EFFECT OF DIETARY INCLUSION LEVELS OF DIATOMACEOUS EARTH ON PRODUCTION, CARCASS CHARACTERISTICS AND FAECAL EGG COUNT OF LAMBS

By

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Effect of dietary inclusion levels of diatomaceous earth on production, carcass characteristics and faecal egg count of lambs

ABSTRACT

The aim of this study was to assess the effect of different levels of diatomaceous earth (DE) on the growth performance, carcass characteristics and faecal egg counts of lambs receiving feedlot diets. A total number of fifty (50) Ronderib X Merino lambs (male and female) with an average body weight of ± 37 kg were used in this study. The animals were divided on a stratified body weight and faecal egg count (FEC) basis into five (5) groups of ten (10) lambs each, namely; T0, T1, T2, T3 and T4. Animals in all the groups were provided with the same standard feedlot diet that only differs in DE inclusion levels. Diets were formulated to contain DE at four different inclusion levels, namely 0.5% (T1), 1.0% (T2), 1.5% (T3) and 2% (T4) of the diet. T0 (0% DE) served as the control group. The animals were fed two times a day at 07:00 and 16:00 respectively. Faecal samples were taken at two-hour intervals between 8:00 and 16:00 before the start of the project and faecal egg counts were done to determine the average FEC. The sheep were also weighed prior to treatments being applied to allocate the animals to the different groups on a stratified FEC and body weight basis. Body weights of all the animals were recorded weekly, while faecal samples were collected on a two-weekly basis to determine FEC. Eye muscle area (*longissimus dorsi*) and fat depth were measured at the start and again at the end of the project before slaughtering. After a 46-day feeding period (20 July – 04 September 2017) the lambs were fasted overnight and slaughtered. All carcass traits were recorded for each animal. No significant differences were observed between the different groups in terms of weekly body weights, body weight change (BWC) and average daily gain (ADG). The inclusion of different DE levels did not have a significant effect on most of the eye muscle area, fat depth, carcass and fat measurements. Regarding FEC, there was a general decrease in the roundworm counts from the start to the end of the project, while the coccidia counts showed a general increase. However, the results did not show a positive response in FEC with the inclusion of different levels of DE. From the results of this study, it can be concluded that DE at different inclusion levels did not have a positive effect on most of the measured parameters.

Keywords: Lambs, faecal egg count, diatomaceous earth

DECLARATION

I, **ANANIAS THABO NKWANA** declare that;

(i) The research reported in this dissertation, except where otherwise indicated, is my original research.

(ii) This dissertation has not been submitted for any degree or examination purposes at any other university.

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DEDICATION

This work is especially dedicated to my dear late grandmother **Mrs Mamohlatlego Mokwape Molewa.** I would not be where I am today if it was not for her effort to make sure that, from her old age grant, I furthered my studies.

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“My favourite animal is the turtle. The reason is that in order for the turtle to move, it has to stick its neck out. There are going to be times in your life when you’re going to have to stick your neck out. There will be challenges and instead of hiding in a shell, you have to go out and meet them.” – Ruth Westheimer

LIST OF ABBREVIATIONS

ADG	-	Average daily gain
FCR	-	Feed conversion ratio
FEC	-	Faecal egg count
FI	-	Feed intake
DAFF	-	Department of Agriculture, Forestry and Fisheries
DE	-	Diatomaceous earth
EMA	-	Eye muscle area
FD	-	Fat depth
GADI	-	Grootfontein Agricultural Development Institute
SiO_2	-	Silicon dioxide
nH_2O	-	Nitrogen water
EFMA	-	Earth Fertilizer Manufacturer Association
IDPA	-	International Diatomite Producers Association
USDA	-	United States Department of Agriculture
cm	-	Centimetre
g	-	Gram
Kg/ha	-	Kilogram per hectare
SFP	-	Standard fertilizer practice
NPK	-	Nitrogen Phosphorus Potassium
%	-	Percentage
˚C	-	Degree Celsius
PSE	-	Pale Soft Exudative
DFD	-	Dark Firm Dry

FAO	-	Food and Agriculture Organization
BW	-	Body weight
WW	-	Weaning weight
DP	-	Dressing percentage
RFI	-	Residual feed intake
USAID	-	United States Agency for International Development
SAFA	-	South African Feedlot Association
CP	-	Crude protein
ME	-	Metabolisable energy
NMSU	-	New Mexico State University
SBM	-	Soybean oilcake meal
NPN	-	Non-protein nitrogen
MJ/kg	-	Megajoule per kg
DM	-	Dry matter
pH	-	Potential of hydrogen
MLA	-	Meat and Livestock Australia
NRC	-	National Research Council
EC	-	Eastern Cape Province
mm	-	Millimetre
T	-	Treatment
ID	-	Identity
SAS	-	Statistical Analysis System
GLM	-	General Linear Model
FDA	-	Food and Drug Administration

BWC	-	Body weight change
EMAC	-	Eye muscle area change
FDS	-	Fat depth start
FDE	-	Fat depth end
IMF	-	Intramuscular fat
FDC	-	Fat depth change
V1-V3	-	Fat depth measurements

TABLE OF CONTENTS

CHAPTER 2

LITERATURE REVIEW

CHAPTER 3

MATERIALS AND METHODS

CHAPTER 4

RESULTS AND DISCUSSION

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

GENERAL INTRODUCTION

1.1 Introduction

Sheep farming is one of the common enterprises in South Africa, and it plays a vital role in the livestock industry (Brundyn *et al.,* 2005). There are about 20 sheep breeds in South Africa, including the Merino, Dorper, Mutton Merino, Dohne Merino, Dormer and the Black-headed Persian (DAFF, 2010). According to the report presented by DAFF (2011), sheep farming is practiced throughout the country, but is concentrated in the more arid parts of the country, i.e. the Northern Cape, Eastern Cape, Western Cape and Free State. Sheep numbers in South Africa is estimated at 24.5 million distributed in all nine provinces. Nearly 86% of the sheep are in the Eastern Cape, Northern Cape, Free State and the Western Cape, whereas the other five provinces share the remaining 14% of the country's sheep numbers.

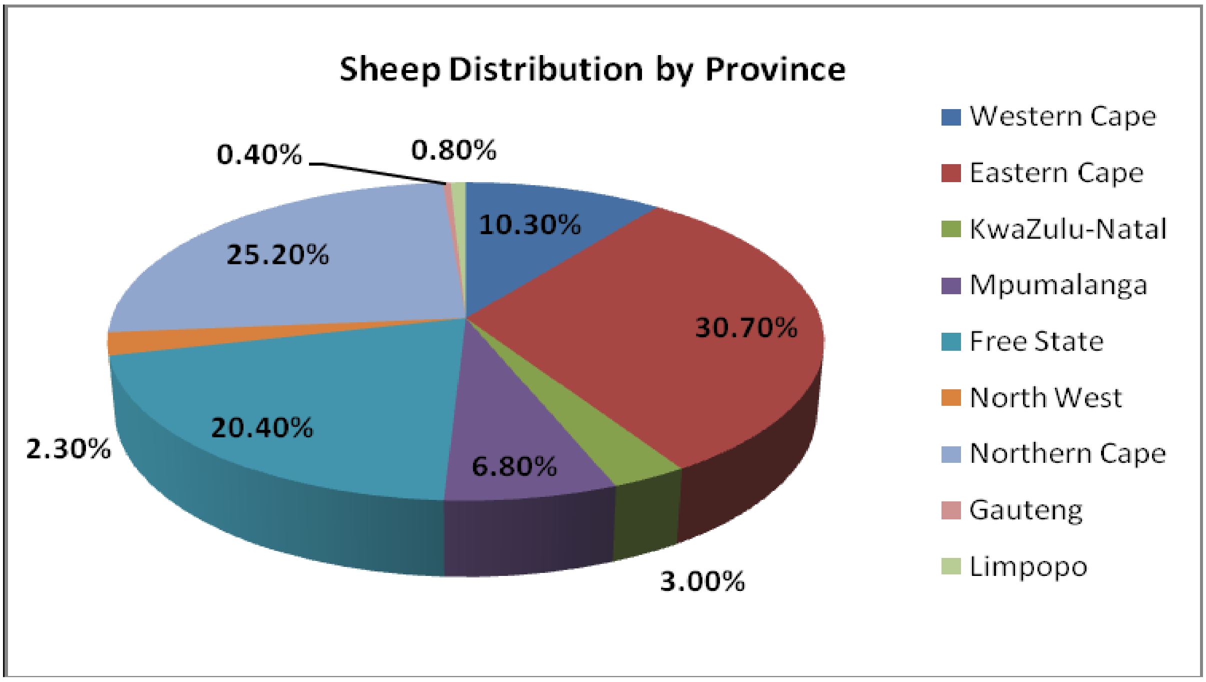

Figure 1.1: The geographic distribution of sheep in South Africa (DAFF, 2010) (www.daff.gov.za)

Products such as meat, milk, leather, wool and other by-products such as dung for fuel or fertiliser, are the most important economic produce that are derived from sheep. The price of mutton has increased considerably over the last decade because of the decreased numbers of sheep produced in South Africa. The declining of sheep numbers is mainly due to predation and stock theft, as well as severe drought conditions. This reduction in sheep numbers warrants intensive rearing and finishing of sheep for the consumer markets (DAFF, 2011). Merino-type sheep such as the Dohne Merino and the South African Mutton Merino, and non-woollen types such as the Dormer and Dorper are regarded as the key sheep breeds in South Africa suitable for intensive rearing and finishing in feedlots (Van der Westhuizen, 2010; Cloete *et al.,* 2012).

Extensive small stock production is understood to be traditional in South Africa. However, with a dramatic rise in the population, a vast increase in the demand for red meat due to the increase in income of the middle class can arise (Optifeeds, 2016). According to a report published by Optifeeds (2016), a feedlot is synonymous with economy of scale. A feedlot system in the current economic environment is radically affected by low margins due to high feed costs. However, the high feed costs are caused by the unembellished drought that the sheep farmers experienced in the past seasons. It is therefore of the utmost importance to lessen the costs and losses to generate the maximum profit from the business. The lambs that are bought or bred for the business determine to a large extent the success that will be achieved. Meat types, wool types and cross breeds tend to perform well in the feedlot. Lot feeding is the practice of housing animals in a confined area and providing all nutritional requirements in the form of rations. It allows operators greater control over the quality and timing of supply than is possible with grass finishing, which is subject to seasonal conditions (Buloke Shire Council, 2016).

Feedlotting therefore enables sheep producers to attain a steady supply of quality lamb to meet market specifications for weight and fat score. It also provides an opportunity to sustain production during times of low pasture availability, or to achieve rapid growth when feed prices are low. Six to ten weeks (40 to 70 days) is the period of time for lot feeding sheep when the objective is to finish off stock for the market. As a secondary function, lot feeding is used as part of general farm management, particularly to maintain stock during drought, and to keep stock off establishing pastures at the break of the season (Buloke Shire Council, 2016).

The main benefits of lamb lot feeding are:

- Animals can be bought to suit a particular market's requirements for weight and quality.
- Continuity of supply can be improved (finishing lambs at times of the year that are traditionally non-seasonal).
- Seasonal variations clearly have an impact on lamb prices for the domestic market, so if producers can deliver when there is a shortage, they can take advantage of higher prices.
- Lot feeding allows farmers to establish more attractive supply chain arrangements and premium markets away from the traditional sale yard methods (which still account for the majority of prime lamb sales).
- A management tool to help control feed availability, limit soil erosion and seed contamination, improve pastures, and improve stock condition. Keeping stock off pasture for four to six weeks allows it to become well established at the break of the season, and stubble can be more easily maintained. These benefits may also be achieved by a broader strategy of sheep 'containment' (in semi-intensive pens and paddocks) without the infrastructure needed in a formal feedlot (Buloke Shire Council, 2016).

Lawrie (1998) stated that animal growth is defined as an increase in bodyweight that is attained by hypertrophy and hyperplasia until a mature size is reached, which is supplemented by changes in body conformation. Maximisation of an animal's growth performance and minimisation of the animal's number of days in the feedlot are influenced by feedlot diets (Notter *et al.,* 1991). To be able to obtain the individual daily intake, average daily gain (ADG) and feed conversion ratio (FCR) for each lamb, the weights of the lambs must be recorded weekly, along with feed intake (Brand *et al.,* 2017). Feedlot diets are intended to maximise growth performance and minimise the number of days on feed (Notter *et al.,* 1991).

According to Deutschlander (1994), monitoring parasitic worms in a livestock operation is perilous to sustaining a productive and healthy flock of sheep or herd of cows. Diatomaceous Earth (DE), also known as Diatomite, is a naturally occurring substance comprised of the fossilised remains of diatoms, a type of hard-shelled algae. Diatomite is defined as a soft, chalk-like sedimentary rock that is easily crumbled into a fine white to off-white powder (History of Diatoms, 2006; 2016). Diatoms are microscopic-sized, hard-shelled beings which originated in both marine and fresh waters. The diatom shells are covered in sharp spines that make them dangerous to exo-skeletal insects, but not to animals with internal skeletons (Hagan, 1999). Diatomite consists of approximately 33% silicon, 19% calcium, 5% sodium, 3% magnesium, 2% iron and many other trace minerals such as titanium, boron, manganese, copper and zirconium (Rampradheep & Sivaraja, 2016).

Diatomite has been acknowledged as an organic product for animal health and nutrition. It is mined all over the world, and in South Africa it is mined from seven different sources in the Olifantshoek area in the Northern Cape Province (Koster, 2010). It is used as a filtration aid, as a mild abrasive, as a mechanical insecticide, for animal health and in animal feeding.

1.2 Research problem statement

- Optimal DE inclusion levels in the diets of animals are not known.
- The effect of DE on animals is not scientifically proven.
- The effect of DE on ADG and FCR has not been established.

1.3 Rationale/ Motivation

The use of DE is a natural practice that remains common in many parts of the world. Furthermore, reports of drug resistance have been made in every livestock host and to every anthelmintic class. In some regions of the world, the extremely high prevalence of multi-drug resistance in nematodes of sheep and goats threatens the viability of small-ruminant industries (Kaplan, 2004). The present work aims to scientifically assess the effect of levels of DE on the growth performance, carcass characteristics and faecal egg counts of lambs receiving feedlot diets.

1.4 Aim of the study

The aim of this project is to assess the effect of different levels of DE on the growth parameters, carcass characteristics and faecal egg counts of lambs receiving feedlot diets.

1.5 Objectives of the study

The objectives of the project are to:

- determine the effect of DE on body weight, body weight change and average daily gain (ADG) of lambs;
- determine the effect of DE on faecal egg counts (FEC);
- determine the effect of DE on eye muscle area, fat depth and carcass characteristics of lambs.

1.6 Hypotheses

- Diatomaceous earth improves the economic viability of feedlots.
- Diatomaceous earth has a positive effect on the average daily gain of sheep and goats.
- Diatomaceous earth reduces faecal egg counts in sheep.
- Diatomaceous earth has an effect on body weight, body weight change and average daily gain (ADG) of lambs.

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CHAPTER 2

2 LITERATURE REVIEW

2.1 Introduction

Diatomaceous earth (DE), also known as diatomite, is claimed to be an effective and alternative natural anthelmintic for sheep, goats and other livestock. However, there is a lack of scientific literature to support its use (Schoenian, 2013). Bernard *et al*. (2009) conducted a study to determine the effect of DE on goats naturally infected with internal parasites such as *Haemonchus contortus, Eimeria* and *Trichostrongyplus sp.* Goats were treated with DE at different concentrations, but the results were not positive. Over the duration of the study, there were increases in faecal egg counts while packed cell volumes decreased, and it was concluded that DE had no anthelmintic effect on goats. However, there were significant differences in body weight change among the treatments, with positive gains in the groups which received the lowest dose of DE (Bernard *et al.,* 2009).

There are claims that DE, when it is crushed, becomes an effective animal feed supplement. However, the product mined should be of food grade and of high quality with no heavy metals, toxins or contaminants (Uses for diatomaceous earth / Animal production, 2018). Documented benefits of using food grade DE as a feed supplement for livestock and farm animals include, among others, the following:

- improved weight gain and feed conversion ratio;
- increased production;
- accelerated growth/development;
- internal parasite control; and
- increased general health and appearance.

(Uses for diatomaceous earth/ Animal production, 2018).

It is essential to determine the optimal feeding levels in different species and for different applications through proper scientific studies. At this stage it appears that the optimal levels may vary between 0.5 and 2% of the total diet of the animal. Wang *et al.* (1994) indicated that the addition of DE to animal feeds at a level of 2 to 4%

does not affect palatability of the feed to animals. However, longer term studies are required to determine optimal quantities and duration of inclusion (McLean *et al.*, 2005). There is a lack of scientific evidence to support the claims by farmers and veterinarians. The lack of reliable data may be due to the large variation in the properties of diatomite between sources, which makes the results obtained seem particular to a specific grade and source of DE. Nonetheless, there are numerous testimonies on results and observations by farmers.

Some testimonies claim that an inclusion level of between 1% and 2% of DE in feedlot diets showed significant performance improvements. Feed conversion rate was improved by 5% and 11%, and overall profitability per lamb was in favour of the groups with 1% and 2% DE respectively above the control group (Koster, 2010). In a dairy herd, 15 to 20% higher butter fat percentage was recorded, and an improvement in milk quality and quantity was observed when compared to the group that had no DE included in the diet. Lambs fed with DE appeared to have faster weight gain, cleaner tails and brighter wool. The overall body condition of the lambs also seemed to improve (Deutschlander, 1994). However, these claims might be due to the ability of DE to control parasitic worms, and not as a result of the nutrients it contains, and therefore rendering the animals healthier, resulting in highly productive animals. Researchers suggest that there is a need to authenticate popular claims for alternative treatments as to their efficacy and impact on animal welfare.

