 kg, which agrees with the carcass weights of A2 Dorper lambs reported by Strydom *et al*. (2009), while the 43kg suggested by Brand *et al.* (2017), corresponded to a carcass weight of 21.5 kg. While the final slaughter weights of the latter closely represent those of Treatment 4 lambs, the average cold carcass weights of this group (19.78 kg) were notably lower and could be explained by the full-gut weighing in the current study.

Dorper's are regarded as an early-maturing sheep breed and thus tend to deposit fat at an early age, therefore they tend to be slaughtered at lower live weights when compared to later maturing breeds (Brand *et al*., 2018). According to Cloete *et al.* (2000) Dorper lambs are also known to reached slaughter weight earlier than woollen breeds. This risk of dorper's depositing excessive fat is especially true under intensive/favourable environmental conditions, where Dorper lambs are often slaughtered at low live weights (32-35 kg) to avoid their carcasses being classified as over fat (Truter, 2017). As noted by Cloete *et al.* (2000), earlier studies on Dorper's show that slaughter weights were typically at 30-33 kg liveweight (Basson *et al.,* 1970; Terblanche *et al.,* 1973*;* as referenced by Cloete *et al.,* 2000 & Terblanche, 2013), In more recent studies, Dorper lambs were however slaughtered closer to 40 kg (Snyman *et al.,* 1996). Cloete *et al.* (2000) ascribes this trend to selection pressures within the breed towards increased growth performance and against fat localisation.

Table 4.3 shows that no differences in any of the weight data parameters measured between the sexes could be established despite the rams being on average numerically slightly heavier than ewes for the three parameters. While Van der Merwe (2020) agrees with this trend, the differences between the sexes was greater, with ram carcasses on average 7% heavier than that of ewe lambs, compared to the 0.7% difference in cold carcass weights between the sexes seen in in the current study (Table 4.3).

Table 4.3. Means and standard error of the means of the weight data; lamb final liveweight (kg), warm carcass weight (kg) and cold carcass weight (kg) between sexes.

Item	Sex		SEM	P - value
	Ram	Ewe		
Final weight (kg)	39.01	38.26	0.64	0.41
WCW[1] (kg)	18.21	18.16	0.32	0.87
CCW[2] (kg)	17.66	17.63	0.32	0.77

[1] Warm carcass weight
[2] Cold carcass weight

The significant differences reported for the final weights and cold carcass weights (Table 4.2) across the treatment groups can be attributed to significant differences in DMI (Table 3.2) and ADG (Table 3.8) discussed in Chapter 3. Considering the raw data generated from the study, Treatment 4 yielded the heaviest ($P < 0.05$) final weights and carcass weights, corresponding to the highest average for both sexes. Opposing this is the relatively low final weights recorded for Treatment 7, accompanied by relatively high carcass weights for both sexes when compared to Treatments 1, 2, 3, 5 and 6. After Treatment 4 ewes, Treatment 7 ewes had the highest cold carcass weight, averaging 18.5 kg. Although studies by Strydom *et al.* (2009); Van der Merwe (2020) and Van der Merwe *et al.* (2020) were performed on rams and ewes, they did not specify the carcass weights between the sexes, with the values reported being an average of the sexes.

Much of the literature cited refers to fat deposition in reference to carcass weight. Although the carcass classification was recorded for all animals within the current study, it was not statistically analysed and for that reason, little reference is made to either the animal's class or the level of fat deposition. Van der Merwe (2020) describes ewe lambs being slaughtered at lighter body weights than ram lambs (thus lighter carcass weights) due to ewes maturing earlier than rams and therefore depositing fat at a lower live weight than rams (Owens *et al.*, 1993).

Findings from the current study agree with Van der Merwe (2020), who noted that significant differences in carcass weight, still resulted in the carcasses classified as the same class and therefore implying a relatively similar fat coverage between animals.

4.4.2. Slaughter data

Tables 4.4 and 4.5 shows the slaughter data with the slaughter percentage on both the warm and cold carcass and the difference between these two considering treatment and sex as main effects respectively. While the effect of treatment yielded significant (P < 0.05) differences for the first two parameters, the effect of sex resulted in a tendency (P = 0.06) for difference for slaughter % of the warm carcass (Table 4.5). Table 4.6 shows a tendency of interaction (P < 0.10) between the main effects of treatment and sex for the parameters of the slaughter % of both the warm and cold carcasses.

Table 4.4. Means and standard error of the means for the slaughter data; the slaughter percentage of both the warm and cold carcass and the difference (%) between the two across the seven treatment groups.

Item	Treatment#							SEM	P-value
	1	2	3	4	5	6	7		
% warm	48.97^{ab}	45.47^{d}	46.20^{cd}	46.80^{bcd}	46.23^{cd}	47.53^{bc}	49.05^{a}	0.52	< 0.01
% cold	47.45^{b}	44.09^{c}	44.77^{bc}	45.42^{bc}	44.84^{bc}	46.11^{b}	47.57^{a}	0.50	< 0.01
% diff	3.13^{b}	3.02^{b}	3.08^{b}	2.95^{b}	2.99^{b}	2.99^{b}	2.99^{b}	0.26	0.17

[abcd] Means within rows with different superscripts differ significantly (P < 0.05)
[#] 1: control – standard feedlot ration; 2: low-energy; 3: high-protein; 4: high-protein, low-energy; 5: high-fat, low-starch; 6: high-fat, low-starch, high-protein; 7: control + β agonist

The slaughter percentage also known as dressing percentage or carcass yield is defined as ratio of carcass weight to the live weight of the animal, expressed as a percentage and calculated as (carcass weight/live weight) x 100 (Boler, 2014). Since dressing percentage is a function of live weight and carcass weight and many factors influence these, such as digestive tract size and fill, slaughtering procedures, fleece/skin weight, distribution of body fat and secondary sex characteristics influence these, it is important that dressing percentage is interpreted correctly, with care taken when comparisons are made (Casey *et al.* 2003). The conditions of full gut/digestive tract, under which the final liveweights were recorded will therefore negatively influence this slaughter percentage data.

