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THE EVALUATION OF THE NUTRITIVE VALUE OF BAOBAB SEED CAKE AND MACADAMIA OIL CAKE AS FEED FOR RUMINANTS

By

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A thesis submitted in fulfillment of the requirements for the degree of Doctor of Philosophy in Agriculture (Animal Science)

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DECLARATION

I, Masiza Samuel Mikasi, hereby declare that this thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy in Agriculture at the Department of Animal Science, School of Agriculture, University of Venda by me is of my own work and investigation, and has not previously been submitted for a degree at this or any other university. Reference material contained in this proposal has been duly acknowledged.

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M.S. Mikasi

DEDICATION

This thesis is dedicated to my departed father Mr. Masenyani Daniel Mikasi. His dream was for his children to attain the highest qualifications.

ACKNOWLEDGEMENTS

I would like to show my sincere gratitude to my main promoter Prof. J.J. Baloyi for the professional and moral support he gave me throughout this study. I would also like to thank Dr. E. Bhebhe my co-promoter for his professional support. You joined the team at the right time. Let me take this opportunity to thank Mr. A.J. Netshipale for his moral support you gave me even when you were in the Nertherlands. My sincere gratitude goes to Mr. Mashudu Rambau for the technical support throughout the study. To Mr. M.E. Nyathi, your help with the laboratory work is insurmountable and for the lack of words, I wish to say thank you very much.

I extend my special gratitude to Mr. Paul Grey (GiyaMlimi farm) for allowing me to use your facilities and technical staff on the farm to carry out the growth and apparent digestibility trials. To my research assistants Messers Mulaudzi M. and Makgahlela C, thank you very much for the sacrifices and hard work you put into the execution of the research experiments.

To my wife and kids I appreciate the sacrifices you made during my studies. Thank you very much for your support and understanding.

ABSTRACT

Horticultural by-products such as seed and nut oil residues have the potential to replace conventional protein and energy sources in diets for ruminants.

The objective of the study was to evaluate the nutritive value of Macadamia oil cake and Baobab seed cake as nutrient supplements for feedlot animals. Several experiments were carried-out to evaluate the nutritive value of Macadamia oil cake and Baobab seed cake as feed for ruminants. The nutrient composition of the cakes were determined using both proximate and modern methods of analysis of feeds and a t-test was used to compare the means of Macadamia oil cake and Baobab seed cake. The *in sacco* technique was used to determine the rumen degradability parameters of dry matter, crude protein and Amino acids of the cakes. This experiment was conducted using a completely randomized design. A three step-in vitro technique was used to conduct a post ruminal digestibility trial and the study was arranged in a completely randomized design. An apparent digestibility trial was conducted using metabolism cages and fecal bags to avoid the mixing of urine and faeces and the experiment was carried out as a completely randomized design arranged in a 2 x 2 factorial. A growth trial was conducted using a completely randomized block design arranged in a 2x2 factorial with two protein supplements and two inclusion levels as factors and blocked by sex of the lambs.

The two cakes had similar ($P>0.05$) dry matter, fat, hemicellulose and gross energy contents. Baobab seed cake had significantly ($P<0.05$) higher ash, crude protein, acid detergent lignin and nitrogen free extract than macadamia oil cake. Macadamia oil cake had significantly ($P<0.05$) higher crude fiber, acid detergent fiber, neutral detergent fiber and cellulose concentrations. Baobab seed cake had significantly ($P<0.05$) higher calcium, magnesium, potassium, phosphorus (macroelements), zinc, and copper than macadamia oil cake. Macadamia oil cake was significantly ($P<0.05$) higher in manganese and iron contents than Baobab seed cake. Sodium content was not significantly ($P>0.05$) different between the two cakes. Baobab seed cake had more (Tryptophan, Cysteine, Arginine, Aspartic acid, Glutamic acid, Valine, Phenylalanine, Isoleucine, Leucine) Amino acids which were significantly ($P<0.05$) higher in quantity than macadamia oil cake with the two cakes having similar ($P>0.05$) remaining Amino acids contents. Generally Macadamia oil cake had more ($P<0.05$) saturated and mono-unsaturated fatty acids than Baobab seed cake whereas Baobab seed cake had more ($P<0.05$) poly-unsaturated fatty acids.