Users of food grade DE have reported four other distinct uses in livestock and poultry production, namely: insect and parasite control, mineralization, absorption and grain protection. There are many testimonies documented on the uses of DE, but more proper scientific work is required to confirm the testimonies and some peer-reviewed work that already exist. Due to DE being formed under water, it does not dissolve in water. Even in the stomach of animals surrounded with powerful digestive juices, it just passes all the way through the body almost complete. A very small amount is leached out as it passes through the stomach and intestinal tract.

The use of DE to control internal parasites in organic livestock production is widely reported (Sooby *et al.,* 2007). For a flock to remain productive and healthy in a livestock operation, the control of parasitic worms remains critical. Some insecticides have been banned due to the negative effects they have on animals and/or humans. However, DE has been used for many years as a natural de-wormer for animals, with claims of success against internal worms and parasites. McLean *et al.* (2005) reported that cattle and sheep which received a specifically selected DE supplement, had low faecal egg counts (FEC) for the period of the experimental period, compared to animals supplied with anthelmintics. A study at Clemson University in South Carolina reported that DE usage increased productivity and profit on dairy farms where an alternative for chemical products was required (Koster, 2010).

Numerous on-farm trials have been done in South Africa to determine the impact of diatomite as a natural pesticide replacement for internal parasite control. The outcomes of the study conducted by Bernard *et al.* (2009) accord with previous experiments relating to DE, which confirmed no significant reductions of faecal egg counts in sheep. Regardless of the endorsement for the use of DE as an effective anthelmintic, the evidence presented in the study did not support DE as an effective alternative de-worming drench for goats. Fernandez *et al.* (1998) conducted a study using beef steers, and found no significant differences in feed conversion ratio, average daily gain, dry matter intake and days on food between the control and treatment groups.

Performance of young cattle is also affected by heavy parasite burdens. Under organic regulations, anthelmintics are permitted as a dose in accordance with the farmer's overall strategy to reduce the use of anthelmintics (McLean *et al.,* 2005) or where the farmer can demonstrate a necessity to dose, i.e. where faecal egg counts (FEC) of the flock or individuals are high and the animals are losing condition. Different treatments to anthelmintics comprise diverse species of grassland, nematode trapping fungi, mineral supplementation, herbal and homeopathic remedies. Recently the use of DE has also been supported as an alternative treatment. Although the action of diatomaceous earth on parasites is unclear, it has been suggested that the abrasive action of the powder penetrate or scratches the outer protective layer of invertebrates including internal parasites, resulting in death by dehydration (McLean *et al.,* 2005). Diatomite is also rich in trace elements, and it may be the improved nutritional status of the animals that has permitted them to cope with a parasite burden.

2.2 Diatomite

Paschen (1986) and Arik (2003) described diatomite rock as a loose, earthy or insecurely cemented porous and lightweight rock of sedimentary source, predominantly moulded by wreckages of armour (skeletons) of diatom algae: diatomea and radiolaria. Diatomite is a microscopic diatom alga whose size ranges from 0.75 to 1 500 microns; sometimes this rock is called infusorial earth, kieselguhr, or mountain meal. The main apparatuses of the siliceous armour are silica hydrates of a dissimilar degree of water content (opals) $SiO_2 nH_2O$. Diatomite rock belongs to the group of silica-bearing materials. Diatomite has its beginning from a siliceous, sedimentary rock consisting predominantly of the fossilised skeletal remains of diatom, a unicellular aquatic plant related to the algae, during the tertiary and quaternary periods. Earth Fertilizer Manufacturer Association (EFMA) (2016) explains in their publication that diatomite refers to the light-coloured sedimentary rock which is self-possessed of the residues of one-celled algae known as diatoms. The diatomite comprises of siliceous belongings, and these properties are what make diatomite useful as a filter, as an absorbent, and as a filler for rubber, paint, and plastics (EFMA, 2016).

2.2.1 Formation of diatomite

When the single celled plants called diatoms die, their skeletal remains sink to the bottom of lakes and oceans, and then form a diatomite rock/ diatomite deposit (Rocks compare nature, 2015; 2018). The Lost Hills oil field in California contains several producing horizons, and it has the Etchegoin formation of the producing horizons. The Etchegoin formation of the Pliocene series comprises soft, huge diatomite beds of Pliocene series of very high porosity and remarkably low permeability. In numerous ways, the conditions bear a resemblance to a chalk formation. The depth of the foremost zone ranges from about 900 to 1,900 ft. The shafts are usually accomplished with fitted liners across 600 to 1,000 ft, of which the net productive thickness is about 500 ft (Stosur & David, 1976). Correspondingly, deposits of diatomaceous earth are diverse, with changing mixtures of pure diatomaceous earth joint with other natural clays and minerals. The diatoms in each deposit contain different amounts of silica, depending on the age of the deposit (Antonides, 1997). The diatomite in most commercial diatomite sources is called the sedimentary rock or siltstone of fossils of the diatoms. When the diatom dies, the siliceous shell or frustule of the diatom fluster in the lake or sea where they accrue at mutable rates. Sediments of very active diatom colonies may accumulate several millimetres of thickness in one year (Anonymous, 1987). The accretion period of the siliceous shells of diatoms began during the cretaceous period (35 to 65 million years ago), but most of the commercial deposits exploited today are of Miocene age, which was about 26 to 27 million year ago (Anonymous, 1987). Today some diatom species are still plentiful in lakes and seas (Round *et al.,*1990). Ample of the beer brewed in the United States is filtered through diatomaceous earth sourced from diatomite formed in a freshwater environment; salty marine diatomite would ruin the beer (Nummi, 2016).

2.2.2 Diatomite sources

Bunch *et al.* (2013) discovered that products which comprise of diatomaceous earth are most commonly dusts, and other formulations include wetable powders and pressurised liquids. Presently, there are over 150 products registered for use inside and outside of buildings, farms, gardens and pet kennels, and some products can also be used directly on dogs and cats. Alali (1991; 1994) evaluated the physical and chemical properties of the diatomite and concluded that the Jordanian diatomite is similar to the Danish diatomite (Molar) product. Alali & Abu-Salah (1993) and Qararah & Alali (1995) investigated the deposit and recommended a detailed evaluation. After some selected samples were investigated by El-Harithi (1990), he decided that the diatom frustules were deposited in a shallow marine outer shelf depositional environment. A conclusion was made that the high saline water is the most important hindrance for mining and utilising the Azraq diatomite, and that the diatomite layers are under the water table in the depression. Research conducted by the New South Wales Mineral Research Department established that diatomite deposits formed in marine environments are found on elevated coastlines of most continents. The largest deposits of this type occur along the Pacific Rim, northern and southern Europe, northern Africa and the east coast of South America. Anonymous (1987) reported that the largest part of world reserves of diatomite is in Europe and the United States of America.

2.2.3 Properties of diatomaceous earth

Diatomite are mineral deposits of diatomaceous algae, those commercially broken being limited to a relatively modem age, starting from the Miocene. Older deposits have suffered tectonic processes, carrying about alterations of the texture and crystalline phase of the mineral. Amorphous silica, an integral part of the diatom frustulae, is the main component of diatomite, though variable quantities of other materials (metal oxides, clays, salts (mainly carbonates) and organic matter) may also be present. Chemical precipitation and atmospheric contact, together with the prevailing environmental conditions, are determinant factors in the nature and importance of the impurity content of a deposit (Mendioroz *et al.,* 1989). Despite the massive disparities in shape and size, each diatom species has two things in common, chemically the same silica shell and physically an intricate pricked structure (Natural Feeds & Fertilizer Ltd, UK, 2017). Eldernawi *et al.* (2014) indicated that the essential components of the diatomite valorisation are potted in the chemical and physical properties' improvement, which would play a crucial role as far as its use as industrial rock is concerned. Furthermore, diatomite is white if pure, universally buff to grey in places, and rarely black. Therefore, under the mineralogy-petrology investigation of the key characteristics and features of the diatomaceous earth is its high content of biogenic amorphous silica (opal-A), with a form of diatom frustules. The frustules fundamentally are chemically inert in most liquids and gases. Ebeling (1971) and Korunic (1998) reported that the physical and chemical properties of DE, such as the percentage of amorphous silicon dioxide, pH value, porosity and active surface, sorption capacity, particle size distribution, and the adherence of DE particles to seed, are the critical factors affecting their insecticidal action.

2.2.4 Mining and processing of diatomaceous earth

The process and mining of diatomite is a procedure that wants precision and delicacy. It involves extensive facilities as well as top-quality equipment to aid in reducing the amount of material. To help reduce costs, the diatomite material is often mined in an open pit as well as surface mines, though some processes use specific extraction approaches used underground for extracting diatomaceous earth. The International Diatomite Producers' Association (IDPA) (1997) explained that in shallow mining, a momentous thickness of earth, known as overburden, may have to be disconnected. As soon as this layer is disconnected, and the uncontaminated part of the diatomite strata is exposed, it is then cut from the bed with powerful scrapers and stockpiled (IDPA, 1997). The process of crushing and drying out is performed on a natural grade diatomite or uncalcined diatomite. The percentage normally found in crude diatomite ranges between 40% and 60% moisture, but it is sometimes higher (U.S. Environmental Protection Agency, 1985). Diatomite processing is commonly done near the mine to reduce the cost of hauling mine-run rock, which may cover as much as 65 percent of the cost, but the cost of delivering energy to the site is also considered when deciding on an area to mine diatomite. If the weather allows, the ore is stockpiled in the open air to isolate it by grade, and to reduce the normally high moisture content before supplying it to the processing facility (Dolley & Moyle, 2002). Diatom structure is the single most important factor in filtration. In the future stages of processing, calcining is usually done in rotary kilns. Special precaution by plant operators need to be taken to mitigate any health hazards from free crystalline silica in mining areas (Dolley & Moyle, 2002).

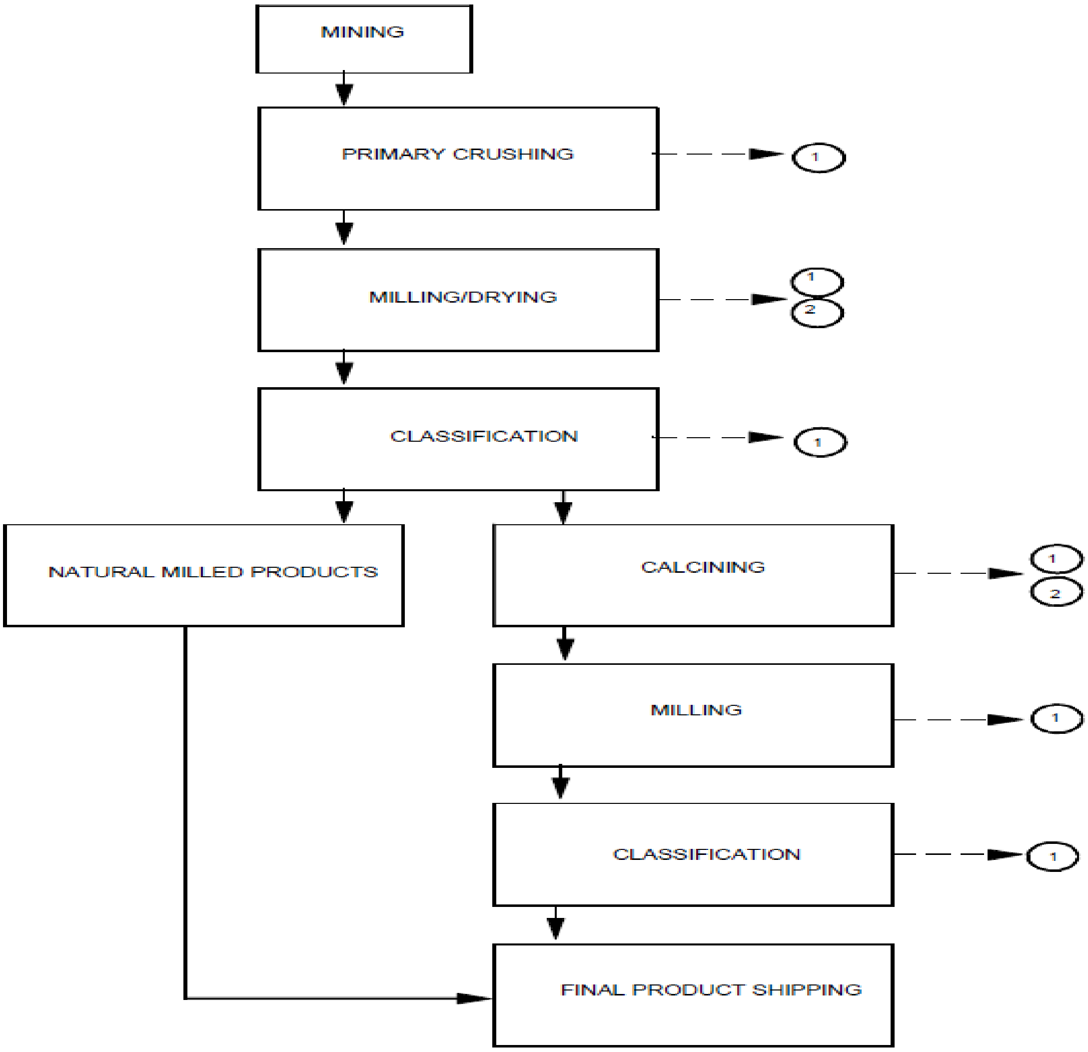

Figure 2.1: Typical process flow diagram for diatomite processing (U.S. Environmental Protection Agency, 1985).

2.2.5 Uses of diatomaceous earth

Food processing products such as beer, whiskey and fruit juice, and organic liquids such as solvents and oils are primarily filtered by using diatomite. Diatomite is frequently used as a filler in paint, paper, asphalt products and plastic (U.S. Environmental Protection Agency, 1985). Insect pests of stored products are accountable for substantial economic losses in the storage sector. The *Sitophilus zeamais* mots (Coleoptera: Curculionidae) is a major corn pest, and its by-products are found in almost all storage and processing facilities in Brazil (Aguiar *et al.,* 2010; Conceição *et al.,* 2012). Control of the temperature of the grains and the post-inert employment, such as diatomaceous earth, are examples of non-chemical auspicious methods for the combined treatment of insect pests of stored products (Kavallieratos *et al.,* 2007; Wakil *et al.,* 2010). Rojht *et al.* (2010) explained that diatomaceous earth originates from sediment of carapaces of diatomaceous algae, and when in contact with insects, it causes the removal of the layer of wax from their cuticle, bringing about their death by dissection. Fossil shell flour DE used in agriculture must be milled until it is almost completely amorphous. This means it has no crystalline form left to cause damage to larger organisms. Instead, it has small sharp edges which can damage tiny parasites and larvae on stored grain, in animal manure, on infected plants and in the stomachs of livestock and people (Diatomite Canada, 2005).

Diatomite Canada (2005) has found that since DE has an attractive mineral composition, users have reported four distinct uses on the farm: parasite control, mineralisation, deodorisation/absorption, and grain protection. Each use has its own traditional stories, facts and fiction associated with it. Degirmenci and Yilmaz (2009) reported the uses of diatomite as a partial replacement for cement in the manufacture of cement mortar. Furthermore, diatomite was used at 0, 5, 10 and 15% replacement by weight for cement while sand and water quantities were kept constant.

2.2.5.1 Parasite and insect control

According to a study conducted by Bennett *et al.* (2011), DE has the potential to eliminate parasites in organic free-range hens. Mclean *et al.* (2005) have established that cattle and sheep which received the diatomaceous earth supplement had low faecal egg counts (FEC) for the duration of the experimental period, compared to animals in the anthelmintic groups. Hills (2017) reported that diatomaceous earth is commonly used as a natural insecticide, and that it is one of the top natural ways to get rid of ants. Diatomaceous earth with fossil shell flour has been used for at least two decades as a natural de-wormer for animals. Furthermore, it is believed that the fossil shell flour DE scratches and dehydrates parasites. Some scientists believe that the fossil shell flour DE is a de-ioniser or de-energiser of the worms or parasites (Diatomite Canada, 2005). For vigorous use, the fossil shell flour DE must be nurtured long enough to catch all the freshly hatching eggs or cycling of the worms through the lungs and back to the stomach. It is suggested that a minimum of 60 days at 2% of dry weight of the grain ration work accurately. Koster (2016) further indicated that several on-farm trials have also been done in South Africa to determine the influence of diatomite as a natural pesticide replacement for internal parasite control. One trial was conducted in a sheep feedlot in the Northern Cape from March 2009 to improve the quality of life of Dorper lambs, and to help remove internal parasites. This trial was done by including diatomite in their feed, as opposed to inoculating the sheep, and the results were positive, as there was a decline in internal parasites.