Considering slaughter percentage of the warm carcass relative to the lamb's final weight, Table 4.4 shows no significant difference between Treatments 1, 4, 6 and 7, however the latter was similar only to Treatment 1. Treatments 2, 3, 4 and 5 were also similar. Treatment 7 yielded the highest numeric (49.05%) average slaughter percentage/most favorable dressing percentage, while Treatment 2 yielded the lowest (44.09%), with an average of 47.04% recorded across the seven treatments (Table 4.4).

A similar trend was found when considering the slaughter percentage of the cold carcass relative to the lamb's final weight. This finding was expected given that the cold carcass weight was extrapolated from the warm carcass weight less 3%. Treatments 1, 3, 4, 5 and 6 were similar and Treatments 2, 3, 4 and 5 did not differ. Treatment 7 however yield a significantly ($P < 0.05$) higher (47.57%) slaughter percentage of the cold carcass relative to the lamb's final weight compared to the other groups, an average of 45.54% was recorded across the seven treatments. This average is significantly lower than studies by Brand *et al.* (2017) and Van der Merwe (2020), who's Dorper lambs yielded slaughter percentages based on cold carcass weights of 49.9% and 49.7% respectively. Possible explanations include the significantly heavier final weights (43.5 kg), accompanied by the long time spent on feed (105 days) and the heavier cold carcasses weights (18.2 kg) for these studies respectively. The result of Treatment 7 yielding the highest slaughter percentage (cold carcass) disagrees with Du Toit (2017), who found no significant differences in dressing % when comparing different inclusion levels of R-salbutamol, a β adrenergic receptor. In contrast to Du Toit (2017) and in agreement to the current study Mantiziba, (2014) reported that the supplementation of Zilpaterol hydrochloride (β agonist), while having no effect on carcass weight, it significantly ($P < 0.05$) increased the dressing percentage in feedlot finished steers. Davila-Ramirez *et al.* (2014) and Davila-Ramirez *et al.* (2015) also reported increased hot and cold carcass weights and dressing percentage following supplementation with Zilpaterol hydrochloride.

Cloete *et al.* (2000) reported that the dressing percentages of Dorper lambs were relatively constant (approximately 50%) for a wide range of environmental conditions. Although differences were recorded, a similar trend of relatively stable dressing percentages (average 45.54%) were observed across the seven significantly varying treatment diets of the current study. Van Niekerk and Steenkamp (1995) reported an increase in dressing percentage with the lamb's slaughter weight, with approx. 40% at 25 kg liveweight, compared to approx. 50% at 40 kg liveweight. It can be extrapolated that an average increase in dressing percentage would have been observed with an increase in the lamb's final weight. This agrees with Brand *et al*. (2018), who stated that the dressing percentage of a carcass increases with the level of subcutaneous fat cover, thus lambs with a greater distribution of subcutaneous fat will present a higher carcass yield. The latter authors also noted that Dorper lambs tend to have higher dressing percentages than woollen breeds in comparative studies. This was confirmed by Van der Merwe (2020) who stated that the highest dressing percentage was obtained by the Dorper breed (49.9%) in the study of seven different South African sheep breed types.

No differences in the slaughter percentage between the warm and cold carcasses across the treatments, once again was expected, given that the cold carcass weight was an extrapolation.

Table 4.5. Means and standard error of the means of the slaughter percentage of both the warm and cold carcass and the difference (%) between the sexes.

Item	**Sex**		**SEM**	**P - value**
	Ram	**Ewe**		
Slaughter % (warm)	46.66	47.42	0.28	0.06
Slaughter % (cold)	45.25	45.83	0.27	0.13
% Difference	3.02	3.13	0.14	0.11

Table 4.5 shows that there was a tendency (P = 0.06) for difference in slaughter percentage of the warm carcass between the sexes, with ewes averaging a higher slaughter percentage. Furthermore, ewes averaged numerically higher slaughter % (cold carcass) and a higher difference in slaughter % (warm vs. cold) than then rams. The finding that ewes had a higher dressing % was expected, as this is a common trend throughout much of the literature cited (Davila-Ramirez *et al.,* 2014; Davila-Ramirez *et al.,* 2015; Du Toit, 2017; Van der Merwe, 2020; Van der Merwe, *et al.,* 2020). Van der Merwe, 2020 reported that the dressing percentage of ewe lambs was significantly higher (P < 0.001) than that of ram lambs (49.1% *vs.* 47.2%), respectively. The reasoning for this trend is the heavier developed sexual organs and thicker skins of mature male animals negatively effects dressing percentage (Lee, 1986; Du Toit, 2017 &) Cloete *et al.* (2000) explains that the weight of testes from rams contribute to

the offal component and not the carcass, therefore lowering dressing percentage of rams compared to ewes. Furthermore, as mentioned by Brand *et al*. (2018), the dressing percentage of carcasses increases with the level of subcutaneous fat, similarly to early maturing breeds being slaughtered at lower live weights, ewe lambs are typically slaughtered at lighter body weights than ram lambs, due to them maturing earlier than rams, thus depositing fat at a lower body weight (Owens *et al*., 1993). The relatively higher level of subcutaneous fat in ewes compared to rams further explains the higher dressing percentage recorded for ewes in the current study.

The forementioned tendency for difference (Table 4.5) is responsible for the tendency of interaction ($P < 0.1$) between the main effects of treatment and sex for the slaughter % of the warm carcasses, similarly, is the link between the warm and cold carcass weights. For the slaughter percentage (warm and cold carcasses) parameters, the interaction was owing to the superior performance of Treatment 7 lambs, specifically the ewe lambs within this group. The warm slaughter percentage was significantly highest for the ewes averaging 50.86%, compared to 47.24% for rams, while the ewe lambs of Treatment 2 yielded the lowest numeric slaughter percentages.

Table 4.6. The interaction of the main effects of treatment and sex on the slaughter data, the slaughter percentage of both the warm and cold carcass and the difference (%) between these two.