The *in sacco* rumen degradability characteristics of baobab seed cake and macadamia oil cake were estimated for dry matter and crude protein of the cakes. Macadamia oil cake had significantly (P<0.01) higher a value for dry matter than boabab seed cake. Baoaba seed cake had significantly (P<0.01) higher a value for crude protein than macadamia oil cake. the b, c, and a+b values for dry matter of both Baobab seed cake and Macadamia oil cake were not significantly (P>0.05) different form each other. However, the potential degradability (a+b) value for crude protein of baobab seed cake was significantly (P<0.01) higher than that of macadamia oil cake. The b and c constants of the two cakes for crude protein were not significantly (P>0.05) different from each other. The ED (Effective degradability) values calculated at three outflow rates (0.02, 0.05, 0.08) were estimated for dry matter and crude protein of Baobab seed cake and macadamia oil cake. The ED of the two cakes calculated at 0.02 outflow rate did not significantly (P>0.05) differ from each other. However, baobab seed cake had significantly (P<0.05) higher ED value at outflow rate of 0.05 whereas macadamia oil cake had significantly (P<0.05) higher ED value calculated at outflow rate of 0.08. The ED values of baobab seed cake for crude protein calculated at the three outflow rate were significantly (P<0.01) higher than those of macadamia oil cake. The two cakes did not significantly (P>0.05) differ in dry matter ruminal degradability but baobab seed cake had significantly (P<0.05) higher ruminal crude protein disappearance from 16 to 72 hours of incubation than macadamia oil cake. The *in situ* Amino acid degradation was determined on 0, 12, 16, 24, and 48 hour of ruminal incubation of the cakes' samples and generally they were significant (P<0.05) differences for both cakes according to different incubation periods. The 3-step *in vitro* digestibility trial revealed that baobab seed cake had significantly (P<0.05) higher dry matter, crude protein and Amino acids digestibility values than macadamia oil cake. Apparent digestibility study revealed that nutrient intake, faecal and urine outputs, and digestibility of nutrients were not significantly (P>0.05) different between baobab seed cake and macadamia oil cake. However, lambs on 10% macadamia cake having retained significantly (P<0.05) more nitrogen than the lambs on 15% macadamia oil cake, 10% and 15% baobab seed cakes diets. However, the inclusion of either baobab seed cake or macadamia oil cake at 10% or 15% in the diets of lambs did not significantly (P>0.05) affect the DOMR, microbial protein yield and purine derivates output.

For the growth trial the lambs were offered four diets formulated to contain 10% MOC (control), 15% MOC, 10 BSC and 15% BSC. The inclusion of 15% MOC and 10% BSC in the diets of lambs did not significantly (P>0.05) affect their final body weight, total weight gain, average daily feed intake, average daily weight gain, warm and cold carcass masses between these two

groups. The inclusion of 10% MOC and 15% BSC in the diets of lambs did not significantly affect average daily feed intake and animal performance between these two groups. However, lambs on 10% MOC and 15% BSC had significantly (P<0.05) higher average daily feed intake and animal performance compared to lambs on 15% MOC diet. The feed conversion efficiency and of the lambs in the four diets were not significantly (P>0.05) different. The dressing percentage, carcass length, neck weight, fat thickness, body weight thickness and rib eye area of the carcasses of lambs in this trial did not differ significantly (P>0.05) except for spleen and skin with lambs on 10% BSC diets having the least skin weight and lambs on 10% MOC diet having heaver spleens.

Generally BSC had higher (P<0.05) nutrient content than MOC. BSC and MOC were highly degradable in the rumen whereas BSC was higly digestible post-ruminally compared to MOC. The diets of fattening lambs formulated to include 10% or 15% of BSC or MOC as protein supplements did not affect the apparent digestibility of the diets. Macadamia oil cake can be incomporated in the diet of finishing lambs as a protein supplement at 10% inclusion level without compromising the growth and carcass characteristics of the lambs. Baobab seed cake as a protein supplement can be included in the diet of finishing lambs at up to 15% inclusion level without deleteriously compromising on the growth and carcass characteristics of the animals.

Keywords: chemical composition, degradability, post ruminal digestibility, growth performance, sheep, MOC, BSC

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LIST OF ABBREVIATIONS

%	percentage
^{0}C	Degrees celcius
a	Zero time interception
AA	Amino acid
ADF	Acid detergent fibre
ADFI	Average daily feed intake
ADG	Average daily gain
ADL	Acid detergent lignin
AM	after morning
ANOVA	Analysis of variance
AOAC	Association of Official Analytical Chemistry
b	Slowly degradable fraction
BSC	Baobab seed cake
BSM	Baobab seed meal
BWT	Body weight thickness
c	Rate of degradation
Ca	Calcium
CCM	Cold carcass mass
CF	Crude fibre
CL	Carcass length
cm	centimeters
CP	Crude protein
DM	Dry matter
DOMR	Digestible organic matter fermented in the rumen
DP	Dressing percentage
ED	Effective degradability
EE	Ether extract
FA	Fatty acid
FBW	Final body weight
FCR	Feed conversion ratio
FT	Fat thickness
g	grams

GE	Gross energy
HCL	Hydrochloric acid
IBW	Initial body weight
IND	Intestinal nutrient digestion
IVCPD	*In vitro* crude protein digestibility
IVD	*In vitro* digestibility
IVDMD	*In vitro* dry matter digestibility
k	Outflow rate
kg	Kilograms
KH_2PO_4	Potassium dihydrogen phosphate
L	litre
Ltd	Limited
M	mole
Max	Maximum
ME	Metabolizable energy
mg	milligrams
Min	Minimum,
MJ	Mega joules
mm	millimeters
MN	Microbial nitrogen yield
MNC	Macadamia nut cake
MOC	Macadamia oil cake
MSC	Marula seed cake
N	Nitrogen
Na	Sodium
NDF	Neutral detergent fibre
NFE	Nitrogen free extractives
NRC	National Research Council
NRD	Nutrient remaining after digestion
ns	Not significant
NTK	Noord Transvaal Koperasie
NW	Neck weight
OM	Organic matter