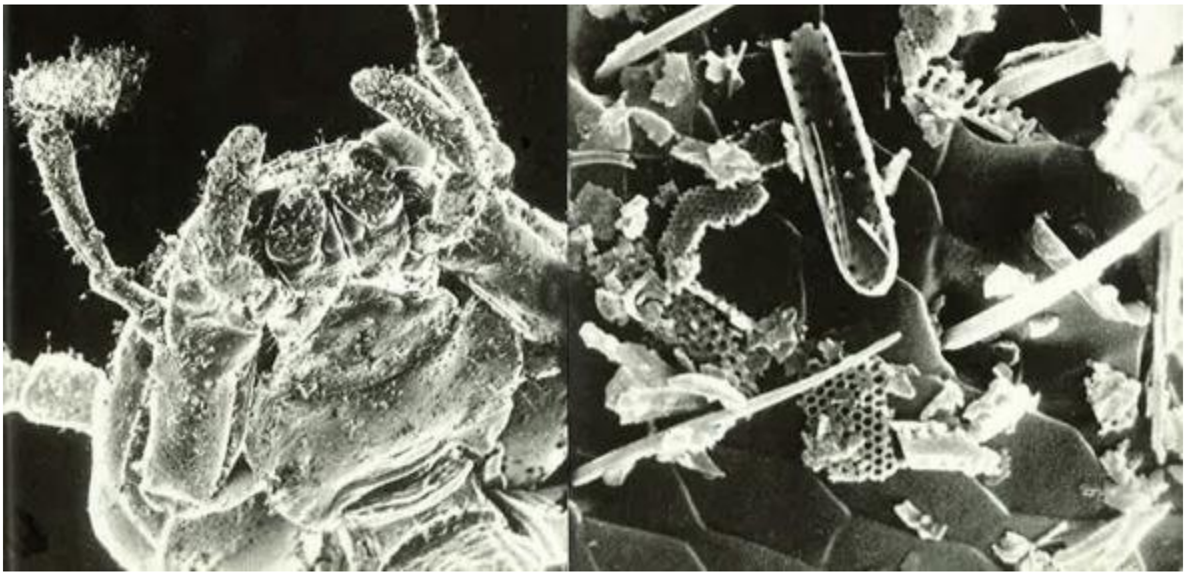

Figure 2.2: The picture above shows that, when crawling insects come in contact with food grade diatomaceous earth, it is much like crawling across shards of broken glass. The insect’s movement across the DE helps the razor-sharp edges to lacerate its body (Manic Organic SA, 2005; 2013).

2.2.5.2 Mineralisation

Koster (2010) proved in a trial that feeding diatomite with its possible large range of functions, may at the same time act as a comforting tool to alleviate or prevent any calcium-related performance or health issues if and when they may occur in human beings. It is reported that animals which are fed fossil shell flour DE, gain weight because of the reduction in parasite population, which results in decreased stress on the animal and increased food assimilation (Diatomite Canada, 2005). A natural food grade diatomaceous earth is characterised by 15 trace minerals; amongst them are the following major trace elements: calcium, magnesium, sodium, potassium, copper, zinc, iron, phosphorous, selenium, etc. People using it witnessed shinier coats, better overall health, better production, etc., in their animals who are fed food grade diatomaceous earth regularly (Wolf Creek Ranch Organics, 2001; 2008). Diatomaceous earth further increases mineral absorption. Silica is water-soluble and does not endure in the body for very long. However, when complemented by diatomaceous earth, it aids the body in keeping optimal absorption of these important minerals (Of the Harvest Word Press, 2013). Heinegard & Oldberg (1989) reported that silicon deficiency distresses the connective tissue metabolism, as this element influences the biosynthesis of glycosaminoglycans and collagen, which are necessary for organic bone matrix formation.

2.2.5.3 Deodorisation/absorption

As reported by Koster (2016), deodorisation/absorption is one of the main benefits of DE, and its function is endorsed as the undigested DE pass through the large intestine with the manure. According to the report presented by Diatomite Canada (2005), deodorising and absorption are natural functions of fossil shell flour DE. These will endure to transpire as undigested fossil shell flour DE passes through with manure. Reduced fly hatching is usually observed in manure from livestock that were fed fossil shell flour DE. Some dairy and hog farmers are also spreading it in bedding (for odour and moisture control) in addition to that coming through the manure. It was further discovered that DE binds NH_3 effectively and can therefore be used as an odour reducer in most intensive farming operations (Koster, 2016).

2.2.5.4 Grain protection

Ceruti & Lazzari (2005) explained that diatomaceous earth (DE) is a very effectual insect control measure in stored grain IPM (Integrated Pest Management), owing to its low cost, easy application, reduction of active ingredient residues, lower environmental contamination and operator safety. Amongst numerous varieties of inert dusts, it has been discovered that diatomaceous earth (DE) has a countless potential for controlling urban and stored product pests, and has been deliberated by many researchers worldwide (Subramanyam *et al.,* 1989; Aldryhim, 1990, 1993; Arthur & Zettler, 1991; Lorini & Scheneider, 1994; Arthur, 1996, 2002; Golob, 1997; Korunic *et al.,* 1998; Rupp *et al.,*1998; Subramanyam *et al.,*1998; Fields, 2000; Mewis & Ulrichs, 2001). Grain and flour can be stored successfully if fossil shell flour DE is used as a remedy to chemical contamination of stored grain. The Agricultural

Research Service of the USDA confirmed the results after a comparison with malathion and untreated grain on 1,000 bushels of wheat was performed.

2.2.5.5 Increases production yields

An experiment conducted by Pati *et al.* (2014) showed that the presentation of silicon significantly increased grain and straw yield, as well as yield-attributing parameters such as plant height (cm), number of tillers m^{-2}, number of panicle m^{-2}, and 1000-grain weight (g) of rice. The utmost grain and straw harvests were witnessed in the treatment comprising DE at 600 kg ha^{-1} in combination with standard fertiliser practice (SFP). Furthermore, it was found that the concentration and uptake of silicon, nitrogen (N), phosphorus (P) and potassium (K) in grain and straw were also greater under this treatment, compared to others. Schildbach (1988) and Schildbach *et al.* (1992) discovered that diatomite sludge can be used as an agricultural fertiliser, but due to its high moisture content, the distribution of diatomite sludge to the fields is problematic. According to research performed by Australian agricultural researchers, a natural silica significantly increases crop yield, which means increased revenue for growers. Natural silica provides the plant with energy and reinforces its ability to protect itself against stress. Soil treated with DE will have optimal fertility through enhanced water, physical and chemical properties and by permitting nutrients in the soil, such as phosphorus, to endure in a plant available form. All crops benefit from silica nutrition, and when used as recommended, crops typically average a 15% to 35% increase in yield within the first season. It has been discovered that different crops such as rice and sugarcane, which can yield up more silica than nitrogen, typically average a 20% to 70% increase in yield (Uses for diatomaceous earth/Animal production, 2018).

2.2.5.6 Other benefits of diatomaceous earth

Diatomaceous earth can act as a persuasive overall decontamination agent, a durable natural chelation agent, and it absorbs heavy metals such as those contained in vaccines, drinking water and foods (Of the Harvest Word Press, 2013). Diatomaceous earth is a natural method for neutralising toxic spills. It is also a common ingredient in oil-absorbing natural facial products and masks (U.S. Centres for Disease Control, 2014).

2.3 Factors influencing lamb growth, performance and carcass characteristics in a feedlot

The factors that affect lamb growth and performance can be classified into two categories, which are environmental and animal factors (Priolo *et al.,* 2001; Campbell *et al.,* 2011). Environmental factors consist of pre-slaughter handling and diets, whereas animal factors are described as age, genetics and sex.

2.3.1 Environmental factors

2.3.1.1 Pre-slaughter handling

Pale Soft Exudative (PSE) and Dark Firm Dry (DFD) meats are two of the major quality defects facing the meat industry. Furthermore, these defects lessen consumer acceptability, shelf life and yield of meat, therefore affecting profits immensely (Adzitey & Nurul, 2011). Breed, sex, species, pre-slaughter and post-slaughter handling of animals are among the main inclining factors contributing to PSE and DFD in meats. Dark Firm and Dry (DFD) meat and Pale Soft Exudative (PSE) meat can be defined in relation to the characteristics of normal meat. Adzitey & Nurul (2011) suggested that both conditions occur in all species, depending on how animals are handled pre-slaughter.

(i) Dark Firm and Dry (DFD) meat

During pre-slaughtering, this is a condition that can be found in carcasses of cattle or sheep, and occasionally in pigs and turkeys soon after slaughter. Warriss (2000) explains that when animals are exposed to chronic or long-term stress before slaughtering, DFD meats can occur. Examples of chronic stress are transportation of animals over long distances, long hours of food deprivation, and overcrowding of animals in the lairage over a long period of time. Chronic stress prior to slaughter leads to the depletion of stored glycogen, thus less glycogen is available post-mortem, affecting the normal process of acidification and leaving the pH of meat high. The carcass meat is darker and drier than normal and has a much firmer texture. Furthermore, the muscle glycogen has been used up during the period of handling, transport and pre-slaughter and consequently, after slaughter, there is little lactic acid production, which results in DFD meat. This meat is of inferior quality, as the less pronounced taste and the dark colour is less acceptable to the consumer and has a shorter shelf life due to the abnormally high pH-value of the meat (6.4-6.8). The animal that was stressed yielded DFM meat, and it further indicates that the carcass is from an injured and diseased animal that occurred before the slaughtering of the animal (FAO, 2001).

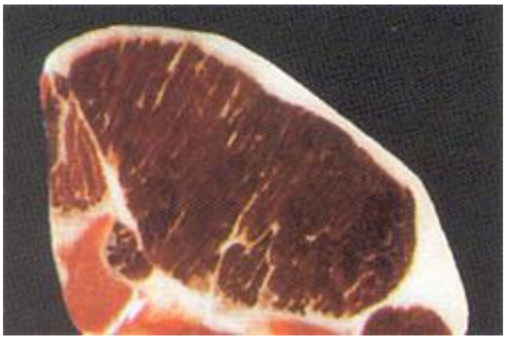

Figure 2.3. Dark Firm and Dry (DFD) meat carcass after slaughter (FAO, 2001).

(ii) Pale Soft Exudative (PSE) meat

If animals are exposed to acute stress just before slaughtering, it can lead to PSE meat. The use of electric goads, fighting among animals just before sticking, beating of animals prior to slaughter, and overcrowding in the lairage can lead to PSE meat in an acute or short-term stress situation (Adzitey & Nurul, 2011). In PSE meat, the degree of acidification after slaughter is stimulated faster than normal, and lower pH values are reached in the muscle when the temperature of the carcass is still high. The combination of low pH and high temperature in PSE meat causes the denaturation of some muscle proteins, leading to a reduction in their water-holding capacity (Warriss, 2000). Furthermore, Warriss (2000) clarified that light scattering from the meat surface is probably due to differences in refractive indices of the sarcoplasm and myofibrils.

Figure 2.4. Pale Soft Exudative (PSE) meat carcass after slaughter (FAO, 2001).

(iii) Normal meat carcass

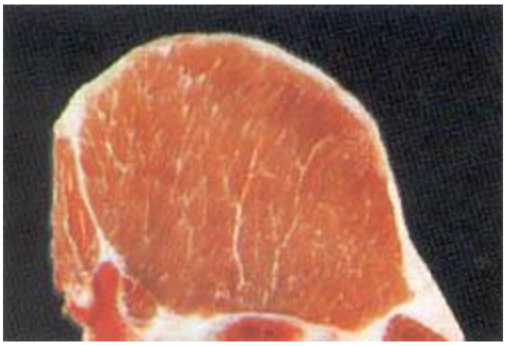

Figure 2.5. Normal meat carcass after slaughter (FAO, 2001).

2.3.1.2 Diets

Malik *et al.* (1996) did a comparison between low, medium and high energy diets fed to lambs in a feedlot with similar ADG and found that the lambs receiving the high-energy diet attained a feed conversion efficiency that is superior to those receiving the low or medium energy level diet. The laboratory's outcomes on animal nutritional status influences the ability of animal to reach its genetic potential for growth, reproduction, and longevity and to respond to pathogens and other environmental stresses (The national academic press, 1995). It is important both to have a nutritionally balanced diet for the welfare of laboratory animals and to safeguard that experimental results are not predisposed by unintended nutritional factors. The process of selecting the kinds and amounts of ingredients (including vitamin and mineral supplements) to be used in the production of a diet containing planned concentrations of nutrients is called diet formulation. Knapka (1983) recorded that a variation in the composition of the individual ingredients can produce changes in the nutrient concentrations of natural-ingredient diets. Alberti *et al.* (1992) found that diets comprising of diverse percentages of dehydrated lucerne in concentrates for bulls produced significant effects in succulence, but tenderness, flavour and contributory meat quality remained unaffected. Research conducted by Resconi *et al.* (2009) with lambs receiving different pasture and concentrate amounts, found that the inclusion of concentrates in the diet enhanced the meat's sensory quality and was related to the lowering of undesirable odour and taste intensity. Furthermore, lambs served only on concentrates produced meat that had the highest fat flavour intensity and the best overall suitability. Prado *et al.* (2013) studied the effect of protein level (13% or 15%) and quality (lys/met ratio 3.5/1 or 3/1) added to the ration and related to meat acceptability. Mutton and beef acceptability increased when 15% protein was incorporated into the diet, instead of only 13%, regardless of the lysine level added.

2.3.2 Animal factors

Notter *et al.* (1991) reported that sheep upraised for meat production form a major part of the economy of many countries in the world. This was confirmed by a large variation between these countries in climatic conditions, management procedures and in genotypes available. Round-about animals are grazed continuously outdoors, with only limited supplementation of available pastures, whereas others are housed from birth and fed scientifically formulated diets. Producing lambs in a feedlot is a major economic decision, as lambs produced in a feedlot reach their slaughter weights at a younger age than lambs grazing pasture. Another study conducted by researchers in the province of Eskisehir in Turkey showed that the breed, size, and age of a ewe, the birth type, lamb's sex, as well as maintenance and feeding conditions, are known to have an important impact on the body weight (BW) and weaning weight (WW) of lambs (Dickerson & Glimp, 1975; Gaskins *et al*., 2005; Notter *et al.,* 2005; Aliyari *et al.,* 2012; Aktas & Do˘gan, 2014).

2.3.2.1 Age and weight of animal

Akpa *et al.* (2017) reported that, as far as sheep is concerned, the young animals were a better source of supply of fore and hind quarters, whereas adult animals were better in providing live weight, carcass weight, dressing percentage, head weight, skin weight, legs weight and edible offals. The significant effect observed in the study by Akpa *et al.* (2017) could be attributed to the fact that fat deposition is more in older animals than in younger ones. The better source of fore and hind quarters in sheep could be as a result of the fact that the young animals brought for slaughter were at their rapid growth performance, whilst the superiority of adult sheep in supplying live weight, carcass weight, dressing percentage, head weight, skin weight, legs weight and edible offals could be as a result of increased carcass characteristics with increased age. Hammond (1983), Abouheif *et al.* (1990), Kadim *et al.* (2008) and Hamed *et al.* (2014) reported that age is among the factors that affect carcass characteristics in animals. However, Marichal *et al.* (2003), Peña, *et al.* (2007), Mayi & Alkass (2010) and Kaić *et al.* (2012) indicated an increase in the characteristics of sheep with increasing slaughter age, but contradicted the findings of Bonvillani *et al.* (2010) and Assan (2012), who reported that the contribution of visceral organs and fat depots as percentages of empty body weight did not change with slaughter weight in Criollo Cordobés and Matebele goats respectively. Animal age can considerably affect the sensory properties of sheep meat. Jeremiah *et al.* (1998) clarified that consumer reception of shank roast flavour was grander for lambs 6-12 months of age, whereas butt roast flavour suitability was more for lambs 6-15 months of age. Furthermore, Jeremiah *et al.* (1998) reported that roast flavour was less acceptable to consumers when roasts were from lambs 3-6 months of age. Age is mostly regarded as being accountable for the physiological ability to exchange feed into meat – the younger the lamb, the better the performance in terms of growth and feed conversion rate (FCR) (Veekos, 1988).

2.3.2.2 Genetic Selection

Lambs perform according to their potential genetic and physiological abilities (Veekos, 1988). It was also found that the capability of lambs to take feed and produce meat varies perceptibly between breeds and within breeds. However, the feedlot owner must select a lamb like the crossbreeds between meat and wool, which will perform well. For a farmer to exploit the genetic resources more proficiently, it is essential to characterise the various breeds/genotypes for traits of economic importance. This will assist the farmers to choose breeds based on performance data rather than phenotypic characteristics only (Moyo & Mpofu, 2000). Olivier (1999) clarified that the sheep selection experiments of the latter half of the 20th century failed to clasp the imagination of the sheep farming public at large. A clear distinction is the fact that the public were better capable to classify with the more traditionally managed flocks or studs that were maintained alongside. However, both categories contributed markedly to the improved understanding of scientific sheep breeding by the research community, and to the present South African sheep industry structures. Olivier (1981) indicated that selection for economically important traits in the Klerefontein Merino flock, as derived from deviations from the control flock, were sub-standard in an initial study but the responses to selection for economically important traits in this flock, as derived from deviations from the control flock, were disappointing in an initial study (Olivier, 1981). Erasmus (1988; 1990) further elaborated that when it became probable to separate genetic trends from environmental trends by mixed model methodology, it was clear that genetic drift in the control flock masked trends in live weight and clean fleece weight in the selection lines. It was then guessed that the unintended genetic change in the control line could be a function of random genetic drift and/or unintentional selection by the flock manager.

2.3.2.3 Effects of sex on lamb growth and performance

Sex had a substantial effect on body weight from 100 to 180 days (Singh *et al.,* 1984). Fitzhugh & Bradford (1983) indicated that the amount of sexual dimorphism at birth, conveyed as the male to female weight ratio, differs over the range of 1.03-1.05 for sheep. The sex of the lambs on feed can considerably affect the subsequent growth and performance perceived by some sheep producers and lamb feeders. Crouse *et al.* (1981) observed ram and wether lambs and established that ram lambs had considerably greater slaughter weights and ADG. McClure *et al.* (1994) found that over a three-year span, male lambs (rams and wethers) had greater ADG, final body weights, and chilled carcass weights than female lambs. Another study done by Okeudo & Moss (2008) matched the growth of four sexes of lambs and found that intact rams and vasectomised ram lambs had greater ADG than ewe lambs, with wether lambs being intermediate. The general conclusion made was that rams grow the fastest, followed by wethers and lastly ewes. Schoeman & Burger (1992) and Fahmy (1989) established higher body weights of lambs at 180 and 365 days of age for males than females (41.1 kg and 52.2 kg vs. 34.5 kg and 47.6 kg, respectively).