Item	Treatment														SEM	P
	1		2		3		4		5		6		7			
	R	E	R	E	R	E	R	E	R	E	R	E	R	E		
% warm	47.44^{bcd}	48.56^{b}	45.98^{cde}	44.95^{e}	45.50^{de}	46.89^{bcde}	46.87^{bcde}	46.74^{bcde}	45.92^{cde}	46.53^{bcde}	47.68^{bc}	47.39^{bcd}	47.24^{bcd}	50.86^{a}	0.73	0.06
% cold	46.01^{bc}	45.91^{bc}	44.60^{bcd}	43.59^{d}	44.07^{cd}	45.47^{bcd}	45.50^{bcd}	45.34^{bcd}	44.50^{bcd}	45.18^{bcd}	46.25^{b}	45.97^{bc}	45.82^{bc}	49.34^{a}	0.71	0.05
% Diff	3.00	3.13	3.02	3.03	3.13	3.03	2.91	2.98	3.10	2.89	2.99	2.99	3.01	2.98	0.37	0.20

^{abcde} Means within rows with different superscripts differ significantly ($P < 0.05$)

$^{\#}$ 1: control – standard feedlot ration; 2: low-energy; 3: high-protein; 4: high-protein, low-energy; 5: high-fat, low-starch; 6: high-fat, low-starch, high-protein; 7: control + β agonist.

4.4.3. Cost data

The two most significant input costs in feedlot systems include the lamb purchase price and the cost of feed (Van der Merwe, 2020) as these two parameters represent the specified costs when determining the overall cost of fattening the lambs. The purchase price is a function of the lamb start weight and the store lamb price at the time of purchase (R41.82/kg; November 2020), while feed costs were determined on a dry matter (DM) basis considering the total feed (DM) consumed, a function of cumulative intake (cDMI), and the costs of the different diets of the various treatments (Table 4.1). Tables 4.7 and 4.8 show the cost data with parameters of purchase price and feed costs considering treatment and sex as main effects respectively. While the effect of treatment yielded significant differences in feed costs ($P < 0.01$), the effect of sex yielded no differences.

Table 4.7. Means of the lamb purchase price and total feed costs per lamb on DM-basis associated with the trail period, across the treatment groups.

Item	Treatment[#]							SEM	P-value
	1	2	3	4	5	6	7		
Purchase (R)	1114^{ab}	1091^{b}	1109^{ab}	1210^{a}	1082^{b}	1110^{ab}	1170^{ab}	37.79	0.2
Feed (R)	184.49^{c}	237.76^{b}	296.95^{a}	269.67^{ab}	291.26^{a}	286.76^{a}	194.17^{c}	13.64	< 0.01

[abc] Means within rows with different superscripts differ significantly ($P < 0.05$)
[#] 1: control – standard feedlot ration; 2: low-energy; 3: high-protein; 4: high-protein, low-energy; 5: high-fat, low-starch; 6: high-fat, low-starch, high-protein; 7: control + β agonist.

Table 4.7 shows that purchase price did not differ) across the treatments, this was expected owing to the fixed store lamb price, together with lambs being randomly allocated to the groups. However, there were some differences across the treatments, owing to the relatively high start weight of Treatment 4 lambs, thus yielding the highest numeric purchase price, which differed ($P < 0.05$) from Treatments 2 and 5, owing to these groups relatively lower start weights.

As expected, the parameter of average feed cost yielded a different pattern, due to the varying costs of the different diets and well as the varying intakes across the treatment groups. Treatment 3, with numerically the highest feed cost, was similar to Treatments 4, 5 and 6, while Treatment 2 and 4 did not differ and Treatments 1 and 7 resulted in similar feed costs respectively. The high average feed cost (R297/lamb) of Treatment 3 was due to the relatively high cDMI and diet cost relative to the control. The average feed cost per lamb across the groups was R251.58, while the high costs associated with Treatment 5 and 6 were because of the relatively high DMI together with a high diet cost (Treatment 5) and a significantly ($P < 0.05$) elevated diet cost, despite the relatively lower cDMI, of Treatment 6 respectively (Table 4.1). Despite the elevated intakes recorded for Treatment 2, the low diet cost resulted in this group having a lower-than-average feed cost. The relatively low feed costs of Treatment 1 and 7 were associated with the low cDMI recorded for these groups.

Table 4.8. Means of the lamb purchase price (R) and total feed costs on DM-basis (R) associated with the trail period, between the sexes.

Item	Sex		SEM	P - value
	Ram	Ewe		
Purchase price (R)	1118	1135	20.20	0.55
Feed costs (R)	259.03	244.13	7.29	0.15

Table 4.8 shows that no differences were recorded for the cost parameters between rams and ewes. Although the marginally higher purchase price of the ewe lambs is due to the ewes on average numerically having a slightly higher start weight compared to the rams (27.13 kg vs. 26.73 kg) respectively. While the marginally higher feed costs associated with the rams is owing to their higher average cDMI than the ewes (62.80 kg vs. 59.45 kg) respectively (Chapter 3). This finding of rams consuming more than ewes and therefore being associated with higher feed costs is well documented (Miranda de Vargas *et al.,* 2014; Du Toit, 2017; Van der Merwe, 2020).

4.4.4. Revenue data

The two factors influencing the carcass value is the is the meat/carcass price (R/kg), which is a function of the classification of the carcass, together with the weight of the cold carcass (Van der Merwe, 2020). These two factors, the carcass price (R/kg) allocated to the specific carcass at the time of slaughter (December 2020) and the cold carcass weight were considered when determining the revenue achieved (R/head). Other parameters known to influence profit margins are the income over specified costs (R/head) and (R/kg) and were included in the revenue data.

Tables 4.9 and 4.10 shows the revenue data with parameters meat/carcass price (R/kg), the value of the carcass (R/head), the margin over specified costs (R/head) and margin over specified costs (R/kg) considering treatment and sex as main effects respectively. While the effect of treatment yielded significant ($P < 0.05$) differences in carcass price (R/head) and the margin parameters (R/head) and (R/kg), the effect of sex yielded a tendency ($P < 0.10$) to differ for carcass price (R/kg). However, Table 4.11 shows a tendency ($P < 0.10$) of interaction between the main effects of treatment and sex for the margin over specified costs (R/head) and a significant interaction ($P < 0.05$) for margin over specified cost (R/kg) was detected.