P	Phosphorus
p	Nutrient disappearance over time
Pa	Equivalent amounts of purine absorbed
PD	Potential degradability
ppm	Parts per million
PTY	private
RCPD	Rumen crude protein degradability
RD	Rumen degradability
RDMD	Rumen dry matter degradability
REA	Rib eye area
RUAA	Rumen undegraded Amino acid
RUN	Rumen undegraded nutrient
RUP	Rumen undegraded protein
RUR	Rumen undegraded residue
SAPA	South African Poultry Association
SEM	Standard error mean
TMR	Total mixed ration
TWG	Total weight gain
UK	United Kingdom
USA	United States of America
WCM	Warm carcass traits

CHAPTER 1: INTRODUCTION

1.1 Background

The most commonly used protein supplements for feedlot animals in South Africa are soyabean meal, sunflower oil cake and cotton seed cake. Henning (1999) indicated that feed accounts for 70-80% of the variable costs of intensive feeding of livestock. Protein and energy are considered basic feed components that belong to the abnormally high-cost of concentrate feeds of ruminants, because of the continuous increases in their prices (Mustafa and Alamin, 2012). Protein is an expensive but essential nutrient for animal performance (Dabiri and Thoney, 2004). Protein and energy constituents of the feed materials are positively related to a better growth performance of ruminant animals (Khalid *et al*., 2012). The supplementation of animal rations with a protein source is necessary to meet the protein and Amino acid requirements of the animal for a better performance (WHO, 2007). In developing countries, ruminants are mainly fed crop residues and generally receive only 62% of their crude protein requirements (Sarwar *et al*. 2002).
Recently in a South African context the cost of purchasing protein supplements shows an increasing trend on a year to year basis. The price of soyabean meal and sunflower oil cake per ton in South Africa from 2006 to 2016 ranged from R1800 – R6300 and R1400 – R4900, respectively (SAPA, 2016).

These conventional seed cakes have become unaffordable to small-scale and subsistence sheep and cattle farmers due to their continued rise in prices as well as the transport costs due to the distance between the production sites and the location of the farmers especially those in Vhembe and Mopani districts of Limpopo Province (South Africa). This is partly due to the fact that often farmers have to travel for more than 100 km to the place where the cakes are produced.

The rise in the prices of soybean and sunflower meals reported by SAPA (2016), as well as the lack of suppliers of these conventional oilcakes to small-scale farmers in Vhembe district warrants a search for locally produced alternative feed raw materials which can be used as protein supplements for ruminants. Some of the by-products produced from the horticultural processing industry along the Levubu valley possess protein quantities required to become a protein supplement. A by-product feed stuff is a product that has value as an animal feed and results from the harvesting or processing of a commodity from which food or fibre is derived (Fadel, 1999). The commercial and small food-processing industries in the Levubu valley, Limpopo Province, Republic of South Africa produce considerable quantities of fruit and nut waste materials, which could be used as possible alternative feed resources. Macadamia (*Macadamia ternifolia*) oilcake (MOC) and Baobab (*Adansonia digitata*) seed cake (BSC) are examples of such resources.

The MOC is obtained from the extraction of oil from cracked, insect damaged or poorly formed Macadamia nuts using a base of soybean hulls to prevent the mashed nuts from sticking to the sides of the oil extracting machine. However, some oil producers do not include soybean hulls during the oil extraction process. The BSC is obtained from the mechanical extraction of oil from Baobab seeds by first removing the hard seed cover and then pressing oil from the seed using the screw press technology. Some farmers in Vhembe region use MOC and BSC to feed their livestock especially during the dry season until the grazing pastures becomes available after the first rains in summer.

The MOC has a potential to be used as a ruminant feed (Skenjana *et al*., 2002; Acheapong-Boateng *et al.*, 2008). Soyabean meal can be replaced by the inclusion of 10% of MOC in the diets for feedlot cattle and fattening lambs without affecting feed intake and growth performance of the animals (Acheapong-Boateng *et al.*, 2017/2008). Roasted and ground Macadamia nuts could be used as energy supplements in sheep rations (Sherrod and Ishizaki (1966; 1967).The MOC (24.5% CP) and Macadamia nut cake (25.55% CP) has potential to be used as protein supplements in diets for broilers and pigs respectively (Acheapong-Boateng *et al*., 2016; Tiwari and Jha, 2016). The inclusion of BSC in diets for dairy cows negatively affects the quantity and quality of milk (Madzimure *et al*., 2010). Soyabean meal cannot be completely replaced by BSC in the diets for growing sheep without negatively affecting the performance of the animals (Belewu and Ibikunle, 2009). The objective of the study was therefore; to evaluate and compare the nutritive values of BSC and MOC used as protein supplements in ruminants.

1.2 Problem statement

The availability and access of feed ingredients especially protein supplements in Vhembe District, particularly for those farmers who opt to mix their own rations, is problematic. The only feed company (Brenco Feeds) in Louis Trichardt town in recent years refuses to sell feed ingredients to farmers except if they buy complete rations for the animal species. Buying readymade feeds from feed companies has a potential of increasing the feed costs as most of the feeds were formulated to meet the nutrients requirements of high producing animals. The local Noord Transvaal Koperasie (NTK) stores in the District normally don't sell these conversional protein supplements. This means that a farmer who wants to formulate his/her own ration for his/her animals must travel to Polokwane and beyond to buy the protein feed ingredients. The travelling costs will add on to the already high prices of these ingredients. This for a small-scale farmer who wants to fatten his/her animals for slaughter will reduce the profit margins from the sale of animals or meat.