2.4 Production efficiency of lambs in a feedlot (feed for maintenance, feed conversion ratio (FCR) and average daily gain (ADG)

Dickson-Hoyle & Reenberg (2009) reported that the intensive production of meat is the fastest growing sector of the world meat industry, and that it produces 40% of meat consumed globally. Montanholi *et al.* (2008) reported that in all livestock production systems, feed becomes a major expense, ranging from 60 to 80% of the total costs across the most mutual farm animal species. Nolte (2006) suggested that lambs which are raised on poor quality forages, have declined growth performances, an increase in mortality rates, and ultimately ewes have problems with conception in the subsequent mating season. Archer *et al.* (1999) reported that feed efficiency can be measured by several methods, such as feed conversion ratio, relative growth performance, Kleiber's rate, residual body weight gain (RG), and residual feed intake (RFI). However, Leme & Gomes (2007) proposed that the animals with lower RFI eat less food than that estimated for their body weight and weight gain. It is understood that feed intake and growth are the most common important economic mechanisms when calculating profitability in a growth period.

The addition of feed intake and gaining information in selection decisions would facilitate genetic improvement of efficiency and profitability of meat sheep production. As a feedlotter, to include efficiency of feed intake and gain information in selection decisions, appropriate measurements of these traits are required. Feed intake is an economically important trait that is difficult to measure in all production systems (Ponzoni, 1986). Therefore, by weaning lambs early and finishing them in a feedlot, these problems can be prevented. When fattening lambs in a feedlot, the producer is expected to maintain a high growth performance or average daily gain (ADG), which equates to the amount of live weight gained (g) by the animal per day. Another important aspect of feedlotting is the feed conversion ratio (FCR) of the lambs, which is the amount of feed (kg) the animal must consume to gain one kg of bodyweight. Feed efficiency has been measured as the feed conversion ratio (FCR), which is feed intake divided by weight gain. Lastly, feed conversion ratio is defined as the average quantity of feed consumed by the animal to gain one kilogram in body (live) weight (Van der Westhuizen *et al.,* 2004). Replication of younger animals have higher growth performances, and thus by marketing these lambs at an earlier age (21 weeks or 5 months), the producer makes use of the young animal’s peak growth performance (Malik *et al.,* 1996). Only nutrients in excess of those required for maintenance can be utilised for gain. A further saving in cost would be brought about by lower non-feed costs due to the reduction in length of stay (Maree & Casey, 1993).

2.5. Sheep feedlot management

Feedlotting is the exercise of housing animals in a restricted area and providing all nutritional requirements in the form of rations. A feedlot allows producers to achieve a reliable supply of quality lamb to meet market specifications for weight and fat score (Buloke Shire Council, 2016). Al-Abri *et al.* (2014) found that sheep finishing is an economically feasible enterprise in any scale of production and produces profit margins. The use of locally accessible feed materials in supplementing sheep has been shown to be economically more feasible than keeping sheep extensively without any method of supplementation (Abebe *et al.,* 2013).

2.5.1 Economic considerations

It is perilous that a careful financial analysis be undertaken to assess the viability of feedlotting lambs before committing resources to an intensive feeding system (Duddy *et al.,* 2016). The feedlot industry in South Africa is struggling to realise economies of scale. In a feedlot, producers need to estimate the margin that exists between the present value of the lambs, and their expected value when finished. Buying light lambs to feedlot and then selling them at trade weights of below 40 kg live weight is generally not recommended. As most lambs require 10-14 kg of feed to produce 2 kg of live weight (1 kg of carcass weight), ration costs are a major issue within a feedlotting programme (Duddy *et al.,* 2016). When buying feed, feed quality, availability and price need to be considered carefully. Feeds need to be assessed on a dry matter, landed on-farm basis. Feedlotting involves financial risk. Lamb deaths, non-feeders, poor growth performances and unexpected changes in feed or market prices can affect the economic success of the venture (Duddy *et al.,* 2016). The total cost of the final carcass comprises the purchasing price of the weaner (53%), the price of feed (37.4%), overheads (5.3%), mortality and morbidity (0.5%) and marketing (3.8%) (SAFA, 2003). An analysis conducted by USAID showed that it is imperative to do a cautious financial analysis to assess the sustainability of a lamb feedlot before obligating resources to an intensive feeding system (USAID, 2009).

Van Zyl *et al.* (1999) has found that for a farmer to be sustainable in his/her farming enterprise, a consideration for profitability is required as is defined as the percentage ratio between profit earned during a particular period and the capital to realize those gains, in one way or another "interest on capital". It is thus possible for the producer to compare his interest on capital against interests from alternative investments. The main measurement of profitability in agriculture is farming or business profitability.

$$\text{Profitability on total capital} = \frac{\text{Net Farm Income (NFI)}}{\text{Average total capital utilised}} \times \frac{100}{1}$$

2.5.2 Feedlot infrastructure management and design

According to USAID (2009), when starting a feedlot there are some important things a farmer needs to take into consideration, such as construction costs and labour user-friendly feedlot, because of the constricted and flexible profit margin in feeder lamb feedlots. USAID (2009) explains that a farmer needs to make a careful selection of a well-drained site with a proper slope away from the lamb shade shed, the feed bunk and the hay rack with easy access to water. A hay storage cover and grain storage need to be placed near the feed bunk, yet with easy access to the road for the convenience of hay and grain delivery (USAID, 2008). It is suggested that the feedlot size should be determined by the number of lambs to be penned. Furthermore, as a guide, offer each lamb a minimum of five square meters of pen space; however, an additional 10 to 20 square meters per lamb will reduce social stress and the number of shy lambs. The sheep feedlot project should have four lots of 100 lambs each, totalling 400 lambs. Each lot optimally should be 1,500 square meters in size as suggested by the United States Agency for International Development (USAID, 2008). SAFA (2003) recommended that feedlots will wherever possible, be established on ground which has a mild slope, adequate to ensure the rapid run-off of rain water to prevent the pens from becoming excessively waterlogged or muddy. It further indicated that to facilitate inspection, all pens should be numbered or identified with a letter of the alphabet. Handling facilities and loading ramps should be designed and constructed to prevent animal injuries and bruising or abrasions and must prevent animals from falling or jumping off. The feedlot pens should be constructed according to specifications of pen area per size/mass class, ground surface and climatic conditions. These criteria determine the minimum pen space per animal, which may not be less than nine square meters per bovine, and two square meters per sheep (SAFA, 2003).

2.5.2.1 Feeding equipment

Feeding troughs are the most important equipment in the pen. The crib should be strategically placed so that it is easy to clean and fill. The troughs should be designed to keep roughage and concentrate during the adaptation period of the lambs. Troughs should be far from the water troughs so that the feed don't get wet. To avoid self-feeders, it is better to regularly provide fresh food for the sheep to optimise their intake. The water troughs should be washed daily to ensure clean drinking water. Water troughs should be at least 30 cm from the ground, so that no manure or soil can be kicked into the water (Optifeeds, 2016). It is very important that feed is available at all times for easy access to animals. By way of doing this, it will facilitate higher rates of gain per day, which improves overall feedlot efficiency, and it will also help to reduce the risk of digestive problems and shy feeders (MLA, 2010). Troughs can be simple and inexpensive, which will make the feedlot cost expenditure low and make the feedlot sustainable. They can be accessed from one or both sides and should be constructed to prevent lambs from standing in them and contaminating the feed (USAID, 2008). Hirning *et al.* (1994) stated that the bottom of the feed trough can be at ground level, but the edge of the trough should not be more than 15 cm above the ground to allow the lambs to easily reach over the edge of the trough. Some provision will need to be made to keep the lambs from climbing into the feed trough. This can be accomplished by placing a board over a portion of the feeder or trough, making it difficult for the lambs to stand up while in the trough.

Figure 2.6. Different feeding troughs

2.5.3 Nutritional management and basic feedlot nutrition

Hatfield *et al.* (1997) suggested that management practices to advance growth performance of ruminants include manipulating feed so that the rate of digestion is not too rapid, which could lead to digestive problems, nor too slow, which could result in poor feed efficiency rates. Feedlotters need a comprehensive knowledge of nutrition to operate a successful feedlot. Financially, it is important to minimise feed costs, yet boost live weight gain and maximise feed conversion efficiency. It is of utmost importance to the feedlotter to consider that live weight gain and feed conversion efficiency depend on the feed intake and nutrient content of the feedlot diet (Sneath & Bath, 2011). According to Neary (1997), a diet high in forages also aids in maintaining the rumen pH by increasing rumen motility and encouraging rumination. At steady intervals, feeding will help uphold constant fermentation and inhibit acidosis by maintaining a consistent population of bacteria (i.e. no sudden die-offs or explosions in microbe numbers).

2.5.3.1 Hay

Hay is commonly fed by producers who finish their own lambs, or small groups of purchased feeders. This type of diet is popular because it utilises home-grown and home-stored products, and it is not labour intensive. Lambs are usually self-fed good quality hay (>16% CP) until market weights are reached. However, to adjust lambs to feed and prevent losses from grain overload and overeating disease, lambs are usually started on medium quality hay for the first 2-3 days (Rook, 2000). Sneath & Bath (2011) showed that legumes make excellent quality hay with good crude protein (CP) levels (for example: lucerne, lablab, medics, etc.). Furthermore, legume stubbles tend to have lower CP and ME levels (for example: cowpeas, mung beans, soybeans, etc.). They suggested that caution should be taken to control potential bloating problems when legume hay is fed with grain. The fibre content is dependent on stage of growth and leaf content (e.g. mature alfalfa has a high stem to leaf ratio), and the protein content of legumes is generally higher than grass forages (Alberta Lamb Producers, 2009).

2.5.3.2 Concentrates

Research conducted by FAO (1983) indicated that the primary role of concentrate feeds is to provide concentrated sources of necessary nutrients for livestock production. It further points out that these nutrients include not only macro-nutrients of energy and protein, but also important specific nutrients such as amino acids, fatty acids, enzymes, vitamins, minerals and others. It has being shown that many ruminant production systems also use concentrate feeds. Moreover, in diary production and in fattening periods for meat production, concentrates could form a high quantity of diets (over 30% and 70% respectively) in intensive production systems. Ruminant production systems of lower intensity sometimes utilise concentrate feeds to supplement roughage-based diets, either to mitigate the seasonality of forage supplies, or to meet the higher nutrient requirements for particular classes of stock or animals in critical physiological states of draught animals (FAO, 1983). Preston & Leng (1987) have distinguished that concentrated feeds have varying roles in feeding systems for ruminant animals, depending on the roughage or forage resources available and the required levels of productivity.

2.5.3.3 Energy feeds

Rook (2000) reported that energy is provided to the feedlot lamb in three basic forms: carbohydrates (sugars, starches & cellulose digestion products) as the major source; fats (which is a minor source); and excess protein – as an expensive source of energy. Furthermore, it is shown that feeding alfalfa pellets and shelled corn diets can also become an economic issue if energy levels are not appropriate. Studies conducted by New Mexico State University (NMSU) show that energy deficiencies can cause reduced growth performance, loss of weight, reduced fertility, lowered milk production, and reduced wool quantity and quality (NMSU, n.d.). However, it is realised that the primary restraining nutrient for newly arrived feedlot cattle is energy. Dietary fat supplementation provides the opportunity for enhanced dietary energy density. Cole and Hutcheson (1987) found that 4% fat blend added to 13.4% CP diets tends to increase feed intake of stressed newly arrived cattle for the first 14 days, but not for the entire 28-day receiving period.

2.5.3.4 Protein feeds

Some studies show that protein is an expensive addition to any lamb ration, thus, excessive feeding of protein should be avoided. Protein supplementation customarily involves feeding alfalfa pellets, soybean oil meal (SBM) or urea (NPN). Feeder lambs (true ruminants), unlike young (<60 lb; 27-28 kg), early-weaned, creep-fed lambs, can utilise NPN protein sources (Rook, 2000). Protein and energy requirements are inter-dependent. Growing cells require both protein and energy for maintenance purposes, and to deposit both fat (energy) and protein in genetically determined ratios. Requirements for tissues therefore need to be thought of in terms of a desirable protein:energy ratio in the absorbed nutrients. Protein, or more specifically the essential amino acids, are provided by digestion of rumen microbial protein and 'escape' or 'bypass' proteins that pass from the rumen into the lower gut. Ruminants, including sheep, on the other hand, can manage quite well even if there are no true protein or amino acids in their diet, because all 20 amino acids, including the essential amino acids, can be synthesised from sources of non-protein nitrogen (NPN) such as urea by the microbes in the rumen. Lambs require a diet of about 15% crude protein to supply sufficient ammonia for the growth of rumen microbes; the requirements depend on their induction weight and their genetic potential for growth. Younger lambs, and lambs selected for higher growth performances and improved feed efficiency, have higher requirements for amino acids (Nolan, 2013). McGregor & McLaughlin (1980) assessed diets containing 9-21% CP, and either 12.4 or 14.4 MJ DE/kg DM for growing weaner wethers. They concluded that diets for weaner wethers should contain 18% CP. Their diets contained barley, oats and linseed meal. Some true protein will be provided by most feed ingredients. Providing a feedlot diet that is predominantly grain and is balanced for ME and crude protein, there are unlikely to be substantial benefits from including additional bypass protein sources in the diet. However, if some other minerals are limiting, or the diet is deficient in other essential nutrients, a non-specific benefit might be obtained when high-protein meals are included (McGregor & McLaughlin, 1980).

2.5.3.5 Vitamins and minerals

Optimum mineral allowances are needed to permit animals to attain their full genetic potential for optimum performance (McDowell, 2003). Kinser (2001) suggested that small stock cannot achieve their full genetic potential if their micro-nutrient needs are not met, even if they receive 100% of their protein and energy needs. Vitamins are essential nutrients. Sheep obtain their vitamins from green forage and microbial synthesis in the gut. Animal production can be limited by a deficiency of any of the essential components of a balanced diet, i.e. ME, amino acids, minerals, vitamins or water. Mark & Scott (2006) clarified that sheep with their ruminant digestive system, can make vitamins from the raw materials consumed in their diet. They do this very well with all the B-vitamins; thus, these are no concern for sheep. Consequently, when eating fresh pasture or well-made hay, no supplemental vitamins are needed. Furthermore, sheep do not eat the same amount of minerals throughout the year. They have a craving for salt and consume a complete mineral supplement to get salt. Some ingredients, such as dicalcium phosphate and especially magnesium oxide, are not very palatable; thus, intake may be lower when these ingredients are included (Mark & Scott, 2006).

2.5.4 Water management

According to Freking & McDaniel (2003), sheep and goats must have free-choice access to clean, fresh water at all times. A mature animal will drink between three-fourths to one and one-half gallons (3.4 – 6.8 litres) of water per day. Water requirements and intake increase significantly during late gestation and during lactation. Water requirements increase considerably when environmental temperatures rise above 70˚ F (21 °C) and decline with very cold environmental temperatures. An animal's nutrient requirements will increase if it has to consume cold water during cold weather. Rain, dew and snowfall may dramatically decrease free choice water intake. Various health problems are caused by inadequate water intake by animals. In addition to that, water and feed intake are completely correlated, meaning that the more feed a sheep eats, the more water is needed. It is of importance that producers at all times use common sense when providing water for animals in a feedlot. Tolera (2008) indicated that water is the most significant nutrient in animal feeding and animal health. It is the most plentiful ingredient of the animal body in all phases of growth and development. An animal's body contains 75-80% water at birth, and about 55-65% water at maturity. Furthermore, water has several vital functions in the bodies of animals, including the following:

- it is a medium in which all chemical reactions in the body take place;
- it is an ideal lubricant to transport feed;
- it aids in excretion of waste products from the body;
- it regulates body temperature; and
- it is a buffering agent to regulate the pH of body fluids.

Water is one of the cheapest, yet most over-looked feed ingredients in feeder-lamb diets. It is suggested that water should be fed free-choice and in a clean, potable form (not ice and snow). It is a must that water quality is especially important in a feedlot setting where lambs rotate back and forth between water supply and self-feeders. If waterers are not cleaned daily: 1) water quality deteriorates, 2) water intake is reduced, and 3) urinary calculi problems often result (Rook, 2000).

2.5.5 Health management

According to Meat & Livestock Australia researchers (MLA, 2010) feedlots and intensive finishing systems entail good management to ensure the deterrence of disease and the maintenance of good animal health and welfare. Specifically, nutritional, infectious and parasitic diseases are of importance.

According to USAID (2009), there are numerous health and disease issues frequently found within a feedlot system. Several numbers of health dilemmas associated to livestock are preventable, through vaccinations for common diseases, vitamin shots when entering the feedlot, proper balanced feed rations, and good daily management. Three of the more mutual health and/or disease problems found within feedlot systems are discussed below.

2.5.5.1 Acidosis

Acidosis ensues because of the extensive use of highly processed grain and low levels of roughage in beef cattle and sheep finishing diets (USAID, 2009). It was found that lambs that are not familiarised to grain, and are started on grain too fast, are prone to acidosis. Acidosis is most likely to occur when:

- lambs are being introduced to grain;
- there is a rapid escalation in grain intake; and
- there is a rapid variation of grain in the ration.