Table 4.9. Means of the meat/carcass price (R/kg), the carcass value (R/head), the margin over specified costs (R/head) and margin over margin over specified (R/kg) across the treatment groups.

Item	Treatment#							SEM	P-value
	1	2	3	4	5	6	7		
Carcass (R/kg)	84.00	84.00	83.67	83.67	84.00	83.67	84.00	0.22	0.68
Carcass (R/h)	1496^{b}	1371^{b}	1472^{b}	1654^{a}	1387^{b}	1450^{b}	1497^{b}	48.35	< 0.01
Margin (R/h)	197.90^{a}	41.78^{c}	66.75^{bc}	174.74^{a}	13.08^{c}	53.47^{bc}	132.94^{ab}	29.34	< 0.01
Margin (R/kg)	11.13^{a}	2.42^{cd}	3.69^{cd}	8.83^{ab}	0.73^{d}	2.57^{cd}	6.62^{bc}	1.59	< 0.01

^{abcd} Means within rows with different superscripts differ significantly ($P < 0.05$)
1: control – standard feedlot ration; 2: low-energy; 3: high-protein; 4: high-protein, low-energy; 5: high-fat, low-starch; 6: high-fat, low-starch, high-protein; 7: control + β agonist.

Table 4.9 shows that carcass price (R/kg) did not differ across the treatments. This was expected owing to the fixed meat/carcass prices for the different carcass classifications (Appendix 2). However, when considering the carcass value (R/head), Treatment 4 resulted in the highest ($P < 0.01$) revenue being achieved. This finding was expected due to the significantly higher cold carcass weights of this group (Table 4.2). Similarly, the lowest numeric carcass value for Treatment 2 was associated with the lowest numeric cold carcass weight of this group.

Although the carcass classification was recorded for all animals within the study, it was not statistically analysed and therefore the carcass price (R/kg) was an indication of the carcass classifications. The relatively small differences in meat/carcass price (R/kg) between classifications, implies that the cold carcass weight has a greater influence on the overall carcass value (R/head). This finding of relatively small differences in meat/carcass price (R/kg), agrees with Van der Merwe, (2020), who noted that significant differences in carcass weight, still resulted in the carcasses classified as the same grade and therefore implying a relatively similar fat coverage between them.

For the current study, the two specified costs were the feed costs and the purchase price of the lambs. When evaluating profit margins, it is important that the costs be included in the conclusions, therefore, the margin over specified cost (R/head) is an important parameter to consider when evaluating margins. Given that the cost of feed differed significantly ($P < 0.05$) across the treatment groups (Table 4.7), it was expected that the margin over the specified costs would also be significantly influenced across the treatments. The low feed cost of Treatment 1 was responsible for this groups having the highest numeric margin over specified feed cost (R/head), which was similar to Treatments 4 and 7, owing to the elevated cold carcass weights and the relatively low feed intake and associated feed costs of these groups respectively. The latter also did not differ significantly from Treatments 3 and 6 because of their higher feed costs compared to the control, owing to their high intake and higher dietary unit cost respectively. Furthermore, Treatments 2 and 5 also did not differ significantly from Treatments 3 and 6. The lowest average margin over specified costs (R13.8/head) recorded for Treatment 5 was due to the relatively high feed cost and low carcass weights recorded for this group (Table 4.2).

When considering the raw data, it is clear that significant variation exists on both an individual basis and within the treatment groups and this variation effects the margin parameters (R/head) and (R/kg). The wide variation is important as it was noted that several animals yielded negative margins over the specified costs, these animals have a negative influence on both the groups margins and the overall profitability. Treatment 1 and 4, the groups which yielded the two highest margins over specified feed cost (R/head), were the only two Treatments in the study where no individuals within the group resulted in a negative margin, thus implying that each animal within these two groups resulted in a positive profit margin. Individual animal performance can severely influence the profitability of a finishing system (Jolly & Wallace, 2007) and when lambs are considered as groups rather than individuals, many high (and poor) performing lambs are hidden in the averages.

The parameter margin over specified costs (R/kg), was similar to margin over specified costs (R/head) however, it is expressed as a value per kg and calculated by the margin over specified costs (R/head) / cold carcass weight (kg), allowing for easier comparison of profit margins per unit (kg) (Hoffmann, 2021). Table 4.9 shows that this parameter closely follows the pattern of the margin over specified feed cost (R/head), which was expected owing to the latter being a function of the margin over specified costs (R/kg). Again, Treatment 1 resulted in the highest numeric margin over specified costs (R/kg), which was similar to Treatment 4, owing to this groups elevated cold carcass weights and Treatment 7, owing to the relatively low feed intake and associated feed cost of this group. Furthermore Treatments 2, 3, 6 and 7 were also similar. The lowest average margin over specified costs (R0.73/kg) recorded for Treatment 5 was due to this group having the lowest margin over specified feed cost (R/head), owing to the high associated feed cost and low carcass weight recorded for this group which also did not differ from Treatments 2, 3 and 6.

Table 4.10. Means of the revenue data; the meat/carcass price (R/kg) and margins over specified cost (R/head) and margins over specified cost (R/kg) between the sexes.

Item	Sex		SEM	P - value
	Ram	Ewe		
Carcass (R/kg)	84.00	83.71	0.117	0.09
Carcass (R/head)	1483	1467	25.843	0.66
Margin (R/Head)	106.41	88.06	15.683	0.41
Margin (R/kg)	5.66	4.62	0.850	0.39

Table 4.10 shows a tendency for difference (P = 0.09) was recorded for the parameter of carcass price (R/kg) between rams and ewes, with rams on averaging yielding carcasses with a higher meat price (R/kg) than the ewes, this owing minor difference in carcass classifications between the sexes, with some ewe lambs receiving lower meat/carcass price (R/kg) due to them being classified as overfat. .Although the carcass classification was recorded for all animals within the study, it was not statistically analysed and for that reason, little reference is made to either the animal's class or the level of fat deposition.