There has been a few research work done on MOC as a protein supplement/source in feedlot diets on growth performance of cattle and sheep in the past (Acheapong-Boateng *et al.*, 2016/ 2008). Madzimure *et al.* (2010) evaluated the effect of BSC on milk production of dairy cows. Ørskov (1987) indicated that while proximate analysis results may be interesting, only biological measurements (*in sacco* ruminal degradability, *in vitro/ in vivo* digestibility) can provide sufficient information on the nutritive value of fibrous feeds or residues. Protein sources differ in the chemistry of their Amino acid profile and availability of CP in rumen and post-ruminal sites (Gleghorn *et al*., 2004; Bateman *et al*., 2005). Over and above all these, livestock farmers (small-scale and subsistence) are already using these cakes as either the sole feed or in combination with other feed ingredients without the knowledge of the nutritional composition and value of the residues. This poses a danger of insufficient supply of animals with major nutrients (energy and protein) which are central to the optimal performance of the animals.

The production of both BSC and MOC in Vhembe district happens within Makhado municipality, however, these cakes are produced by two different companies and as a result they are sold at different prices. Due to the variances in the prices of BSC and MOC there is a need to carryout a research study under the same conditions to compare the nutritive value of the cakes. Such a study will assist farmers who live closer to the production sites of these cakes to choose the least cost cake based on scientific information on its nutritional value and inclusion level in the diets of ruminants. There is therefore, a need to do an intensive evaluation of the nutritive value of the cakes produced in South Africa in order to provide nutritive information necessary for farmers during feed formulations.

1.3 Justification

There is limited information on the use of MOC and BSC produced in South Africa as feed for ruminants. Acheampong-Boateng *et al*., (2008) evaluated the feeding value of MOC while Skenjana *et al*., (2006) determined rumen degradability of dry matter and crude protein as well as *in vitro* digestibility of organic matter of MOC using sheep. Dry matter, organic matter and crude protein alone do not provide useful information for ration formulation since the breakdown of the ingredients mentioned earlier to their chemical constituents is often required to formulate a balanced diet. No information exists as far as I know about the nutritive value of South African produced BSC. Futher more, there is no study about the comparison of the nutritive value of BSC and MOC done under the same conditions. This study will therefore provide information about the utilization of true protein by ruminants and the response of sheep when the cakes are included in their diets at two different levels. This will therefore, make it possible for farmers to choose the most affordable cake and apply an appropriate inclusion level when formulating sheep diets. The study will also assist farmers and scientists in understanding the extent to which crude protein (Amino acids) are utilized in the alimentary canal of ruminants.

1.4 Objectives

1.4.1 Main objective

The main objective of the study was to undertake a comprehensive nutritional evaluation of MOC and BSC as protein supplements for ruminants.

1.4.2 Specific objectives

The specific objectives of the study were to:

i) compare the chemical composition of MOC and BSC
ii) Evaluate and compare the rumen degradability of dry matter, crude protein and Amino acids of MOC and BSC

iii) Evaluate the apparent digestibility of MOC and BSC based diets
iv) Evaluate the *in vitro* digestibility of MOC and BSC nutrients
v) To compare the growth performance and carcass characteristics of sheep fed MOC and BSC based diets included at two different inclusion levels.

1.5 Null hypothesis

i) There is no significant difference between chemical composition of MOC and BSC

ii) Ruminal degradation of MOC will not be significantly different from that of BSC

iii) The inclusion of MOC and BSC at different levels in diets for sheep do not significantly affect the nutrient intake and apparent digestibility of nutrients by lambs.

iv) *In vitro* digestion of MOC does not differ from that of BSC

v) Growth performance and carcass characteristics of lambs are not significantly affected by the inclusion of MOC and BSC at different levels.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Determination of the nutritional value of feedstuffs begins with chemical composition evaluation using proximate analysis of the material and other modern methods such as the Kjeldahl, and the van Soest methods. However, biological measurements (*in sacco, in vitro, in vivo* digestibility) are needed to compliment chemical composition analysis to estimate the nutritive value of fibrous feedstuffs (Ørskov 1987).