Huntington (1997) reported that ruminal, intestinal, and total tract digestibility of starch is more with steam-flaked corn and sorghum than with their dry-rolled counterparts. Owens *et al.* (1998) defined both acute and sub-acute acidosis as conditions that can follow in ruminants fed high-concentrate diets. Furthermore, acute acidosis is an explicit illness that occurs in combination with consumption of an excessive quantity of readily fermented carbohydrates, which increases the total acid supply from the rumen (Owens *et al.,* 1998).

2.5.5.1.1 Clinical findings

Morris *et al.* (2010) discovered that the quickness of onset of clinical signs varies and is subject to the nature and quantity of feed consumed and the adaptation of the animal to the diet. Moreover, unadapted animals may possibly die from quantities of feed that are readily consumed by animals conditioned to the feed. When ruminants consume excessive amounts of readily fermentable carbohydrates, ruminal pH drops below 5.5 (the normal physiological nadir). Any additional intake puts the ruminant at risk of ruminal acidosis. Intake suppression is the animal's last resort for regulating ruminal pH. Depressed dry matter intake becomes especially evident if ruminal pH falls to about 5.5 and below. Intake depression may be mediated by pH receptors and/or osmolality receptors in the rumen. Inflammation of the ruminal epithelium (rumenitis) causes pain and contributes to feed intake depression during ruminal acidosis (Morris *et al.,* 2010).

2.5.5.1.2 Treatment

It is found that animals with mild cases may recover without treatment. In more severe forms, the damage to the animal may be so extensive that even with intensive therapy only limited success will be achieved (The Merck Veterinary Manual, n.d.). According to Morris *et al.* (2010), emptying of the rumen by oral lavage or rumenotomy is indicated if circumstances permit, but this is not practical in a feedlot environment. It is significant on the onset to spot-on the acidosis and restore the hydration status of the animal: the oral administration of magnesium oxide, together with eight to 12 litres of lukewarm water (for cattle), is essential and at the same time one can administer monensin bullets (2 grams in cattle only) through the stomach tube (Stock *et al.,* 1995). The volume of water allows for the distribution of the magnesium oxide and the monensin within the rumen (The Merck Veterinary Manual, n.d).

2.5.5.1.3 Prevention and control

Primarily controlling of acidosis occurs when ruminal acidosis is contained via the technique of feeding, diet composition and diligent feed bunk management, as well as the use of ionophores such as monensin, salinomycin and lasalocid (NRC, 1996). Only monensin limits feed intake and the use of buffers in the diet such as feed lime (Stock *et al.,* 1995). Fewer ruminal lesions develop when the ratio of concentrate to roughage is decreased, and when the transition from a roughage-based to a concentrate-based diet is lengthened. Increased roughage in the ration, particularly in the starter ration, gradual step-ups in terms of starches and sugars, and multiple daily feedings increase the time of mastication and saliva flow (Zinn & Plascencia, 1996). The pH of saliva is between 8.1 and 8.3 – it is the best buffer and available in copious volumes. This increases the buffer to the rumen and provides a continuous and uniform fermentation that reduces intraruminal acidity, which in turn lowers the number of ruminal lesions and indirectly the number of liver abscesses. There are supplementary technologies such as straight fed microbials available that may promote the prevention of ruminal acidosis, more especially for cattle that have been preconditioned or backgrounded and are accustomed to feed, but for reasons such as transport, revaccination, etc., are away from feed for a protracted length of time and may overeat when given feed (Zinn & Plascencia, 1996).

2.5.5.2 Bloating

Smith (2000) and Undersander (2001) described bloating as possibly the most acquainted health condition when talking about pastures. The first symptom is often dead or distressed animals. Furthermore, it can be a sudden and fatal occurrence in sheep. Bloating is when ruminate animals consume highly digestible forage legumes (high in protein and low in fibre). Bloating is often reported as a cause of death in feedlot cattle, and it has been recognised as an important component of mortality associated with digestive disorders (Nagaraja *et al.,* 1998). Cheng *et al.* (1998) stated that bloating occurs when the animal is prevented from expelling ruminal gas, which subsequently places pressure on the diaphragm and lungs, thereby affecting breathing and potentially resulting in death. Feedlot bloating is characterised as frothy, with the formation of stable foam. Eructation of gas through the oesophagus is inhibited when the cardia is covered with foam. Neary (1997) mentioned that it causes the pH of the rumen to drop, together with an increase of gas production and binding of protein molecules into a surface film over the ruminal contents. Furthermore, all these reactions cause the gas to be trapped, and the animal blows up.

2.5.5.2.1 Prevention and treatment of bloating

Ionophores, most notably monensin, seem useful for decreasing the incidence of feedlot bloat. Feeding monensin decreases the incidence of frothy bloating on irrigated wheat pasture (Branine & Galyean, 1990). Owens *et al.* (1997) suggested that feeding less extensively processed grain to avoid feedlot bloating is probably not an economically viable alternative. As with acidosis and liver abscesses, adding roughage to the diet should slow the overall rate of fermentation, stimulate salivation, and lower acid production, thereby decreasing the chances of bloating. Feedlot bloating often occurs as cattle are transitioned from high-roughage, starter diets to high-grain, low-roughage finishing diets (Cheng *et al.,* 1998).

2.5.5.3 Bladder and kidney stones

Also known as water belly and urinary calculi, it is caused by the formation of stones within the bladder and/or kidney tracts. The bladder will eventually burst, leading to death. Bladder stones can form when rations are low in calcium in relation to phosphorous, high magnesium intakes, too little roughage (good hay), and poor water quality causing low water intake (USAID, 2009). The calculi usually lodge in either the sigmoid flexure, a large “s”-shaped curve of the penis just behind the scrotum, or in the urethral process, which is an extension of the urethra that protrudes several centimetres beyond the end of the penis. It is noted that a severe occurrence of urinary calculi is found in feeder lambs about four to six weeks after entry into the feedlot (Hartwig, 2000).

2.5.5.3.1 Prevention and treatment of bladder and kidney stones

According to USAID (2009), a feedlotter need to make sure the calcium to phosphorus ratio is correct in the ration (add ground limestone if needed), feed high quality alfalfa-grass hay (Alfalfa is high in calcium, grass is high in phosphorus), make sure the ration contains adequate fibre, and keep the water supply fresh and clean. Treatment of affected lambs may be rewarding, especially if the condition is diagnosed soon after onset. The most effective treatment is a surgical procedure called a ureterostomy, which involves amputation of the penis and suturing it to the skin in the area just below the pelvis. Chances of recovery are much less if rupture of the urinary bladder has already occurred. Amputation of the urethral process, a quick and simple procedure, is performed if the calculus is lodged in this structure (Hartwig, 2000).

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CHAPTER 3

3 MATERIALS AND METHODS

3.1 Experimental location

This project was conducted at Grootfontein Agricultural Development Institute near Middelburg in the Eastern Cape Province. The Institute is situated at latitude S 31.47167 South, longitude E 25.02767 East and 1 279 m above sea level. Middelburg is a town in the Eastern Cape province of South Africa. It lies in the Upper Karoo, with a population of 19,000. It is located in the Inxuba Yethemba Local Municipality, which is part of the Chris Hani District Municipality. Middelburg (EC) normally receives on average ± 360-370 mm of rain per year, with most rainfall occurring mainly during autumn. It receives the lowest rainfall (3 mm) in July and the highest (51 mm) in March. The monthly distribution of average daily maximum temperatures (Figure 3.1) shows that the average midday temperatures for Middelburg (EC) ranges from 15.3 °C in June to 30.2 °C in January. The region is the coldest during July when the mercury drops to 0.2 °C on average during the night.

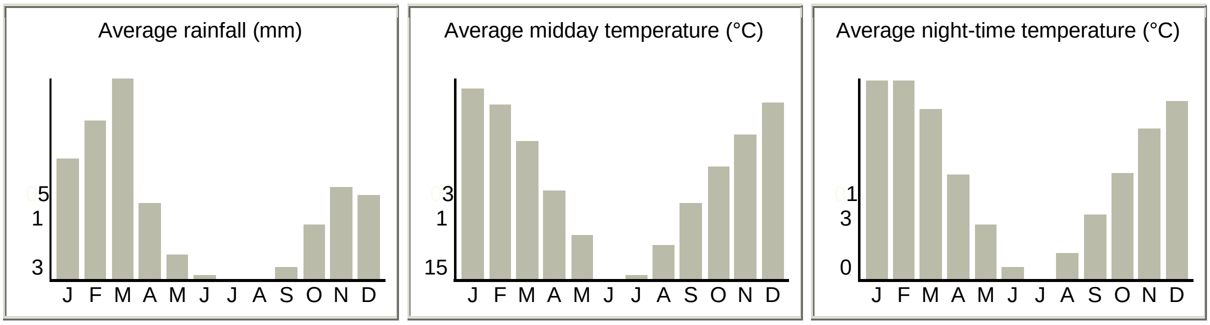

Figure 3.1. The average rainfall, midday temperature and night-time temperature values for Middelburg (EC) per month (www.saexplorer.co.za)

Grootfontein Agricultural Development Institute is a key role-player in sheep and goat production research in South Africa. The institution has built a knowledge base that supports the profitability and sustainability of the small stock sector and enhances natural resource management in small stock producing areas. The research programme is strongly client-driven and is financially supported by the industry.

Figure 3.2. Grootfontein Agricultural Development Institute (www.googleearth.co.za)

3.2 Experimental animals

Fifty (50) Ronderib X Merino lambs with an average body weight of ± 37 kg were used in this study. The lambs consisted of both male and female animals. The animals were divided on a stratified body weight and faecal egg count (FEC) basis into five (5) groups of ten (10) lambs each, namely; T0, T1, T2, T3 and T4. The lambs were tagged with individually numbered ear tags of different colours amongst groups for easy identification: T0 (white, 1-10), T1 (orange, 1-20), T2 (green, 21-30), T3 (red, 31-40) and T4 (blue, 41-50). The diets were provided in a milled form to ensure diatomaceous earth (DE) availability for the lambs. All the groups of animals were confined to pens throughout the experimental period.

3.3 Experimental diets

Animals in all the groups were provided with the same standard feedlot diet that only differs in DE inclusion levels. Diets were formulated to contain DE at four different inclusion levels, namely 0.5% (T1), 1.0% (T2), 1.5% (T3) and 2.0% (T4) of the diet. T0 (0% DE) served as the control group. The DE was included as part of the feedlot diet. The animals were fed two times a day at 7:00 and 16:00 respectively. The feeding time was followed precisely to accommodate the animals as creatures of habit, and to ensure a healthy constant rumen environment. The feeding troughs and water troughs were cleaned regularly to ensure that animals receive fresh feed and water. The left-over feed was removed and weighed every Thursday. The average daily intake was initially 1.4-1.5 kg per animal per day. At the end of the feeding period (2 weeks adaptation and 6 weeks project) it was expected that the animals would weigh about 45-47 kg on average. If an average body weight of 40-42 kg is taken for the calculation of feed intake, it can be assumed that the average feed intake would be about 1.6-1.7 kg per animal per day. Over a 7-8 week feeding period, it would equate to about 800-850 kg feed mixture per group of 10 animals.

3.3.1 Adaptation of the animals

A few bales of unmilled lucerne hay were made available for the adaptation period. An adaptation period of 14 days was allowed for the animals to familiarise themselves to the feedlot environment. During this period the animals initially received only lucerne hay for Day 1 and 2 to get them adapted to the feedlot environment. Thereafter the feedlot diets were introduced separately from the lucerne hay and increased gradually, for example Day 3 – 150 g, Day 4 – 300 g, Day 5 – 450 g, Day 6 – 600 g, Day 7 – 750 g, Day 8 – 900 g, Day 10 – 1200 g, Day 11 – 1350 g and Day 12 – 1500 g. During the adaptation period, lucerne hay was always available, but provided at a decreased quantity while the intake of the feedlot diets increased.

3.3.2. Composition of the experimental diets

The feed mixtures for all the groups were mixed at the same time to ensure uniformity. After mixing, the feed was placed in feed bags and each bag was marked with the group name (T0, T1, T2, T3 and T4) and weighed. The weight of the feed bags was also written on the bags to avoid confusion during feeding. All the feed bags of each group were put together in the store. A register was kept at the store to record the amount of feed that was given to the animals to ensure proper accountability of feeds used. At the end of each week, the left-over feed in the troughs were weighed back to determine the weekly feed intake of the different groups.

Table 3.1: Composition of the feedlot diets

Ingredients	**T0 (%)**	**T1 (%)**	**T2 (%)**	**T3 (%)**	**T4 (%)**
Lucerne hay	50	50	50	50	50
Maize	38.1	38.1	38.1	38.1	38.1
Feed grade urea	0.5	0.5	0.5	0.5	0.5
Cotton oil cake meal	2.5	2.5	2.5	2.5	2.5
Molasses meal	8.0	8.0	8.0	8.0	8.0
Feed lime	0.6	0.6	0.6	0.6	0.6
Salt	0.3	0.3	0.3	0.3	0.3
Diatomite (DE)	0	0.5	1.0	1.5	2.0

The amount of each feed used in the mixing of the feed depended on the batch size that was mixed at once, e.g. for a batch size of 100 kg, the amount of each feed that was mixed was the same as the percentages in the above table. The control group received 0% DE inclusion, Treatment 1 (T1) 0.5%, Treatment 2 (T2) 1.0%, Treatment 3 (T3) 1.5% and Treatment 4 (T4) 2.0%. The commercial DE product used contained 700 g diatomite per kg of product.

For every 100 kg of feed mixture the inclusion level of the diatomite was as follows:

- Control group: 0.0% diatomite = 0 kg diatomite
- Treatment 1: 0.5% = 0.5 kg diatomite = 0.71 kg diatomite product
- Treatment 2: 1.0% = 1.0 kg diatomite = 1.43 kg diatomite product
- Treatment 3: 1.5% = 1.5 kg diatomite = 2.14 kg diatomite product
- Treatment 4: 2.0% = 2.0 kg diatomite = 2.86 kg diatomite product.

3.4 Experimental layout and procedure

Faecal samples were taken and the sheep were weighed prior to treatments being applied. Lambs were then allocated to the different groups in order for each group to be balanced for live body weight and FEC. Faecal collections were done at 2-hour intervals between 8:00 and 16:00 to determine the average FEC before the start of the project. Ten animals per group were placed in pens where they were fed in groups. The groups consisted of four treatment groups and one control group. The control group (T0) received 0.0% DE inclusion, Treatment 1 (T1) 0.5%, Treatment 2

(T2) 1.0%, Treatment 3 (T3) 1.5% and Treatment 4 (T4) 2.0%. The animals were allowed to adapt to the diets for 14 days before the data collection started. Lamb weights were recorded before the start of the treatment, and again weekly for the duration of the project. Faecal samples were collected before the start of the project and again two-weekly for the duration of the project. Eye muscle area (*longissimus dorsi*) and fat depth were measured at the start and again at the end of the project before slaughtering. Lambs were slaughtered after a 46-day feeding period (20 July to 04 September 2017). Before slaughtering, an electronic stunner was used at a rate of 1 amp for 1 to 3 seconds to induce the brain of the animal. The animals were slaughtered by experienced abattoir officials at the Grootfontein A.D.I. abattoir.

3.5 Data collection

The following data were recorded:

3.5.1 Initial body weight

The lambs were weighed at the start of the project before they were divided into their respective groups.

3.5.2 Body weight

Body weights of the lambs were recorded on an empty stomach after the adaptation period immediately before treatments started and on a weekly basis thereafter until the animals were slaughtered.

Figure 3.3. Weighing of animals

3.5.3 Faecal egg count

Faecel samples were collected from the rectum of all the lambs at the start of the project and thereafter on a two-weekly basis and sent to the Provincial Veterinary Laboratory at Grootfontein for faecal egg counts. There are different types of faecal collection procedures for animals, but the one outlined below was used (USDA, 2017):

- Put on a clean glove. Apply a nickel size amount of water or water-based lubricant to index and middle fingers.

- Insert index and middle fingers into the rectum of the animal, one finger at a time. No need to go very deep. Spread fingers to allow air into the rectum. The air duplicates fullness in the rectum and a wave of muscular movement will often move faeces out into your hand.

- Remove 4 grams of faecal matter. A good-sized adult pellet is about 1 gram.

- Peel the glove off your hand, keeping the faecal sample encased within it.

- Squeeze as much air as possible out of the glove. Twist the wrist portion of the glove and fasten with a label (farm and animal ID) making sure the label sticks to itself, as it won't stick to the glove. You can also twist and tie off the glove and label the glove itself with an indelible marker.

3.5.4 Feed intake

The amount of feed supplied per group was recorded daily. Feed intake per group was determined by weighing back the left-over feeds on a weekly basis.

Figure 3.4. Animals being fed diets in an open feed trough

Figure 3.5. Weighing of feed ingredients

3.5.5 Carcass measurements and grading

At the end of the experimental period, the animals were brought to the nearby Grootfontein A.D.I. abattoir for slaughtering. The animals were fasted overnight, and the fasted body weight was recorded the next day before slaughtering. Fasted animals were weighed before slaughtering, while warm carcass weight and the amount of kidney and abdominal fat was recorded just after slaughtering. The animals were slaughtered at the GADI abattoir using standard slaughtering techniques. The carcasses were hung in a cooler at ± 2 °C for 48 hours. After 48 hours, the cold carcass weight and the following carcass measurements were taken as described by Bruwer & Naudé (1987), Bruwer *et al.* (1987a), and Bruwer *et al.* (1987b):

- hind leg length (cm);
- hind leg circumference (cm);
- carcass length (cm);
- fat depth between the 3rd and 4th sacral vertebrae, 25 mm from the carcass midline (V1, mm);
- fat depth between the 3rd and 4th sacral vertebrae, 50 mm from the carcass midline (V2, mm); and
- fat depth between the 3rd and 4th lumbar vertebrae, 25 mm from the carcass midline (V3, mm).