No significant differences were recorded for all other revenue parameters (Table 4.10). The numerically higher carcass value (R/head) achieved for ram lambs is due to the rams on average having a slightly higher cold carcass weights than the ewes (17.66 kg vs. 17.53 kg) together with their tendency for a higher meat price (R/kg) respectively. The margins over specified costs both (R/head) and (R/kg) were also numerically higher for the rams compared to the ewes, despite the marginally higher feed costs associated with the rams (R259.03 vs. R244.13), owing to their higher average cDMI than the ewes respectively. The marginally lower average purchase price for rams compared to the ewes (R1118 vs. R1135) also contributed to the better returns on the ram lambs. Despite the rams averaging higher carcass value than the ewes, Treatment groups 1, 2, 5 and 7 resulted in ewes on average having a higher carcass value than the rams, the largest difference was Treatment 7, where the ewes yielded carcasses with notably higher values than the rams (R1554.00/head vs. R1439.20/head) respectively. Treatment 4 yielded the largest difference in the carcass value between the sexes, it also had the highest average carcass value (Table 4.9) with rams and ewes averaging (R1726.20/head vs. R1581.80/head) respectively.

The margin parameters both (R/head) and (R/kg), yielded significant variation, the average margins were influenced by the wide variation within the group, with many animals yielding negative margins over the specified costs of purchase price and feed costs. These animals have a negative influence on the group's margins and the overall profitability. Although no differences between the sexes were recorded for the margin (R/head), rams were on average numerically higher than the ewes. Raw data from the study showed that this margin parameter (R/head) yielded a similar pattern to that of the carcass value (R/head), with Treatments 1, 2 and 7 resulted in ewes on average having a higher margin (R/head) than the rams. Also, the largest difference was recorded for Treatment 7, where the ewes yielded a noticeably higher margin than the rams (R185.44/head vs. R80.43/head) respectively. The next most significant ($P < 0.05$) difference in margin (R/head) between the sexes was Treatment 5 with rams and ewes averaging (R62.81/head vs. R-36.64/head) respectively. The negative average margin (R/head) for Treatment 5 ewes is responsible for this group having the lowest average margin (Table 4.9).

Margins (R/kg) and (R/head) over the specified costs, it followed a similar pattern, this is expected given that the margin (R/head) is a function of the margin (R/kg). Similarly, this margin parameter (R/kg) did not result in a significant difference between the sexes, however the margin on the rams were on average numerically higher than the ewes. Again, the raw data shows that the margin (R/kg) of Treatments 1, 2 and 7 ewes were on average higher than that of the rams. The most noticeable difference between the two margin parameters, was the negative margin (R-0.36/kg) for the ewe lambs of Treatment 6.

Although Table 4.10 shows no significant differences in the revenue data involving the margins above specified costs (R/head) and (R/kg), when considering sex as the main effect, Table 4.11 shows a tendency ($P = 0.06$) of interaction ($P = 0.06$) between the main effects of treatment and sex for the margins above specified costs (R/head) and a significant interaction ($P = 0.04$) for the margins above specified costs (R/kg) between the main effects was detected

These interactions between the main effects Treatment and Sex were owing to significant differences across the treatments and differences between sexes for some treatments of the forementioned margin parameters. The poor performance of Treatment 5 lambs, specifically the ewe lambs, with their negative average margins (R/head) and (R/kg) owing to their relatively high feed cost and low cold carcass weight, were primary contributors to these interactions. Furthermore, the notable differences ($P < 0.05$) in margins between

Treatments 2, 3, 6 and 7 and the differences between the sexes of these groups also contributed to the interactions recorded between the main effects. Treatment 2 and 7 ewes yielded better margins than the rams, with Treatment 7 ewes yielding significantly ($P < 0.05$) higher margins (R185.44/head and R9.71/kg) than the average ewe (R88.06/head and R4.62/kg) respectively and Treatment 3 and 6 rams yielded better margins than the ewes respectively.

Table 4.11. Means of the revenue data, including the margin over specified costs (R/head) and (R/kg), which yielded an interaction between the main effects of treatment and sex.

Item	Treatment														SEM	P
	1		2		3		4		5		6		7			
	R	E	R	E	R	E	R	E	R	E	R	E	R	E		
M(R/h)	190^{abc}	206^{a}	10^{ef}	74^{cdef}	111^{abcde}	22^{ef}	192^{ab}	157^{abcd}	63^{def}	-37^{f}	98^{abcde}	9^{ef}	80^{bcde}	185^{abc}	41.95	0.09
M(R/kg)	10.77^{a}	11.48^{a}	0.48^{cde}	4.35^{bcd}	6.17^{abc}	1.20^{cde}	9.47^{ab}	8.19^{ab}	3.69^{bcde}	-2.23^{e}	5.51^{abcd}	-0.36^{de}	3.53^{bcde}	9.71^{ab}	2.25	0.04

^{abcde} Means within rows with different superscripts differ significantly ($P < 0.05$)
$^{\#}$ 1: control – standard feedlot ration; 2: low-energy; 3: high-protein; 4: high-protein, low-energy; 5: high-fat, low-starch; 6: high-fat, low-starch, high protein; 7: control + β agonist.

4.4.5. Growth parameters on profitability

When considering the performance data of average daily gain (ADG) and feed conversion ratio (FCR) considering the main effects of treatment and sex, Tables 3.8 and 3.9 are considered respectively.

The largest numeric ADG (456 g/day) of Treatment 4 was accompanied by the highest ($P < 0.01$) final weight and the highest warm and cold carcasses weights (Table 4.2), which yielded the highest revenue being achieved. However, it did not result in the highest margins, this owing to the relatively high feed costs and purchase price of these animals. Opposing this, Treatment 7 yielded the lowest numeric ADG (298 g/day), which was accompanied by the lowest numeric liveweight gain, however the significantly ($P < 0.05$) higher slaughter percentage, meant relatively high carcass weights and thus increased margin. This finding suggests a link between ADG and overall liveweight gain but not necessarily to carcass weight, which is dependent on other factors.