2.2 Chemical composition of other non-conventional oil cakes/ meals used in feeding livestocks

Globally, the unavailability and high costs of conventional oil cakes/meals such as soyabean meal, sunflower oil cake and cotton seed meals in certain regions of the country have resulted in the use of non-conventional oil cakes/meals as either protein or energy supplements for livestock. Marula seed cake, a by-product which remains after oil has been extracted from marula nuts had high dry matter (DM) content of 901g/kg, ether extract (EE) content of 394g/kg DM and crude protein (CP) content of 470g/kg DM and lower values of neutral detergent fibre (NDF) (194 g/kg DM) and acid detergent fibre (ADF) (131 g/kg DM) (Mlambo *et al*, 2011). Similar values of Marula seed cake with DM values ranging from 938 – 946.6 g/kg , EE content range of 289 – 343.5 g/kg DM, CP content range of 470.0 – 472.1 g/kg DM, crude fibre (CF) content range of 47.9 – 58.2 g/kg DM, and ADF content of 147 g/kg DM were also reported by Mdziniso *et al*., (2016); and, Mthiyane and Mhlanga (2017). The similarities in the chemical composition of Marula seed cake observed in the literature suggest that there is consistency in the production processes of the cake hence the negligible differences in composition. Furthermore, Marula seed cake can be used as a protein supplement in livestock diets due to its reasonably higher CP content. However, the high fat content of this cake may limit its inclusion level especially in the diets of ruminants due to the negative effect of high fat levels on the digestion of food. The chemical composition determined on dry matter basis of Watermelon seed cake contains range of 92.5 - 95.5% DM, 20.62 - 27.18% CP, 7.84 – 10.8% EE, and 21.4 - 27.4% CF (Mustafa and Alamin, 2012; Ibrahim and Mukhtar, 2016). The high DM and medium CP contents of Watermelon seed cake makes it a potential protein supplement for livestocks but its high fibre content may restrict its use in monogastric animals. The low EE content of Watermelon seed cake suggest that it can be included in higher levels in rations for ruminants without negatively affecting the utilization of the nutrients. Decorticated rubber seed oil meal contains CP of 27.4% (Narahari and Kothandaraman 1984). Uncultivated Rubber seed meal have 14.1% moisture, 10.3% CP and cultivated rubber seed meal contains 2.6% moisture and 21.9% CP (Oyewusi *et al*., 2007) whereas the raw, boiled and toasted Rubber seed meals contains DM (%) of 96.91,85.40, and 93.63; CP (%) of 23.31, 24.60, 21.08; EE (%) of 38.47, 23.13, 32.57 and CF (%) of 5.88, 4.47, 4.95 respectively (Udo *et al*., 2016). The differences in chemical compositions of these cakes may be attributed to the differences in the species and the processing methods. The Rubber seed meals with CP content of at least 20% can be regarded as potential protein supplements for livestocks.

2.3 Chemical composition of conventional oil cakes/meals

The plant (seeds) oil industry in South Africa is mainly dependent on local production of soyabeans, sunflower seeds and cotton seeds. Oil is pressed from their seeds leaving tonnes of residues which are mainly used in the animal feed industry primarily as protein sources/supplements for different livestock species. These residues are referred to as soyabean meal, sunflower meal and cotton seed meal and they are mostly used the animal feed industry in South Africa.

The chemical composition of soyabean meal ranged (%) from 89.8 – 90, 45.4 – 47.7, 5.39, 8.2 - 14.1 and 5.3 – 6.59% for DM, CP, EE, NDF and ADF, respectively (Alves *et al*., 2016; Stein *et al*., 2015). Similar findings on the chemical composition of soyabean meal were reported by Nkosi *et al*., (2011) due to their values falling within the ranges of values obtained by Stein *et al*., (2015) and Alves *et al*., (2016). The similarities suggest that soyabean meals are consistent in their chemical composition which may be advantageous to farmers since they may not need to analyze these meals for their nutrients contents. However, Gonzalez *et al*., (2002) analyzed certain varieties of soyabeans and found that they contained CP (%) ranging from 49 – 54 which are above the CP reported by Stein *et al*., (2015); Alves *et al*., (2016); and Nkosi *et al*., (2011). The differences may be attributed to the difference in environmental conditions and the methods of oil extraction as they known to influence the nutritional composition of plant feed materials. This as it may, however, does not take away the fact that Soyabean meal is a high and excellent protein source for livestocks.

The average range of Sunflower meal/oil cake (%) is 90 – 92, 26.6 – 38.0, 19.1 - 30.8, 7.6 – 30.8 of DM, CP, CFand EE, respectively (Habib *et al*., 2013; Nkosi *et al*., 2011; Mirza *et al*., 2004). The data on quantities of the different components of DM are also supported by the findings of several researchers (Rosa *et al*., 2009; Furlan *et al*., 2001; Stringhini *et al*., 2000;; Villamide and San Juan 1998). The data on the chemical composition of Sunflower meals suggest that this meal is consistent in its DM content but varies in CP, CF, and EE contents. These variations may be attributed to the differences in environmental conditions and oil extraction methods as they are known to influence the nutrient contents of meals. Sunflower meal/oil cake can be used as protein supplement particularly for ruminants; however, the high fibre content of some meals may limit its inclusion level in rations for livestocks.

The chemical composition of cotton seed meal/cake (%) range from 89.86 – 92.3, 22.97 – 41.74, 9.77 – 11.92, 3.07 – 24.2 and 4.94 – 10.2% for DM, CP, CF, EE and total ash, respectively (Thirumalaisamy *et al*., 2016;Tripathi *et al*., 2014; Habib *et al*., 2013;; Mirza *et al*., 2004). The Cotton seed cake as reflected on the data (Thirumalaisamy *et al*., 2016;Tripathi *et al*., 2014; Habib *et al*., 2013;; Mirza *et al*., 2004) is produced having little differences in the moisture content however, the other components are vary significantly. The variation may be attributed to differences in processing methods and environmental conditions. Cotton seed meals in general are rich in protein, low to moderate in fibre making them good sources/supplents of protein for livestocks. Their inclusion level in the diets of livestocks could not be limited by the fibre content due to its low to moderate fibre and fat contents. The major limiting factor affecting the inclusion level of cotton seed meal is the presence of gossypol which is an antinutritional factor having a poisoning effect in livestocks especially non-ruminants which are very susceptible to it (McDonald et al., 2011).