3.5.6 Other measurements and calculations

The weight of the lungs, liver, head, feet, offal and heart were also recorded for each animal. Carcasses were graded according to the South African classification system (Agricultural Product Standards Act; Act No. 1999 of 1990; Government Notice No. R. 1948, 26 June 1992). Carcass yield (dressing percentage) and growth performance (average daily gain) from the start of the trial until slaughter were calculated from the recorded data for individual animals, while feed intake (FI) was calculated for each group. Dressing percentage (carcass yield), was calculated as cold carcass weight divided by slaughter weight, multiplied by 100. Average daily gain (ADG) was calculated as end weight (slaughter weight) minus starting weight, divided by number of days in the feedlot.

3.6. Ultrasound measurements

The back-fat thickness and eye muscle area were measured with an ultrasound scanner on Day 1 and again after six weeks just before the animals were slaughtered.

Figure 3.6. PIE Medical Falco 100 ultrasound scanner

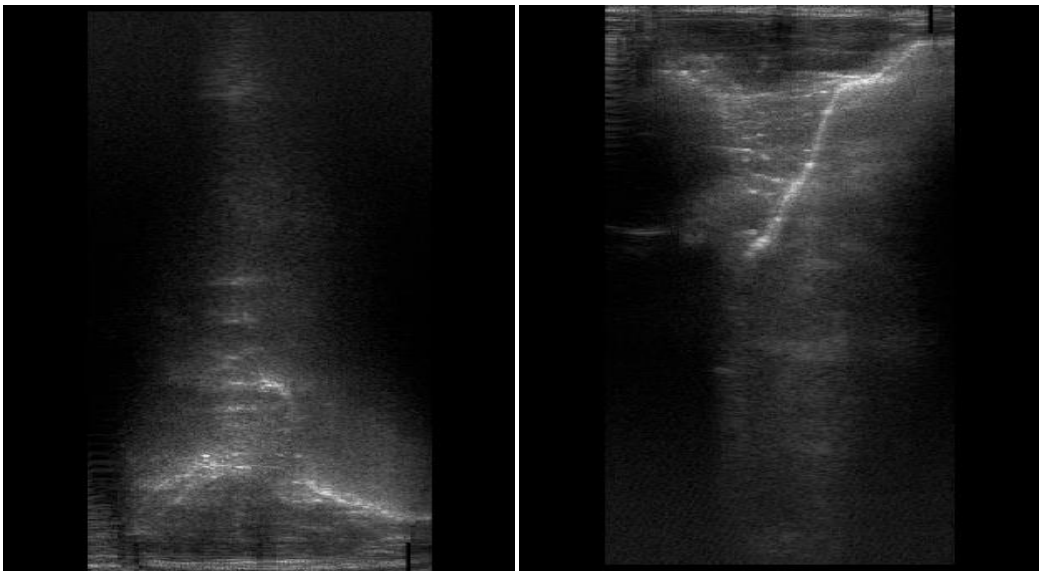

Figure 3.7. Ultrasound images of the eye muscle area and fat thickness on the rump

Ultrasonic measurements were taken by a veterinary technologist at the Grootfontein Agricultural Development Institute, using a PIE Medical Falco 100 ultrasound scanner. The location of the transducer placement by palpation was between the 12th and 13th ribs on the left side of each animal. Before contact with the transducer, the location was shorn, oiled, made dirt free and then oiled again. A super flab guide was used to ensure proper contact between the flat ultrasound transducer and the curvature of the animal’s back. All the animals were measured on at the start of the project and again at the end of the project just before slaughtering.

Figure 3.8. Trimming of wool and oiling of the area to be scanned

3.7 Statistical analysis

The General Linear Model (GLM) procedure of SAS was used to determine the effect of different DE inclusion levels in feedlot diets on the weekly body weights, ADG, FEC, eye muscle area, fat depth and carcass characteristics of the lambs (SAS, 2009). A predetermined significance level of $P < 0.05$ was used for all comparisons.

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3.8 References

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CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

Osweiler & Carson (1997) reported that there are many sheep producers, counting those in certified organic production programmes, who believe that they cannot raise sheep without using some growth promoters and synthetic parasiticides. There has been wide usage of growth promoters as a strategy to improve productivity, and great benefits have been observed throughout the meat production chain. However, the restrictions of growth promoters in several countries, as well as consumer rejection, have led industry and the academy to search for alternatives (Valenzuela-Grijalva *et al.,* 2017). Al-Dobaib & Mousa (2009) reported that growth promoters have been used in meat production for several decades to increase parameters such as daily weight gain and feed efficiency.

Diatomaceous earth (DE) with a composition of less than 7% of crystalline silica is commonly accepted as a safe feed additive in Canada and the U.S. and is accepted as a feed supplement by organisations such as the FDA and USDA (Bennett *et al.*, 2011, Köster, 2013). Diatomaceous earth is frequently publicised as an effective and alternative anthelmintic for sheep, goats, cattle, poultry and other livestock, and is classified as a feed ingredient for livestock health care (Beltran & Martin, 2015). McLean *et al.* (2005) reported that the siliceous material injures the invertebrate cuticle (arthropods and nematodes), which increases penetrability and then causes death by dehydration.

Many sustainable and organic livestock producers use diatomaceous earth (DE) as a method of parasite control to reduce the use of and reliance on synthetic drugs (Macher, 1992). In addition, many producers also claim that animal performance increases when DE is offered, although there is little scientific evidence of its effectiveness. Research reports from various non-peer reviewed, but potentially credible sources, give similar findings. However, Milton & Klopfenstein (2000) found no advantage in feeding DE with regard to intestinal parasites and coccidia when using faecal initiation and egg counts per gram of faeces.

4.2 Growth parameters / body weight data

The average weekly body weights of lambs from the different treatment groups obtained during the feedlot trial are summarised in Table 4.1. There were no significant differences ($P > 0.05$) between the different groups (T0, T1, T2, T3 & T4) in terms of weekly body weights, body weight change (BWC) and average daily gain (ADG). These results concur with the results reported by Osweiler & Carson (1997). They found that the lambs receiving the DE-supplemented feed showed slightly more weight gain (30 lbs for the DE group and 28 lbs for the control group) over a 66-day pasture trial, but the difference was not statistically significant. Hence, the value of DE for improved performance was not demonstrated. Even though Treatment 3 in the current study showed the highest and Treatment 0 the lowest BWC and ADG, no significant differences ($P > 0.05$) were observed between the groups.

Table 4.1: Mean (± S.E.) weekly body weights, body weight change and average daily gain of lambs from the different treatment groups

Parameter	Treatment 0	Treatment 1	Treatment 2	Treatment 3	Treatment 4
Week 1	37.76 ± 1.48[a]	37.51 ± 1.42[a]	37.39 ± 1.48[a]	37.54 ± 1.42[a]	37.52 ± 1.42[a]
Week 2	36.89 ± 1.44[a]	36.93 ± 1.38[a]	37.08 ± 1.44[a]	36.92 ± 1.38[a]	36.81± 1.38[a]
Week 3	39.57 ± 1.47[a]	38.51 ± 1.42[a]	38.40 ± 1.47[a]	38.90 ± 1.42[a]	38.45 ± 1.42[a]
Week 4	40.51 ± 1.61[a]	39.52 ± 1.55[a]	39.38 ± 1.61[a]	40.09 ± 1.55[a]	40.02 ± 1.55[a]
Week 5	40.83 ± 1.68[a]	40.13 ± 1.61[a]	40.68 ±1.68[a]	42.03 ± 1.61[a]	41.48 ± 1.61[a]
Week 6	42.20 ± 1.68[a]	42.56 ± 1.61[a]	43.26 ± 1.68[a]	43.86 ± 1.61[a]	43.55 ± 1.61[a]
Week 7	43.96 ± 1.71[a]	44.41 ±1.65[a]	44.35 ± 1.71[a]	44.76 ±1.65[a]	44.83 ± 1.65[a]
Week 8	44.68 ± 1.72[a]	45.27 ± 1.65[a]	44.89 ± 1.72[a]	45.68 ± 1.65[a]	45.53 ± 1.65[a]
Body weight change (BWC) (kg)	6.91 ± 0.72[a]	7.76 ± 0.69[a]	7.49 ± 0.72[a]	8.14 ± 0.69[a]	8.01 ± 0.69[a]
Average daily gain (ADG) (g)	150.22 ± 15.56[a]	168.66 ± 14.97[a]	162.83 ± 15.56[a]	176.90 ± 14.97[a]	174.09 ± 14.97[a]

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

BWC = End weight – Start weight

ADG = End weight – Start weight / Number of days in feedlot

The mean weekly body weights of the ram and ewe lambs are summarised in Table 4.2. The results show that there were significant differences (P < 0.05) between the mean weekly body weights of the ram and ewe lambs from the start until the end of the trial. The male lambs showed a higher ADG (175.76 ± 10.37) and BWC (8.09 ± 0.51) compared to their female counterparts (ADG = 157.32 ± 8.80; BWC = 7.24 ± 0.40). These differences were, however, not significant (P > 0.05). These findings confirm the results of the study by Schanbacher & Crouse (1980), where the rams grew more rapidly and efficiently than wethers. Seideman *et al.* (1982) reported that it is generally accepted that male lambs grow faster than ewes because they utilise feed more efficiently. Feedlot diets are linked with faster growth performances (Crouse *et al.,* 1981; Arnold & Meyer, 1988; Santos-Silva *et al.,* 2002) and because of this fact, it enables male lambs to fully exhibit their superiority in growth over ewe lambs (Crouse *et al.,* 1981; Seideman *et al.,* 1982; Arnold & Meyer, 1988; Notter *et* *al.,* 1991). The advantage of male lambs' growth performance is ascribed to the presence of testicular hormones, particularly testosterone (Scanbacher & Crouse 1980).

Scrotal size has been associated with ovulation rate, litter size, and age at puberty in several species (sheep, Hanrahan and Quirke, 1988; swine, Proud *et al*., 1976; mice, Islam *et al*., 1976). Serum testosterone level has a high relationship with sexual performance of rams during mating (Sanford et al., 1977). A peak in estradiol is associated with behavioral estrus in the ewe (Norman *et al*., 1968; Plotka and Erb, 1969). Furthermore, sex hormones such as testosterone and estradiol are modified by the hypothalamo-pituitary axis a genetic link between male sexual behaviour and female reproductive performance may be measurable.

Table 4.2: Mean (± S.E.) weekly body weights, body weight change and average daily gain of the ram and ewe lambs

Parameter	Ram lambs	Ewe lambs
Week 1	39.57 ± 0.96[a]	35.52 ± 0.84[b]
Week 2	38.90 ± 0.96[a]	34.95 ± 0.81[b]
Week 3	40.73 ± 0.98[a]	36.80 ± 0.83[b]
Week 4	41.97 ± 1.08[a]	37.83 ± 0.91[b]
Week 5	43.28 ± 1.12[a]	38.79 ± 0.95[b]
Week 6	45.54 ± 1.12[a]	40.63 ± 0.95[b]
Week 7	46.90 ± 1.14[a]	42.02 ± 0.97[b]
Week 8	47.66 ± 1.14[a]	42.76 ± 0.97[b]
Body weight change (BWC) (kg)	8.09 ± 0.51[a]	7.24 ± 0.40[a]
Average daily gain (ADG) (g)	175.76 ± 10.37[a]	157.32 ± 8.80[a]

[ab] Means with different superscripts between ram and ewe lambs differ significantly ($P < 0.05$)

BWC = End weight – Start weight

ADG = End weight – Start weight / Number of days in feedlot

4.3 Eye muscle area and fat depth data

The results of the eye muscle area and fat depth measurements are shown in Table 4.3. There were no significant differences in the eye muscle area (EMA) (start) ($P > 0.05$) between the different treatment groups, with eye muscle area of T3 showing the highest value (9.19 ± 0.31 cm^2). As far as eye muscle area (end) is concerned, again no differences ($P > 0.05$) were observed between the treatments. No significant differences ($P > 0.05$) in fat depth (start) (FDS) were observed between the treatments. Fat depth (end) (FDE) of Treatment 4 was significantly higher ($P < 0.05$) than Treatment 1 and 2 but did not differ from the other treatments. Eye muscle area change (EMAC) indicated no significant differences ($P > 0.05$) between treatments. However, fat depth change (FDC) of Treatment 4 was significantly higher ($P < 0.05$) than Treatment 2, but it did not differ from the other treatments.

Table 4.3: Mean (± S.E.) eye muscle area, fat depth, eye muscle area change and fat depth change of the different treatment groups

Parameter	Treatment 0	Treatment 1	Treatment 2	Treatment 3	Treatment 4
Eye muscle area (start) (cm^2)	8.41 ± 0.32^a	8.88 ± 0.30^a	8.71 ± 0.32^a	9.19 ± 0.31^a	9.17 ± 0.31^a
Eye muscle area (end) (cm^2)	10.39 ± 0.41^a	10.38 ± 0.39^a	10.53 ± 0.41^a	10.58 ± 0.39^a	10.69 ± 0.39^a
Fat depth (start) (mm)	0.36 ± 0.03^a	0.36 ± 0.03^a	0.38 ± 0.03^a	0.39 ± 0.03^a	0.39 ± 0.03^a
Fat depth (end) (mm)	0.61 ± 0.04^{ab}	0.56 ± 0.03^b	0.55 ± 0.04^b	0.59 ± 0.03^{ab}	0.68 ± 0.03^a
Eye muscle area change (cm^2)	1.99 ± 0.24^a	1.50 ± 0.22^a	1.82 ± 0.24^a	1.39 ± 0.23^a	1.52 ± 0.23^a
Fat depth change (mm)	0.24 ± 0.04^{ab}	0.20 ± 0.04^{ab}	0.17 ± 0.04^b	0.20 ± 0.04^{ab}	0.29 ± 0.04^a

^{ab} Means with different superscripts differ significantly ($P < 0.05$)

The mean eye muscle area, fat depth, eye muscle area change, and fat depth change of the ram and ewe lambs are presented in Table 4.4. It was found that there were no significant differences ($P > 0.05$) in the mean eye muscle area, fat depth, eye muscle area change and fat depth change of the ram and ewe lambs in this study. However, the EMAC (1.73 ± 0.14) and FDC (0.23 ± 0.02) of the ewe lambs were higher than the EMAC (1.56 ± 0.15) and FDC (0.21 ± 0.03) of the ram lambs although not significant ($P > 0.05$). Pannier *et al.* (2014) reported higher levels of intramuscular fat for female lambs (4.20 ± 0.04) than males (4.10 ± 0.04).

Table 4.4: Mean (± S.E.) eye muscle area and fat depth of the ram and ewe lambs

Parameter	Ram lambs	Ewe lambs
Eye muscle area (start) (cm^2)	8.98 ± 0.21^a	8.76 ± 0.19^a
Eye muscle area (end) (cm^2)	10.54 ± 0.27^a	10.49 ± 0.24^a
Fat depth (start) (mm)	0.39 ± 0.02^a	0.36 ± 0.02^a
Fat depth (end) (mm)	0.60 ± 0.02^a	0.59 ± 0.02^a
Eye muscle area change (cm^2)	1.56 ± 0.15^a	1.73 ± 0.14^a
Fat depth change (mm)	0.21 ± 0.03^a	0.23 ± 0.02^a

^{ab} Means with different superscripts between ram and ewe lambs differ significantly ($P < 0.05$)

4.4 Faecal egg count data

The results of the effect of diatomaceous earth (DE) on the faecal egg counts of feedlot lambs are presented in Table 4.5. As the lambs were divided into groups at the start of the project based on a stratified body weight and faecal egg count basis, Roundworms 1 at the start of the project (20 July 2017) did not differ significantly ($P > 0.05$) between the different treatment groups. Roundworms 2 (10 August 2017) also did not differ ($P > 0.05$) between the different treatment groups. With regard to Roundworms 3 (24 August 2017), T0 and T1 differed significantly ($P < 0.05$) from T2 and T4 but did not differ ($P > 0.05$) from T3. T2 had the lowest roundworm count (460.00 ± 193.59) on this collection date. At the end of the project (31 August 2017), the Roundworms 4 count of T1 was significantly higher ($P < 0.05$) than T4, but did not differ from T0, T2 and T3. In general, there was a decline in the roundworm counts from the start to the end of the project.

With regard to coccidia, no significant differences ($P > 0.05$) between the treatments were observed at the beginning (20 July 2017) of the project. Coccidia 2 counts (10 August 2017) also did not differ significantly ($P > 0.05$) between the different treatments. There was, however, an increase in the coccidia counts of the groups from the first to the second collection date. For Coccidia 3 (24 August 2017), T2

(1458 ± 283) was significantly higher ($P < 0.05$) than T0 but did not differ from the other three treatments. A general increase in coccidia counts was also observed during this period. At the end of the project (31 August 2017), T1 differed significantly ($P < 0.05$) from T0, T2, T3 and T4. At the end of the trial, Treatment 4 had the lowest coccidia count, but in general the coccidia counts increased from the start of the project until the end, indicating that DE did not have an effect on coccidia.