The parameter FCR yielded a different pattern from ADG but was similar to that of margin above specified cost (R/head) (Table 4.9). Treatment 1 had the highest margin (R197.90/head), owing to the relatively low feed costs- low unit cost of the diet and low DMI, and Treatment 5 the lowest (R13.08), due to the high feed cost- high unit cost of the diet and high DMI which did not correspond to high carcass weights, putting the margin under pressure. Similarly, the elevated DMI of Treatment 2 did not yield high carcass weights however, the low unit cost of the diet allowed for numerically higher margins. These findings suggesting the correlation of efficiency of production (FCR) with the margins achieved and highlight the significance of known performance parameters with profitability. This agrees with (Gardner *et al.,* 1996; Terblanche, 2013; Yeaman *et al.,* 2013) who suggest that feedlot performance, such as average daily gain and feed efficiency, are economically important production traits which influence the cost of gain.

4.4.6. Further Considerations

One of the numerous challenges facing feedlot producers and the sheep industry in general, are small and varying profit margins. This owing to the high input and capital costs, placing pressure on the profit margins (%) and therefore risk of low profitability, associated with intensive systems (Jolly & Wallace, 2007). Despite this, there has been a growing trend of intensification of production systems, such as the feedlotting of lambs, to meet the increasing demand for meat and overcoming some of the many forementioned challenges facing farmers (Robinson, 2011).

Profit is the primary factor determining the existence of any enterprise and this is true for the feed lotting of lambs (Gardner *et al.*, 1996). Profit is considered as the difference between the value of the products/services produced on the farm and the costs of resources used in their production (Van Zyl *et al.*, 2013) while profit margin is defined as the amount by which revenue from sales exceeds the costs of the operation and profitability is the farm/operations income/revenue as a percentage of the average total capital used (Van Zyl *et al.*, 2013). Furthermore, the profit can be considered as the 'interest' on the capital invested in the farming enterprise by the producer i.e. return on capital (ROC) (Landman, 2013).

While the current study is very simplistic in the calculation of its profit margins, with only a limited number of factors being considered, nonetheless some basic economic terms can be summarised and defined:

- **Gross production value (GPV)** is defined as the total value of the saleable product within a specific enterprise, for a particular year (Van Zyl *et al.,* 2013). The GPV reflects the income or revenue expected from an enterprise. Considering the current study, only the 32-day feeding period was considered and was not recalculated translated back to annual terms. The GPV or carcass value was calculated as the carcass/meat price (a function of the carcass classification) multiplied by the cold carcass weight. The various diets/treatments affected carcass weight and dressing % and thus directly impacted GPV.
- **Directly allocatable variable cost (DAVC)** refers to the cost of production including the costs related to and impacted by the production activities (DAFF, 2015). The costs of various feeds, the dry matter %, together with intake effected the feed costs as well as the start weight of the lambs, a function of store lamb price all directly impacted the lambs purchase price of the current study.
- **Gross margin (GM)** is defined as the difference between the estimated GPV and the cost of production (DAVC) (Van Reenen & Marais, 1992; DAFF, 2015). Gross margin is enterprise specific and considered as the first profit margin. According to Terblanche (2013), GM is the most well-known method to calculate the profitability of a production system and can be expressed on either a per enterprise, per hectare or per stock unit basis (Morris, 2009).
- **Margin above specified cost** similar to GM but expresses the margin when the specified cost(s) are subtracted (DAFF, 2015). In the current study, the inputs of feed and the lambs purchase price were the specified costs, given the simplicity or the margin calculations, this parameter, margin above specified cost, was chosen for the comparisons between the main effects of treatment and sex both on units of R/head

and R/kg, calculated as the margin divided by the cold carcass weight.. The margin above specified cost is a measure of the enterprise profitability and is commonly used within the agricultural sector (Van Reenen & Marais, 1992; Van Zyl *et al.,* 2013).

Boehlje *et al.* (1985) suggests that when making the decision on what to produce, only the variable cost should be used for the analysis, explaining that allocating total farm cost (which normally includes a large portion of fixed cost) to different enterprises is difficult and mostly impractical (Van Zyl *et al.,* 2013). Furthermore, the allocation of only those costs associated with a particular enterprise, simplifies record keeping reduces the risk of allocating costs inaccurately during the profitability analysis (Morris, 2009; Terblanche, 2013). Farming operations often comprise more than one enterprise, such as cropping and livestock/feedlotting, and the margins (GM or margin above specified cost) represent the financial contribution of an individual enterprise (Terblanche, 2013). By determining the margin of a given enterprise, this assists producers in assessing the economic viability of production system or comparing the viability of alternatives within the system or production between different systems. In the current study, comparisons between margins were made between the main effects of treatment and sex.

Table 4.9 shows that Treatment 4 yielded the highest ($P < 0.01$) gross product value (GPV) with an average revenue of R1654/head, while the lowest GPV was recorded for Treatment 2 with an average of R1371/head. Considering the margin (R/head) above specified cost, the pattern differs, emphasising that revenue alone is not sufficient, and the importance of including costs when determining margins. Treatment 1 yielded the highest margin numerically of R197.90/head, followed by Treatment 4 with R174.74/head, compared to Treatment 5 with the lowest average margin of only R13.08/head (Table 4.9). A similar pattern was observed when considering the margin as R/kg, taking into account the cold carcass weights. The low profit margin for Treatment 5 due to a high average feed cost, together with relative low average cold carcass weight and low associated GPV. Furthermore, the raw data from the study showed a significant ($P < 0.05$) difference in margin (R/head) between the sexes for Treatment 5 with rams and ewes averaging (R62.81/head vs. R-36.64/head) respectively (Table 4.11). While Tables 4.9 and 4.10 show no significant differences between the sexes in both the specified costs and revenue data respectively, Table 4.10 shows that on average rams yielded better returns with higher GPV and improved margins (R/head and R/kg) when compared to the ewe lambs. However, the raw data shows that Treatments 1, 2 and 7 resulted in ewes on average having a higher margin (R/head) compared to the rams, with the latter yielded a noticeably higher margin than the rams (R185.44/head vs. R80.43/head) respectively (Table 4.11).