2.4. Chemical composition of Macadamia oil cake and Baobab seed cake

Chemical composition of Macadamia oil cake has been studied by several researchers and their findings were rather contradictory (Tiwari and Jha, 2016; van Ryssen *et al*., 2014; Skenjana *et al*., 2011; Acheapong-Boateng *et al*., 2008; Sherrod and Ishizaki, 1967). Macadamia nut cake (MNC) detrmined on dry matter basis contains 91.2% DM, 25.5% CP, 3.7% ash, 11.9% EE, 25.2% CF, 28.0% Acid detergent fiber (ADF), and 35.8% Neutral detergent fiber (NDF) (Tiwari and Jha, 2016). According to the findings of Van Ryssen *et al*. (2014) who determined the chemical composition of MOC on as fed basis, MOC contains 94% DM, 28% ash, 13.2% CP, 36.5% CF, and 22.8% EE, while Skenjana *et al*., (2011) found MOC to be composed of a 94% DM, 4.29% ash, 24.5% CP, 28.69% CF, 26.5% EE. MOC Macadamia oil cake contain 93.8% DM, 2.8% ash, 19.5% CP, 24.9% CF, and 10.4% EE (Acheapong-Boateng *et al*., 2008). These Macadamia residues have similar moisture contents but differ significantly on their CP, EE and fibres contents. The differences amongst the Macadamia oil residues may be attributed to the extraction methods and the inclusion of soyabean hulls during the production of MOC. Contrary to the oil extracted Macadamia residue used in the studies conducted by Acheampong-Boateng, Skenjana, and van Ryssen; Sherrod and Ishizaki, (1967) instead used roasted Macadamia nuts in their studies and found that they contain 98.6% DM, 1.4% ash, 9.9% CP, 70% EE, and 9.2% CF. The differences in the chemical compositions of these Macadamia oil cakes and roasted Macadamia nuts may be attributed to the differences in processing methods. The processing methods involves mechanical oil extraction from the nuts for MOC and roasting of the nuts hence the higher EE contented of the roasted nuts. Phosa (2009) reported a DM and CP of 94 and 13 percent, respectively, which are similar to those of Van Ryssen *et al.* (2014). The variation in the nutrient composition of MOC investigated by the researchers (van Ryssen *et al*., 2014; Skenjana *et al*., 2011; Acheapong-Boateng *et al*., 2008; and Phosa, 2009) produced in the same plant is an indication that MOC differ from one production batch to another and the year in which it was produced. Royal Macadamia (Pty) Ltd in Levubu produced the MOCs' and the cause of the difference might be due to the inconsistency in the amount of soybean hulls added to the nuts during oil extraction as it is evident through varying amounts of CF of the MOC.

There are several studies done on the proximate analysis of BSC across the African continent (Saulawa *et al*. 2014; Babiker, 2012; Madzimure *et al*., 2011) with few studies conducted in South Africa (Chisoro *et al*., 2018). Some of the findings of the proximate analysis of BSC are contradictory while others are similar. BSC contains 90.6% DM, 4.57% ash, 16.9% CP, 5.26% EE, and 25.61% CF (Madzimure *et al*., 2011) which are comparable to 15% CP, 25.99% CF, 3.97% EE, and 9.38% ash reported by Babiker (2012). The CP and ash content of BSC observed by Ezeagu (2005) are comparable to those of Madzimure *et al*. (2011), and Babiker (2012). Contrary to the findings of Madzimure *et al*., (2011) and Babiker (2012), Saulawa *et al*. (2014) who investigated the effect of different processing methods on the proximate analysis of BSC, found that CP ranged from 18.68 – 28.85%, CF (7.84 – 10.78%), EE (2.19 – 4.41%), and ash (5.84 – 8.92%). The CP content (22.86% DM) of BSC (Chisoro *et al*., 2018) falls within the CP range of 18.85 – 28.85% (Saulawa *et al*., 2014). The nutritional composition of BSC

(Nkafamiya *et al*., 2007); Baobab seed (Lamayi *et al*., 2014) fall within the ranges reported by Saulawa *et al*., (2014). The differences between the findings of Madzimure *et al*., (2011), and Babiker, (2012); and those of Saulawa *et al*., (2014) may be attributed to the climatic conditions as well as the processing methods.

Belewu and Ibikunle (2009) evaluating the chemical composition of Baobab seed meal (BSM) observed DM, CP and ash values comparable to the findings of Madzimure *et al*., (2011) but had higher CF and EE values. The differences in CF and EE may be attributed to the processing methods. The chemical composition of a mixture of Baobab pulp and BSM contains 89.3% DM, 11.7% CP, 20.52% CF, 9.67% EE, and 6.03% ash (Oladunjoye *et al*., 2014) falling within the ranges observed by Saulawa *et al*., (2014) but contrary to their respective values reported by Madzimure *et al*., (2011). Baobab seed contains 92% DM, 37% CP, 16% CF, 22.5% EE, 3.5% ash (Sola–Ojo *et al*., 2011) which differs from the findings of Lamayi *et al*., (2014) who also evaluated the chemical composition of baobab seeds. The difference of the nutrients composition of Baobab seeds may be attributed to the varieties of the Baobab trees and environmental conditions.