Table 4.5: Mean (± S.E.) faecal egg counts (roundworms and coccidia) of the different treatment groups

Parameter	Treatment 0	Treatment 1	Treatment 2	Treatment 3	Treatment 4
Roundworms 1 (20 July 2017)	2043 ± 829^{a}	2117 ± 798^{a}	2058 ± 829^{a}	2038 ± 798^{a}	1946 ± 798^{a}
Roundworms 2 (10 August 2017)	1065 ± 326^{a}	817.50 ±325.98^{a}	800.00 ± 325.98^{a}	1388 ± 314^{a}	856.67 ± 354.88^{a}
Roundworms 3 (24 August 2017)	1413 ± 204^{a}	1121 ± 187^{a}	460.00 ± 193.59^{b}	912.50 ± 186.29^{ab}	537.50 ± 186.29^{b}
Roundworms 4 (31 August 2017)	770.00 ± 168.66^{ab}	933.33 ± 162.29^{a}	452.50 ± 168.66 ^{ab}	708.33 ± 162.29^{ab}	325.00 ± 162.29^{b}
Coccidia 1 (20 July 2017)	195.00 ± 104.80^{a}	370.83 ± 100.85^{a}	160.00 ± 104.80^{a}	108.33 ± 100.85^{a}	120.83 ± 100.85^{a}
Coccidia 2 (10 August 2017)	302.50 ± 148.55^{a}	580.00 ± 148.55^{a}	407.50 ± 148.55^{a}	408.33 ± 142.94^{a}	376.67 ± 161.72^{a}
Coccidia 3 (24 August 2017)	350.00 ± 298.52^{a}	745.83 ± 272.51^{ab}	1458 ± 283^{b}	662.50 ± 272.51^{ab}	795.83 ± 272.51^{ab}
Coccidia 4 (31 August 2017)	355.00 ± 366.84^{a}	2358 ± 353^{b}	1133 ± 367^{a}	283.33 ± 352.99^{a}	237.50 ± 352.99^{a}

^{ab} Means with different superscripts in different treatment groups differ significantly ($P < 0.05$)

The faecal egg counts of the ram and ewe lambs are indicated in Table 4.6. Roundworm counts did not differ significantly (P > 0.05) between ram and ewe lambs from the start until to the end of the project (Roundworms 1, 2, 3 and 4). A similar trend was observed in the coccidia counts of ram and ewe lambs, where a significant difference (P < 0.05) between the ram and ewe lambs only occurred at the last collection date (Coccidia 4). In this study, the ram lambs in general had higher roundworm and coccidia counts than the ewe lambs. Stear *et al.* (1995) and Abuargob *et al.* (2015) reported that egg counts in male lambs were consistently higher than females. Barger (1993) reported that the differences between females and intact males could be due to the influence of female endocrine hormones on the immune system. Females have been found to carry lower egg counts than males, and they also have stronger immune responses, especially parasite-specific IgA (Strain *et al.,* 2002).

Table 4.6: Mean (± S.E.) faecal egg counts (roundworms and coccidia) of the ram and ewe lambs

Parameter	Ram lambs	Ewe lambs
Roundworms 1 (20 July 2017)	2010.00 ± 552.59[a]	2070.00 ± 468.89[a]
Roundworms 2 (10 August 2017)	1106.67 ± 224.45[a]	864.00 ± 191.11[a]
Roundworms 3 (24 August 2017)	950.00 ± 129.06[a]	827.33 ± 112.51[a]
Roundworms 4 (31 August 2017)	695.00 ± 112.44[a]	580.67 ± 95.41[a]
Coccidia 1 (20 July 2017)	220.00 ± 69.87[a]	162.00 ± 59.28[a]
Coccidia 2 (10 August 2017)	416.67 ± 102.28[a]	413.33 ± 87.09[a]
Coccidia 3 (24 August 2017)	975.00 ± 188.80[a]	629.67 ± 164.59[a]
Coccidia 4 (31 August 2017)	1300.00 ± 244.56[a]	446.67 ± 207.52[b]

[ab] Means with different superscripts in different treatment groups differ significantly (P < 0.05)

4.5 Slaughter, carcass, fat measurements and internal / other organs data

Slaughter, carcass, fat measurements and internal / other organs data of the different treatment groups, as well as ewe and ram lambs, are summarised in Table 4.7, 4.8, 4.9 and 4.10. The slaughter weight, warm and cold carcass weight, carcass yield, carcass length, hind leg length and hind leg circumference did not different significantly ($P > 0.05$) between the different treatment groups. This is supported by Santos-Silva *et al.* (2002), where no difference in dressing percentage from lambs at 24 and 30 kg live weight was found. The tail weight of T3 and T4 differed significantly ($P < 0.05$) from T0, T1 and T2.

There were significant differences ($P < 0.05$) in slaughter weight (kg), warm carcass weight (kg), cold carcass weight (kg) and cold carcass weight without tail (kg) between the ram and ewe lambs. Tail weight (g), carcass yield (kg), carcass length (cm), hind leg length (cm) and hind leg circumference (cm) did not differ ($P > 0.05$) between the two sexes. Similar results were found by Hawkins *et al.* (1985). Although not significant ($P > 0.05$), ram lambs in this study had a higher dressing percentage (carcass yield) than ewe lambs. This finding does not concur with the findings of other studies performed by Mahgoub & Lodge (1998), Vergara *et al.* (1999), Wellington *et al.* (2003) and Wolf *et al.* (2001), who reported higher dressing percentages in ewe lambs than ram lambs.

The V1 and V2 fat measurement of T3 (12.92 ± 1.26; 11.58 ± 1.09) differed significantly ($P < 0.05$) from T2 (8.75 ± 1.19; 8.15 ± 1.04), but they did not differ from T0, T1 and T4. The V3 fat measurement did not differ significantly ($P > 0.05$) between treatments. The weight of the head and feet, liver, heart, kidneys and abdominal fat of the different treatments did not differ significantly ($P > 0.05$). The weight of the offal of T3 and T4 differed significantly ($P < 0.05$) from each other, but not from the other treatments. The weight of the lungs of T0 and T4 also differed significantly ($P < 0.05$) from each other, but not from the other treatments.

The V1 and V2 fat measurements of the ram and ewe lambs differed significantly ($P < 0.05$), with higher values for the ram lambs. The weight of the head and feet and the offal of the ram lambs were also significantly higher ($P < 0.05$) than the ewe lambs. The results in this study regarding the fat measurements do not concur with results from the literature. Generally female lambs tend to deposit more fat than male lambs. Zgur *et al.* (2003) found that differences between sexes were statistically significant ($P < 0.05$) for dressing percentage and carcass fatness, with female animals having higher dressing percentages and fatness scores. Vergara & Gallego (1999) concurred that higher carcass fatness was found in females than males.

Table 4.7: Mean (± S.E.) carcass measurements of the different treatment groups

Parameter	Treatment 0	Treatment 1	Treatment 2	Treatment 3	Treatment 4
Slaughter weight (kg)	44.67 ± 1.72[a]	44.54 ± 1.56[a]	44.88 ± 1.72[a]	46.30 ± 1.82[a]	45.53 ± 1.66[a]
Warm carcass weight (kg)	21.52 ± 0.96[a]	21.57 ± 0.87[a]	21.15 ± 0.96[a]	22.28 ± 1.01[a]	22.10 ± 0.92[a]
Cold carcass weight (kg)	21.11 ± 0.94[a]	21.15 ± 0.85[a]	20.77 ± 0.94[a]	21.91 ± 0.99[a]	21.67 ± 0.91[a]
Tail weight (kg)	0.39 ± 0.03[a]	0.41 ± 0.03[a]	0.33 ± 0.03[a]	0.43 ± 0.03[b]	0.42 ± 0.03[b]
Cold carcass weight without tail (kg)	20.71 ± 0.92[a]	20.74 ± 0.83[a]	20.45 ± 0.92[a]	21.48 ± 0.97[a]	21.23 ± 0.89[a]
Carcass yield (%)	47.11 ± 0.55[a]	47.42 ± 0.50[a]	46.19 ± 0.55[a]	47.35 ± 0.58[a]	47.46 ± 0.53[a]
Carcass length (cm)	111.52 ± 1.79[a]	111.84 ± 1.61[a]	113.84 ± 1.79[a]	113.65 ± 1.88[a]	112.15 ± 1.72[a]
Hind leg length (cm)	51.90 ± 0.89[a]	52.14 ± 0.80[a]	52.17 ± 0.89[a]	52.12 ± 0.94[a]	51.52 ± 0.85[a]
Hind leg circumference (cm)	66.26 ± 1.25[a]	67.22 ± 1.13[a]	66.72 ± 1.25[a]	67.58 ± 1.32[a]	67.04 ± 1.20[a]

[ab] Means with different superscripts in different treatment groups differ significantly ($P < 0.05$)

Table 4.8: Mean (± S.E.) carcass measurements of the ram and ewe lambs

Parameter	Ram lambs	Ewe lambs

Slaughter weight (kg)	47.59 ± 1.15[a]	42.78 ± 0.99[b]
Warm carcass weight (kg)	22.99 ± 0.64[a]	20.45 ± 0.55[b]
Cold carcass weight (kg)	22.56 ± 0.63[a]	20.09 ± 0.54[b]
Tail weight (kg)	0.42 ± 0.02[b]	0.37 ± 0.02[a]
Cold carcass weight without tail (kg)	22.12 ± 0.62[a]	19.72 ± 0.53[b]
Carcass yield (%)	47.33 ± 0.37[a]	46.88 ± 0.32[a]
Carcass length (cm)	114.09 ± 1.19[a]	111.10 ± 1.03[a]
Hind leg length (cm)	52.65 ± 0.59[a]	51.29 ± 0.51[a]
Hind leg circumference (cm)	67.35 ± 0.83[a]	66.58 ± 0.72[a]

[ab] Means with different superscripts in different treatment groups differ significantly ($P < 0.05$)

Table 4.9: Mean (± S.E.) fat measurements, head & feet, offal and internal organ weights of the different treatment groups

Parameter	Treatment 0	Treatment 1	Treatment2	Treatment 3	Treatment 4
V1 fat (mm)	10.15 ± 1.19^{a}	11.30 ± 1.08^{a}	8.75 ± 1.19^{ab}	12.92 ± 1.26^{ac}	11.17 ± 1.15^{a}
V2 fat (mm)	8.52 ± 1.04^{a}	8.97 ± 0.94^{a}	8.15 ± 1.04^{ab}	11.58 ± 1.09^{ac}	9.33 ± 1.00^{a}
V3 fat (mm)	9.12 ± 1.09^{a}	9.70 ± 0.99^{a}	9.20 ± 1.09^{a}	11.17 ± 1.15^{a}	10.54 ± 1.05^{a}
Weight of head & feet (kg)	3.28 ± 0.10^{a}	3.36 ± 0.09^{a}	3.32 ± 0.10^{a}	3.42 ± 0.11^{a}	3.35 ± 0.09^{a}
Weight of offal (kg)	8.64 ± 0.51^{a}	8.98 ± 0.46^{a}	8.98 ± 0.51^{a}	9.34 ± 0.54^{ac}	7.71 ± 0.49^{ab}
Weight of lungs (kg)	0.50 ± 0.05^{ab}	0.59 ± 0.04^{a}	0.58 ± 0.05^{a}	0.59 ± 0.05^{a}	0.68 ± 0.04^{ac}
Weight of liver (kg)	0.84 ± 0.05^{a}	0.83 ± 0.04^{a}	0.84 ± 0.05^{a}	0.87 ± 0.05^{a}	0.84 ± 0.05^{a}
Weight of heart (kg)	0.24 ± 0.02^{a}	0.28 ± 0.02^{a}	0.25 ± 0.02^{a}	0.27 ± 0.02^{a}	0.26 ± 0.02^{a}
Weight of kidneys (kg)	0.13 ± 0.01^{a}	0.15 ± 0.01^{a}	0.15 ± 0.01^{a}	0.15 ± 0.01^{a}	0.14 ± 0.01^{a}
Weight of abdominal fat (kg)	1.28 ± 0.15^{a}	1.16 ± 0.13^{a}	1.27 ± 0.15^{a}	1.29 ± 0.16^{a}	1.28 ± 0.14^{a}

^{abc} Means with different superscripts in different treatment groups differ significantly ($P < 0.05$)

Table 4.10: Mean (± S.E.) fat measurements, head & feet, offal and internal organ weights of the ram and ewe lambs

Parameter	Ram lambs	Ewe lambs
V1 fat (mm)	12.93 ± 0.79[a]	8.78 ± 0.69[b]
V2 fat (mm)	11.28 ± 0.69[a]	7.34 ± 0.60[b]
V3 fat (mm)	10.67 ± 0.73[a]	9.23 ± 0.63[a]
Weight of head & feet (kg)	3.52 ± 0.07[a]	3.17 ± 0.06[b]
Weight of offal (kg)	9.47 ± 0.34[a]	7.99 ± 0.29[b]
Weight of lungs (kg)	0.61 ± 0.03[a]	0.58 ± 0.03[a]
Weight of liver (kg)	0.85 ± 0.03[a]	0.84 ± 0.03[a]
Weight of heart (kg)	0.27 ± 0.01[a]	0.24 ± 0.01[a]
Weight of kidneys (kg)	0.15 ± 0.01[a]	0.14 ± 0.00[a]
Weight of abdominal fat (kg)	1.31 ± 0.09[a]	1.21 ± 0.08[a]

[ab] Means with different superscripts in different treatment groups differ significantly ($P < 0.05$)

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CHAPTER 5

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

The aim of this project is to assess the effect of different levels of DE on the growth performance, carcass characteristics and faecal egg counts of lambs receiving feedlot diets.

This research report consists of five chapters. Chapter 1 focuses on the introduction of the research study and includes the problem formulation, the research goal, objectives and hypothesis. The chapter also includes the ethical aspects, definitions of some of the main concepts and concludes with the limitations within this study.

Chapter 2 is the literature study on the effect of dietary inclusion levels of diatomaceous earth on production, carcass characteristics and faecal egg count of lambs. This chapter focused on different opinions from various authors regarding the uses and benefits of using DE in dietary inclusion to improve the performance of lambs in the feedlot.

Chapter 3 addresses the research methodology and the research method that was chosen is scientific in nature. The chapter also describes the experimental location, experimental animals, experimental diets, and experimental layout and procedure and data collection methods.

Chapter 4 consists of the results and discussions of the empirical study and discusses the research data after the results were analysed. The analysis of the quantitative data is discussed in this chapter and the qualitative data is analysed and presented in identified themes.

Chapter 5 is the summary, conclusions and recommendations of all the previous chapters, as well as an evaluation of the research goal, objectives and hypothesis.

The limitation in this study is the lack of more research studies or information on the use of DE in animal production. Most of the information presented is based on testimonials from users, not from scientific results.

5.2 Conclusion

The inclusion of different levels (0, 0.5, 1.0, 1.5 and 2 percent) of DE to assess the effect thereof on the growth performance, carcass characteristics and faecal egg counts of lambs receiving feedlot diets did not yield positive results. Diatomaceous earth used as a feed supplement for feedlot lambs did not significantly reduce parasite loads as measured by faecal egg counts. DE also had no significant effect on weight gain (average daily gain) of lambs consuming a feedlot diet containing up to 2.0 percent DE during the feedlot trial that lasted for 46 days. Also, with regard to carcass traits, eye muscle area and fat depth, the inclusion of different levels of DE had no significant effect on most of the traits. Despite the widespread interest in using diatomaceous earth (DE) as a growth promoter and natural anthelmintic, few studies have evaluated its efficacy.

Although diatomaceous earth has been shown to have insecticidal properties, information about the use of this product for gastrointestinal nematode control is scarce and unimpressive, as seen in many reported cases discussed in this study. Controlled studies with published results including sheep, goats and cattle have reported little or no significant impact of diatomaceous earth products on gastrointestinal nematode infection indicators.

5.3 Recommendations

Further investigations of alternative natural additives in feedlot diets that will assist DE need to be conducted, as the results of this study show that DE alone is ineffective. More scientific studies with feedlot diets should be done by increasing the inclusion levels of DE rather than using the generally recommended norm/standard. Recently, research shows that the role of silicon is based primarily on humans and rats, therefore further research needs to be done on how much silicon per se can affect specifically inorganic trace element uptake in livestock.

CHAPTER 6

ADDENDUM A

Effect of dietary inclusion levels of diatomaceous earth on production, carcass characteristics and faecal egg count of lambs

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Abstract

The aim of this study was to assess the effect of different levels of diatomaceous earth (DE) on the growth performance, carcass characteristics and faecal egg counts of lambs receiving feedlot diets. A total number of fifty (50) Ronderib X Merino lambs with a mean body weight of ± 37 kg were used in this study. The animals were divided on a stratified body weight and faecal egg count (FEC) basis into five (5) groups of ten (10) lambs each, namely; T0, T1, T2, T3 and T4. Diets were formulated to contain different DE inclusion levels of 0, 0.5, 1.0, 1.5 and 2.0% respectively. Body weights of all the animals were recorded weekly, while faecal samples were collected on a two-weekly basis to determine FEC. Eye muscle areas (*longissimus dorsi*) and fat depth were measured at the start and again at the end of the project before slaughtering. After a 46-day feeding period (20 July – 04 September 2017) the lambs were fasted overnight and slaughtered. The following carcass measurements were recorded: warm and cold carcass weight, hind leg length, hind leg circumference, carcass length, V1, V2 and V3 fat depth and abdominal fat weight. No significant differences were observed between the different groups in terms of weekly body weights, body weight change (BWC) and average daily gain (ADG). The inclusion of different DE levels did not have a significant effect on most of the eye muscle area, fat depth, carcass and fat measurements. The results also did not show a positive response in FEC with the inclusion of different levels of DE. Therefore, it can be concluded that DE at different inclusion levels did not have a significant effect on most of the measured traits.