While the average positive margins from all groups in Table 4.9 and 4.10, show that all seven treatment groups and both sexes can cover their specified costs of production, significant variation amongst these parameters was present both within treatment groups and between the sexes within treatments.

This measurable variation between animals within groups/flocks that forms the basis of the concept of precision agriculture (PA) (McLeod, 2019). Precision agriculture is a broad concept but can be considered as an all-encompassing term used to describe the various techniques, technologies, and management strategies that address on-farm variability (Maré & Maré, 2015), with the aim of providing farmers more control with improved management to make objective management decisions. Bootle (2001) defines PA as the physical and financial management of farming operations in a site-specific manner, which returns more control, repeatability, and certainty to the farming enterprise, resulting in lower costs and less variable and more predictable returns.

Jolly & Wallace (2007) suggest that individual animal performance can severely influence the profitability of a finishing system and therefore consideration should be given to the opportunity cost of not individually identifying and weighing lambs. When lambs are considered as groups rather than individuals, many high (and poor) performing lambs are hidden in the averages. The significance of variation in FCR and the effect on profitability is highlighted by Burns & Calver (2020), who reported that the FCR of feedlot lambs varied from 3 (the best, most efficient growth) to 14 (worst, least efficient), while lambs all gained 15kg (superior ADG), the significant variation in feed intake between lambs meant that the efficient lambs would have favourable returns while the others would only "break-even at best." Performance for both wool and growth parameters, show a significant difference between the most and least 25% efficient animals within the flock, corresponding to a difference in revenue of up to 5 times between these two groups (Precision pays, 2007). Emphasising that this variation lends for notable opportunity within industry for improved productivity and their associated gains. Oosthuizen (2016) highlights the importance of feedlots producing efficiently, in that way remaining sustainable during unfavourable market conditions and times of poor returns.

Although PA allows for greater efficiency and decreased variable costs, with each animal group being more productive, the investment cost of these operations should be considered (Oosthuizen, 2016). Furthermore, suggesting that for PA to be more profitable than conventional farming systems, there needs to be sufficient variation between management groups to justify the increases in investment costs.

4.4.7. Conclusion

The overall objective of this study was to establish whether the effect of diet and sex yields a difference in revenue achieved and the profit margins for the feedlot finished Dorper lambs.

Small and varying profit margins are one of many challenges facing feedlot producers. This owing to the high input and capital costs of intensive systems, placing pressure on the profit margins and therefore risk of low profitability. Despite these risks, there has been a growing trend of intensification within the industry. Feed costs are known to have a significant influence on feedlot profitability while the lamb purchase price is known to be the largest input cost to feedlot producers. For this study, these two parameters (purchase price and feed costs) represented the two specified costs. Gross product value (GPV) or carcass value represented the revenue (income) generated. The forementioned parameters were used in the economic evaluation, to the point of margin above specified cost, with current market prices (7 January 2021) being used for the calculation.

It can be concluded from this study that Treatment 4 (high protein, low energy) yielded the highest GPV/carcass (R1654/head) of all the treatment groups, owing to the significantly higher cold carcass weights. These high carcass weights are associated with this group having the highest recorded final weight and average daily gain. While the lowest numeric carcass price (R1371/head) was recorded for Treatment 2, with the lowest numeric cold carcass weight. However, margin over specified feed cost (R/head) resulted in Treatment 1 having the highest numeric margin (R197.90), due to the low feed costs of this group, associated with with the lowest average FCR and thus the most efficient growth. Treatments 1 did not differ significantly from Treatments 4 (R174.74) and 7 (R132.94), owing to the elevated cold carcass weights and the relatively low intake and associated feed costs of these groups respectively. While Treatment 5 yielded the lowest average margin over specified costs (R13.8/head), due to relatively high feed cost and low carcass weights recorded for this group.

Considering the slaughter data, Treatment 7 yielded the highest numeric dressing %, with the ewe lambs significantly having the highest dressing % for both their warm and cold carcass, with this contributing positively to this group's margins. The data therefore suggests that supplementation of zilpaterol hydrochloride in the diet during the last month of the finishing period enhances performance, showing the repartitioning capacity of this feed additive.

Results from this study indicate that diet played a significant role in all the parameters (cost, revenue, and margin above specified costs) on the trial Dorper lambs. Differences were also evident between the sexes, while not significant, rams on average outperformed the ewes. There were however exceptions, with notable differences and wide variation in the revenue data, in particular the margins above specified costs. This indicates that further research is required to reduce individual variation and ensuring that all animals, both rams and ewes, yield positive returns from the feedlot finishing of these animals. In addition, it was noted that significant differences of carcass weights fall within the same carcass classification, therefore implying a relatively similar fat coverage between them. As suggested by Van der Merwe (2020), the impact of producing lamb finished on different diets is likely to have a greater effect on producer profitability over effecting the consumer.

Limitations of the study included the fixed slaughter date. The feed period of 32 days might have been too short to produce efficient differences in classification despite the A2/A3 ideal classification achieved. In turn this would have had an impact on dressing %, carcass classification, carcass values as well as feed costs and therefore the margins achieved. Furthermore, the limited carcass traits considered was a further limitation of the study. Further research is required to determine the effect of treatment (diet) and sex on carcass composition and meat quality of feedlot finished Dorper lambs.

4.4.8. REFERENCES

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CHAPTER 5

Conclusion and recommendations

5.1. Conclusion

Given the limited literature available describing the effect of diet and sex on both the performance and profitability of feedlot finished Dorper lambs, this two-part study was conducted. A trial was carried out to determine standard feedlot production parameters as well as to compare the carcass characteristics and profit margins of Dorper lambs on both an individual and groups basis under feedlot conditions. The overall objectives of the study were to determine the effect of treatment (diet) and sex on performance parameters of Dorper lambs (Part one). While Part two considered the effect of diet and sex on carcass characteristics and overall profitability parameters.