In general, BSC contains higher CP and low CF compared to MOC. However, MNC which has no Soyabean hulls added during oil extraction process compares well with BSC on CP and CF values. MNC have the highest EE value compared to BSC and MOC. MOC has high values of NDF and ADF than MNC and BSC as proved by the literature. The high fibre content of MOC is attributed to the Soyabean hulls which are included during the oil extraction process. Soyabean hulls serve as a layer which covers the Soyabean seed and it is the rich in fibre hence the high fibre content of MOC. This implies that BSC/BSM may be more digestible than MOC provided the the Soyabean hulls are high in lignin. It is however very important to note that strangely CP of BSC/BSM content seems to decline with oil extraction because the CP content of Baobab seeds is higher than that of their residual cakes/meal. This phenomenon is goes against the expected rise in CP of the residues when oil is extracted from the seeds.

2.5 Mineral composition of Macadamia oil cake and Baobab seed cake

The MOC contains a range of 0.16 - 0.24% calcium (Ca) and 0.23 - 0.24% phosphorus (P) (Acheapong-Boateng *et al*., 2008; Van Ryssen *et al*., 2014) which are comparable to 0.33% Ca and 0.30% P of MOC (Skenjana *et al*., 2011). The similarities are to be expected as the MOC was produced in the same place (Royal Macadamia Ltd Pty, South Africa). The feed-grade Macadamia nuts contain 0.1% Ca and 0.25% P (Sherrod and Ishizaki, (1967) which falls within the ranges observed by Acheapong-Boateng *et al*. (2008); and Van Ryssen *et al*. (2014). The similarities implies that the Ca and P content of Macadamia nuts are not significantly influenced by neither environmental conditions nor processing methods because feed grade Macadamia nuts were produced and roasted in Hawaii whereas MOC was produced and oil extracted by mechanical method in South Africa.

BSC contains Ca and P with a range of 0.12 – 0.3% and 0.13 – 0.24%, respectively (Nkafamiya *et al*., 2007; Madzimure *et al*., 2011). The BSM contains 0.21% Ca and 0.93% P (Ezeagu, 2005) which are comparable to the ranges of Ca and P values of Nkafamiya *et al*. (2007) and Madzimure *et al*. (2011). The Ca content of boiled and soaked BSM (Saulawa *et al*., 2014) are comparable to the findings of Nkafamiya *et al*. (2007) and Madzimure *et al*. (2011) but different to untreated (raw), toasted, soaked and boiled BSM (Saulawa *et al*., 2014). The differences may be attributed to the processing methods.

In comparison, the Ca and P contents of the MOC and BSC/BSM in the literature are comparable with an exception of P content of BSC reported by Ezeagu (2005) which is higher than that of MOC.

2.6 Amino acids profiles of oil cakes/meals

2.6.1 Amino acid profiles of conventional oil cakes/meals

Soyabean meal has methionine as the least amount of the Amino acids of its protein with a range of 1.41 – 1.52% and glutamic acid as the highest amount with a range of 17.78 – 18.19% (Ravindran *et al.*, 2014). The essential Amino acids of Soyabean meal has a range of 7.48 – 7.74% of leucine as the highest amount within the protein of this meal (Ravindran *et al.*, 2014). Soyabean meal is naturally poor source of methionine as it is evident from the literature and its inclusion in monogastric diets will warrant a supplementation of methionine in the diet.

The Amino acid profiles (lysine, methionine, cysteine, isoleucine, leucine, phenylanine, tyrosine, threonine, tryptophan, valine and histidine, threonine, serine, glutamine, glycine, alanine, phenylalanine, histidine, arginine and proline) for of Sunflower cake and Cotton seed cake has 0.63% and 0.38% methionine respectively as the least amount of Amino acid; and 6.1%

glutamine for Sunflower cake and 4.84% glutamine for Cotton seed cake as the highest Amino acid (Babiker, 2012). Generally, the conventional oil cakes/meals used in the diets of livestocks in South Africa are poor sources of methionine and as such their inclusion in the diets of monogastrics or growing ruminants may need methionine supplementation so that methionine do not become a first limiting Amino acid in their diets.

2.6.2 Amino acids profiles of Macadamia oil cake and Baobab seed cake

The Amino acid profile values for lysine, methionine, threonine, tryptophan, phenylalanine, histidine, valine, isoleucine, leucine, arginine, cysteine, proline, glutamic acid, and tyrosine, of MOC (Skenjana, 2011) are lower than the Amino acid profile of MNC (Tiwari and Jha, 2016). The serine content is 0.90% (Tiwari and Jha, 2016) and 0.95% (Skenjana, 2011) for MNC and MOC, respectively, which are comparable. The differences in the values of Amino acids of MOC and MNC range from 1 – 3 g/kg which may be attributed to the differences in the processing methods of the cakes. This is because MOC contains Soyabean hulls whereas MNC does not have Soyabean hulls. However, these Macadamia residues from the literature seem to be good sources of Amino acids. The methionine of MOC (Skenjana, 2011) is comparable to methionine of MNC (Tiwari and Jha, 2016) with values of 0.24% and 0.34%, respectively. The literature suggests that MOC and MNC are both poor sources of methionine.