Keywords: Lambs, faecal egg count, growth, diatomaceous earth
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Introduction

Sheep farming is one of the common enterprises in South Africa and plays a vital role in the livestock industry (Brundyn *et al.,* 2005). There are about 20 sheep breeds in South Africa, including amongst others, the Merino, Dorper, Mutton Merino, Dohne Merino, Dormer and the Black-headed Persian (DAFF, 2010). The price of mutton has increased considerably over the last decades because of the decreased numbers of sheep produced in South Africa. Merino type sheep such as the Dohne

Merino, South African Mutton Merino and non-woollen types such as the Dormer and Dorper are regarded as the key sheep breeds in South Africa suitable for intensive rearing and finishing in feedlots (Van der Westhuizen, 2010; Cloete *et al.,* 2012). Lawrie (1998) stated that animal growth is defined as an increase in bodyweight that is attained by hypertrophy and hyperplasia until a mature size is reached, which is supplemented by changes in body conformation. Maximisation of an animal's growth performance and minimisation of the number of days in the feedlot are influenced by feedlot diets (Notter *et al.,* 1991). To be able to obtain the individual daily intake, average daily gain (ADG) and feed conversion ratio (FCR) for each lamb, the weights of the lambs must be recorded weekly, along with feed intake (Brand *et al.,* 2017). Feedlot diets are intended to maximise growth performance and minimise the number of days on feed (Notter *et al.,* 1991).

Diatomaceous earth (DE), also known as diatomite, is a naturally occurring substance comprised of the fossilised remains of diatoms, a type of hard-shelled algae. Diatomite is defined as a soft, chalk-like sedimentary rock that is easily crumbled into a fine white to off-white powder (Uses for Diatomaceous Earth /Animal Production, 2018). Diatoms are microscopic-sized, hard-shelled organisms which originated in both marine and fresh waters. The diatom shells are covered in sharp spines that make them dangerous to exo-skeletal insects, but not to animals with internal skeletons (Hagan, 1999). Diatomite consists of approximately 33% silicon, 19% calcium, 5% sodium, 3% magnesium, 2% iron and many other trace minerals such as titanium, boron, manganese, copper and zirconium (Diatomaceous organisation, n.d). Diatomite has been acknowledged as an organic product for animal health and nutrition. It is mined all over the world, and in South Africa it is mined from seven different sources in the Olifantshoek area in the Northern Cape Province (Koster, 2010). It is used as a filtration aid, as a mild abrasive, and as a mechanical insecticide, for animal health and in animal feeding. The aim of this project is to assess the effect of different levels of DE on the growth performance, carcass characteristics and faecal egg counts of lambs receiving feedlot diets.

Materials and Methods

This project was conducted at Grootfontein Agricultural Development Institute near Middelburg in the Eastern Cape Province. The Institute is situated at latitude S 31.47167 South, longitude E 25.02767 East and 1 279 m above sea level. Middelburg is a town in the Eastern Cape province of South Africa. It lies in the Upper Karoo and has an average rainfall of ± 360 mm per year, with most rainfall occurring mainly during autumn. It receives the lowest rainfall (3mm) in July and the highest (51mm) in March. The average midday temperatures for Middelburg (EC) range from 15.3°C in June to 30.2°C in January. The region is the coldest during July when the mercury drops to 0.2°C on average during the night (The South African Weather Bureau Services, n.d).

Fifty (50) Ronderib X Merino lambs with an average body weight of ± 37 kg were used in this study. The animals were divided on a stratified body weight and faecal egg count (FEC) basis into five (5) groups of ten (10) lambs each, namely T0, T1, T2, T3 and T4. All the groups of animals were confined to pens throughout the experimental period. The animals in all the groups were provided with the same standard feedlot diet that only differs in DE inclusion levels. Four different DE inclusion levels were used: 0.5% (T1), 1.0% (T2), 1.5% (T3) and 2.0% (T4) of the diet. T0 (0% DE) served as the control group. The DE was included as part of the feedlot diet. The animals were supplied with unmilled lucerne hay for the adaptation period of 14 days. During this period the animals initially received only lucerne hay for Day 1 and 2 to get them adapted to the feedlot environment. Thereafter the feedlot diets were introduced separately from the lucerne hay and increased gradually while the lucerne hay was decreased. The animals were fed twice a day at 7:00 and 16:00 respectively. The left-over feed was removed and weighed once a week to determine feed intake. The feeding troughs and water troughs were cleaned regularly to ensure that animals receive fresh feed and water.

Lamb weights were recorded before the start of the treatment and on a weekly basis thereafter for the duration of the project. Eye muscle areas (*longissimus dorsi*) and fat depth were measured at the start and again at the end of the project before slaughtering. Faecal samples were collected from the rectum of all the lambs at the start of the project, and thereafter on a two-weekly basis, and were sent to the laboratory for faecal egg counts. Faecal collection procedures for animals were done according to the specifications of the USDA (2017). The fat depth and eye muscle area were measured using a PIE Medical Falco 100 ultrasound scanner on Day 1, and again after six weeks just before the animals were slaughtered.

The lambs were slaughtered after a 46-day feeding period. The animals were fasted overnight, and the fasted body weight was recorded the next day before slaughtering. The animals were slaughtered at the GADI abattoir using standard slaughtering techniques. Warm carcass weight and the amount of kidney and abdominal fat were recorded just after slaughtering. The carcasses were kept in a cooler at ± 2 °C for 48 hours. After 48 hours, the cold carcass weight and the following carcass measurements were taken as described by Bruwer & Naudé (1987), Bruwer *et al.* (1987a) and Bruwer *et al.* (1987b): Hind leg length (cm), Hind leg circumference (cm), Carcass length (cm), Fat depth between the 3rd and 4th sacral vertebrae, 25 mm from the carcass midline (V1, mm), Fat depth between the 3rd and 4th sacral vertebrae, 50 mm from the carcass midline (V2, mm), Fat depth between the 3rd and 4th lumbar vertebrae, 25 mm from the carcass midline (V3, mm). Carcass yield (dressing percentage) and growth performance (average daily gain) from the start of the trial until slaughter were calculated from the recorded data of the individual animals.

The General Linear Model (GLM) procedure of SAS was used to determine the effect of different DE inclusion levels in feedlot diets on the weekly body weights, ADG, FEC, eye muscle area, fat depth, carcass characteristics and fat measurements of the lambs (SAS, 2009).

Results and discussions

The average starting and end body weights, body weight change (BWC) and average daily gain (ADG) of the lambs from the different groups are presented in Table 1. There were no significant differences ($P > 0.05$) between the different groups (T0, T1, T2, T3 & T4) in terms of body weights, body weight change (BWC) and average daily gain (ADG). These results concur with those from a study by Osweiler & Carson (1997) where no significant differences were found in the weight gain of grazing lambs receiving a DE-supplemented feed compared to a control group (no DE). Even though Treatment 3 in the current study showed the highest and Treatment 0 the lowest BWC and ADG, no significant differences (P > 0.05) were observed between the groups.

Table 1 Mean (± S.E.) body weights, body weight change and average daily gain of lambs from the different treatment groups

Parameter	Treatment 0	Treatment 1	Treatment 2	Treatment 3	Treatment 4
Start weight (kg)	37.76 ± 1.48^{a}	37.51 ± 1.42^{a}	37.39 ± 1.48^{a}	37.54 ± 1.42^{a}	37.52 ± 1.42^{a}
End weight (kg)	44.68 ± 1.72^{a}	45.27 ± 1.65^{a}	44.89 ± 1.72^{a}	45.68 ± 1.65^{a}	45.53 ± 1.65^{a}
Body weight change (kg)	6.91 ± 0.72^{a}	7.76 ± 0.69^{a}	7.49 ± 0.72^{a}	8.14 ± 0.69^{a}	8.01 ± 0.69^{a}
Average daily gain	150.22 ± 15.56^{a}	168.66 ± 14.97^{a}	162.83 ± 15.56^{a}	176.90 ± 14.97^{a}	174.09 ± 14.97^{a}

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

The eye muscle area (EMA) and fat depth (FD) measurements of the lambs from the different groups are presented in Table 2. There were no significant differences in the eye muscle area (EMA) (start) (P > 0.05) between the different treatment groups, with eye muscle area of T3 showing the highest value. With regard to eye muscle area (end), again no differences (P > 0.05) between the treatments were observed. No significant differences (P > 0.05) in fat depth (start) (FDS) between the treatments were observed. Fat depth (end) (FDE) of Treatment 4 was significantly higher (P < 0.05) than Treatment 1 and 2, but it did not differ from the other treatments. Eye muscle area change (EMAC) indicated no significant differences (P > 0.05) between treatments. However, fat depth change (FDC) of Treatment 4 was significantly higher (P < 0.05) than Treatment 2, but it did not differ from the other treatments.

Table 2 Mean (± S.E).eye muscle area, fat depth and change in eye muscle area and fat depth from the start to the end of the project of the different groups

Parameter	Treatment 0	Treatment 1	Treatment 2	Treatment 3	Treatment 4
Eye muscle area (start) (cm^2)	8.41 ± 0.32^{a}	8.88 ± 0.30 ^{a}	8.71 ± 0.32^{a}	9.19 ± 0.31^{a}	9.17 ± 0.31^{a}
Eye muscle area (end) (cm^2)	10.39 ± 0.41^{a}	10.38 ± 0.39^{a}	10.53 ± 0.41^{a}	10.58 ± 0.39^{a}	10.69 ± 0.39^{a}
Fat depth (start) (mm)	0.36 ± 0.03^{a}	0.36 ± 0.03^{a}	0.38 ± 0.03^{a}	0.39 ± 0.03^{a}	0.39 ± 0.03^{a}
Fat depth (end) (mm)	0.61 ± 0.04^{ab}	0.56 ± 0.03^{b}	0.55 ± 0.04^{b}	0.59 ± 0.03^{ab}	0.68 ± 0.03^{a}
Eye muscle area change (cm^2)	1.99 ± 0.24^{a}	1.50 ± 0.22^{a}	1.82 ± 0.24^{a}	1.39 ± 0.23^{a}	1.52 ± 0.23^{a}
Fat depth change (mm)	0.24 ± 0.04^{ab}	0.20 ± 0.04^{ab}	0.17 ± 0.04^{b}	0.20 ± 0.04^{ab}	0.29 ± 0.04^{a}

^{ab} Means with different superscripts differ significantly (P < 0.05)

The faecal egg counts (FEC) of the lambs from the different groups are presented in Table 3. As the lambs were divided into groups at the start of the project based on a stratified body weight and faecal egg count basis, Roundworms 1 at the start of the project (20 July 2017) did not differ significantly (P > 0.05) between the different treatment groups. Roundworms 2 (10 August 2017) also did not differ (P > 0.05) from one another. With regard to Roundworms 3 (24 August 2017), T0 and T1 differed significantly (P < 0.05) from T2 and T4, but did not differ (P > 0.05) from T3. T2 had the lowest Roundworm count (460.00 ± 193.59) on this collection date. At the end of the project (31 August 2017), the Roundworms 4 count of T1 was significantly higher (P < 0.05) than T4, but it did not differ from T0, T2 and T3. In general, there was a decline in the roundworm counts from the start to the end of the project. With regard to coccidia counts, no significant differences (P > 0.05) between the treatments were observed at the onset (20 July 2017) of the project. Coccidia 2 counts (10 August 2017) also did not differ significantly (P > 0.05) between the different treatments. For Coccidia 3 (24 August 2017), T2 (1458 ± 283) was significantly higher (P < 0.05) than T0, but did not differ from the other three treatments. At the end of the project (31 August 2017), T1 differed significantly (P < 0.05) from T0, T2, T3 and T4 for Coccidia 4. In general, the coccidia counts of the groups increased from the start until the end of the project. The FEC results of this study are in agreement with a study by Osweiler & Carson (1997) with grazing lambs fed DE in a supplemental ration where no significant difference in faecal egg/gram counts and abomasal gastro-intestinal larval counts were found in control vs. DE-fed lambs.

Table 3 Mean (± S.E.) faecal egg counts of the different treatment groups

Parameter	Treatment 0	Treatment 1	Treatment 2	Treatment 3	Treatment 4
Roundworms1 (20 July 2017)	2043 ± 829^a	2117 ± 798^a	2058 ± 829^a	2038 ± 798^a	1946 ± 798^a
Roundworms 2 (10 August 2017)	1065 ± 326^a	818 ± 326^a	800 ± 326^a	1388 ± 314^a	857 ± 355^a
Roundworms 3 (24 August 2017)	1413 ± 204^a	1121 ± 187^a	460 ± 194^b	913 ± 186^a	538 ± 186^b
Roundworms 4 (31 August 2017)	770 ± 169^a	933 ± 162 ^{a}	453 ± 169^b	708 ± 162^a	325 ± 162^b
Coccidia 1 (20 July 2017)	195 ± 105^a	371 ± 101^a	160 ± 105^a	108 ± 101^a	121 ± 101^a
Coccidia 2 (10 August 2017)	303 ± 149^a	580 ± 149^a	408 ± 149^a	408 ± 143^a	377 ± 162^a
Coccidia 3 (24 August 2017)	350 ± 299^a	746 ± 273^a	1458 ± 283^b	663 ± 273^a	796 ± 273^a
Coccidia 4 (31 August 2017)	355 ± 367^a	2358 ± 353^b	1133 ± 367^a	283 ± 353^a	238 ± 353^a

^{ab} Means with different superscripts in different treatment groups differ significantly (P< 0.05)

The carcass measurements of the lambs from the different groups are presented in Table 4. The slaughter weight, warm and cold carcass weight, carcass yield, carcass length, hind leg length and hind leg circumference did not differ significantly (P > 0.05) between the different treatment groups. Santos-Silva *et al.* (2002) also reported no differences in dressing percentage of lambs at 24 and 30 kg live weight.

Table 4 Mean (± S.E.) carcass measurements of the different treatment groups

Parameter	Treatment 0	Treatment 1	Treatment 2	Treatment 3	Treatment 4
Slaughter weight (kg)	44.67 ± 1.72^a	44.54 ± 1.56^a	44.88 ± 1.72^a	46.30 ± 1.82^a	45.53 ± 1.66^a
Warm carcass weight (kg)	21.52 ± 0.96^a	21.57 ± 0.87^a	21.15 ± 0.96^a	22.28 ± 1.01^a	22.10 ± 0.92^a
Cold carcass weight (kg)	21.11 ± 0.94^a	21.15 ± 0.85^a	20.77 ± 0.94^a	21.91 ± 0.99^a	21.67 ± 0.91^a
Carcass yield (%)	47.11 ± 0.55^a	47.42 ± 0.50^a	46.19 ± 0.55^a	47.35 ± 0.58^a	47.46 ± 0.53^a
Carcass length (cm)	111.52 ± 1.79^a	111.84 ± 1.61^a	113.84 ± 1.79^a	113.65 ± 1.88^a	112.15 ± 1.72^a
Hind leg length (cm)	51.90 ± 0.89^a	52.14 ± 0.80^a	52.17 ± 0.89^a	52.12 ± 0.94^a	51.52 ± .85^a
Hind leg circum-ference (cm)	66.26 ± 1.25^a	67.22 ± 1.13^a	66.72 ± 1.25^a	67.58 ± 1.32^a	67.04 ± 1.20^a

^{ab} Means with different superscripts in different treatment groups differ significantly (P < 0.05)

The fat measurements of the lambs from the different groups are presented in Table 5. The V1 and V2 fat measurement of T3 differed significantly (P < 0.05) from T2, but they did not differ from T0, T1 and T4. The V3 fat measurement did not differ significantly (P > 0.05) between treatments. The weight of the abdominal fat of the different treatments also did not differ significantly (P > 0.05).

Table 5 Mean (± S.E) fat measurements of the different treatment groups

Parameter	Treatment 0	Treatment 1	Treatment 2	Treatment 3	Treatment 4
V1 fat (mm)	10.15 ± 1.19^{a}	11.30 ± 1.08^{a}	8.75 ± 1.19^{ab}	12.92 ± 1.26^{bc}	11.17 ± 1.15^{a}
V2 fat (mm)	8.52 ± 1.04^{a}	8.97 ± 0.94^{a}	8.15 ± 1.04^{ab}	11.58 ± 1.09^{bc}	9.33 ± 1.00^{a}
V3 fat (mm)	9.12 ± 1.09^{a}	9.70 ± 0.99^{a}	9.20 ± 1.09^{a}	11.17 ± 1.15^{a}	10.54 ± 1.05^{a}
Abdominal fat weight (kg)	1.28 ± 0.15^{a}	1.16 ± 0.13^{a}	1.27 ± 0.15^{a}	1.29 ± 0.16^{a}	1.28 ± 0.14^{a}

^{abc} Means with different superscripts in different treatment groups differ significantly (P < 0.05)

Conclusions

The inclusion of different levels (0 to 2 percent) of diatomaceous earth (DE) did not have a significant effect on the growth performance and most of the carcass and fat measurements of lambs receiving feedlot diets. DE also did not significantly reduce parasite loads as measured by means of faecal egg counts. Further investigations of alternative natural additives in feedlot diets that will assist DE need to be conducted, as the results of this study indicate that DE alone seems to be ineffective as a growth promoter and to reduce internal parasite loads.

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Authors' Contributions

The trial was executed by ATN, while PJF and JHH provided supervision.

Conflict of Interest Declaration

The authors declare that there is no conflict of interest.

Disclaimer

The authors of this paper do not endorse the use of any of the supplements used in this study.

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