Results from Part one showed that treatment yielded a significant ($P \leq 0.05$) effect on most of measured feedlot production parameters (DMI, number of feedings, final weight, liveweight gain, ADG and FCR), while the effect of sex was limited and the interaction of treatment and sex was significant for FCR ($P = 0.01$) only. Treatment 4 lambs had the highest final weight, along with superior performance for liveweight gain and ADG across all groups in both ram and ewe lambs ($P \leq 0.05$). Although not significant, rams on average yielded numerically superior performance compared to ewe lambs across the measured parameters. Treatment 1 yielded the best FCR, suggesting that the standard feedlot diet resulted in the most efficient growth, while Treatment 7 was shown not effective in improving feedlot performance for all the recorded parameters.

Results from Part two also show that treatment yielded a significant ($P \leq 0.05$) effect on most of the measured parameters (final weight, warm and cold carcass weight, warm and cold slaughter percentage, feed cost, carcass value and margin above specified cost), while the effect of sex was limited. The interaction of diet and sex was significant ($P \leq 0.05$) for the margin (R/kg) above specified cost only. The highest final weight of Treatment 4 lambs resulted in them having the highest carcass weights and thus the highest carcass value/revenue being achieved. Moreover, Treatment 4 yielded superior performance for these parameters in both ram and ewe lambs ($P \leq 0.05$).. While Treatment 7 yielded the highest slaughter %, with the ewes having the highest slaughter % of all groups (both ram and ewe lambs) ($P \leq 0.05$), Treatment 1 resulted in the highest numeric margins over specified costs (R/head and R/kg); this along with the lowest FCR, suggests the correlation between margin and efficiency of growth. Apart from improving slaughter %, Treatment 7 was shown not effective in improving all other recorded parameters, established that β agonists are not necessarily required to improve performance and thus profitability of feedlot finished Dorper's.

Considering the objectives set out for this study of evaluating the results on animal performance and the profitability thereof, following fattening male and female Dorper lambs on seven treatment diets, it can be concluded that:

- Although carcass classification wasn't statistically analysed, the highest profit margins being achieved with lambs fed a standard feedlot diet, indicates that Dorper lambs did achieve the desired A2 carcasses and sufficient carcass weight.
- Decreasing the dietary energy (starch) content, was shown to have a negative effect on both feedlot performance and the profitability of fattening Dorper lambs.
- By increasing dietary crude protein content, lambs had improved feedlot growth relative to the control, however profitability was negatively influenced due to higher feed costs.
- Increasing dietary protein levels and reducing dietary starch levels had a positive effect on feedlot performance parameters and profitability. It resulted in the highest revenue being achieved however, it did not yield the highest profit margins.
- Substituting (approximately 50%) of the dietary starch for rumen protected fat was shown not effective in promoting growth nor yielding optimal carcasses, with the lowest profit margins being achieved, thus proving not economical in the fattening of Dorper lambs.
- Substituting (approximately 50%) of the dietary starch for fat and increasing dietary protein levels, was not effective in yielding heavier carcasses with optimal classification; and therefore, was not economical in the fattening of Dorper lambs, in part owing to the high feed costs.
- The inclusion of a beta-agonist to the standard feedlot diet did not yield the heaviest carcasses. Although not statistically analysed, desired A2 carcasses were not unanimously achieved; therefore, the inclusion of a beta-agonist did not result in the best margins being achieved.
- Considering all the seven treatments above, it can be concluded that on average, the effect of sex was not significant, with rams on average only marginally outperforming the ewes, on both animal performance and profit margins achieved following fattening of the Dorper lambs.

Considering all the objectives of the study, it can be concluded that Treatment 4 (high-protein, low-energy) was the most effective for the feedlotting of Dorper lambs, yielding superior growth parameters and the highest revenue being achieved. However, Treatment 1 yielded the most efficient growth, along with relatively low feed costs, meant that the standard feedlot diet ultimately resulted in the best profit margins. Results from this study indicate that Dorper lambs can be fattened economically. This research may be valuable to industry players, both Dorper producers and feedlot producers, who typically discriminate against Dorper's, yet often struggle with the supply of lambs entering the feedlots.

5.2. Recommendations and future studies

The major limitation of the study was the fixed slaughter date; therefore, it is recommended that Dorper lambs be fed longer to achieve heavier final weight and thus marginally heavier carcasses. This would have allowed greater variation in carcass classification across the treatments and between the sexes and clearer conclusions could have been drawn on the effect of these two main effects. In future studies, it is recommended that more emphasis be given to both the carcass composition and quality, the meat quality as well as the non-carcass components. There are concerns around the effect of β agonists on meat quality, and more detailed research would be valuable in determining the effect of different treatment diets on tissue composition and meat quality characteristics. Future studies should also investigate the response of other indigenous mutton breeds, such as the Meatmaster, and the effect of treatment and sex on performance and profitability parameters.

APPENDIX 1

Price of the raw materials, the formulated feed ingredients, and the costs of the seven complete treatment diets.

Item		Treatment						
		1	**2**	**3**	**4**	**5**	**6**	**7**
Ingredient (kg/ton)	Rand/ton							
Bergafat®	15000					65	65	
CMS[1]	3000	30	30	30	30	30	30	30
Kalori 3000[2]	5500	25	25	25	25	25	25	25
Maize	3200	530	285	500	280	275	275	530
Soya oilcake	7200	50	30	75	75	50	75	50
Fishmeal	15000			40	40		50	
Oat hay	1800	225	225	225	225	225	225	225
Lucerne	3100	75	75	75	75	75	75	75
Soya hulls	2000	30	300		223	223	153	30
Acid Buff®	13800	5	5	5	5	5	5	5
Salt	710	3	3	3	3	3	3	3
Feed lime	800	8	4	3		5		8
HPC[3]	11900	19	19	19	19	19	19	
HPC[4] + Zilpaterol	50000							19
Total (kg)		1000	1000	1000	1000	1000	1000	1000
Cost per ton		**3285**	**2891**	**3905**	**3644**	**3827**	**4613**	**4009**

APPENDIX 2

The meat/carcass price of the various carcass classifications at the time of slaughter (January 2021).

	Carcass classification						
	A0	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**
Meat/carcass price (R/kg)	72	84	84	84	80	74	72