The chemical composition of Baobab seeds reveals that its protein has acceptable quantity of essential Amino acids profiles for lysine, methionine, cysteine, isoleucine, leucine, phenylanine, tyrosine, threonine, tryptophan, valine and histidine with 1.25% methionine being the lowest and 6.54% leucine as the highest of Amino acid values (Ezeagu, 2005). The Amino acid profile for lysine, methionine, cysteine, isoleucine, leucine, phenylanine, tyrosine, threonine, tryptophan, valine and histidine of Baobab seeds (Osman, 2004) has 1% methionine as the least essential Amino acid and 7% leucine as the highest essential Amino acid of the protein of Baobab seeds. The literature suggest that Baobab seeds are poor sources of methionine and rich in leucine implying that methionine might be the first limiting Amino acid when the Baobab seeds are fed to non-ruminants as protein supplement. The Amino acid profile for lysine, methionine, cysteine, isoleucine, leucine, phenylanine, tyrosine, threonine, tryptophan, valine and histidine, threonine, serine, glutamine, glycine, alanine, phenylalanine, histidine, arginine and proline of BSC contains 0.19% methionine as the lowest Amino acid and 2.92% glutamine as the highest Amino acid composition of the protein (Babiker, 2012).

2.7 Fatty acids profiles of oil cakes/meals

2.7.1 Fatty acid profiles of conventional oil cakes/meals

The oil of Soyabean meal contains 78.55% of unsaturated fatty acids and 22.09% saturated fatty acids (NRC, 2012) making it a very rich source of unsaturated fatty acid. Out of the 78.55% of the unsaturated fatty acid 22.09% is the monounsaturated fatty acids and 56.46% makes up the polyunsaturated fatty acids. Linoleic acid (C-18:2) is the highest fatty acid with 49.79% and Myristoleic (C-14:0) and Palmitoleic acid (C-16:1) are the least fatty acids with 0.28% each of the Soyabean oil composition (NRC, 2012).

Cotton seed oil is rich in Linoleic acid (C18:2) with 55.38% and poor in Palmitoleic acid accounting for 0.04% of the total fatty acids (Okonkwo and Okafor, 2016). A 54.2% of Linoleic acid is the highest fatty acid content of all the fatty acids composition of cotton seed oil from different cotton seed gynotypes (Bolek *et al*., 2016).

Sunflower seed oil is constituted by 90.7% of unsaturated fatty acids with monounsaturated and polyunsaturated fatty acids accounting for 28.3% and 62.4% respectively (Orsavova *et al*., 2015). Linoleic acid accounts for 62.2% of the total fatty acids of sunflower seed oil and 0.02% of Margaric acid being the least fatty acid (Orsavova *et al*., 2015).

The literature provided proof that soyabean, cotton seed, and sunflower oils are rich in unsaturated fatty acids and Linoleic acid is the highest in quantity accounting for more than 50% of the total fatty acids of the oils.

2.7.2 Macadamia oil cake and Baobab seed cake

The fatty acid composition of MOC contain a 20.16% mono-unsaturated fatty acids, 75.96 poly-unsaturated fatty acids and 0.82% poly-unsaturated fatty acids:saturated fatty acids ratio with Oleic acid (C18:1n9c) accounting for 51.9% of the total fatty acids (Skenjana, 2011). The Linoleic and Linolenic acids of MOC account for 2.69% and 0.49% of the total fatty acids, respectively (Skenjana, 2011). The MNC contains 16.18% Saturated fatty acids, 79.84% mono-unsaturated fatty acids, 2.75% poly-unsaturated fatty acids, and 0.17% poly-unsaturated fatty acids:saturated fatty acids ratio with Oleic acid accounting for 57.43% of the total fatty acids (Tiwari and Jha (2016). The oil of MNC contain lower amounts of Linoleic and linolenic acids with 2.56% and 0.19%, respectively (Tiwari and Jha, 2016).The monounsaturated and poly unsaturated values of MOC (Skenjana, 2011) and MNC (Tiwari and Jha, 2016) fatty acids are contradictory and the contradictions may be due to an error when recording these values on the part of Skenjana (2011) because the individual fatty acids of MOC and MNC follow a similar pattern even though their values are different. The difference in Macadamia oil extraction methods could also be the source of the differences in the fatty acid compositions since the MOC had soyabean hulls added and MNC had no hulls added.

BSM contains oil with high in oleic and linoleic fatty acids and less quantities of polyunsaturated/saturated fatty acids ratio (Ezeagu, 2005). BSM contains oil with low percentage of free fatty acids (oleic acid = 0.45%) (Nkafamiya *et al*., 2007) which contradicts the findings of Ezeagu (2005). The differences may be attributed to environmental conditions and processing methods.

2.8 Ruminal degradability of seed/oil cakes

MOC is highly degradable in the rumen of sheep with the degradation values of DM and CP of 84.3% and 92.2%, respectively (Skenjana *et al*., 2006). Marula seed cake has similar high potential degradablility values of DM and CP values ranging from 72.3 – 85.7% and 84.4 - 96.3% respectively (Mlambo *et al*., 2011). The milling of Marula seed cake (MSC) increases the immediately degradable fraction but reduces the slowly degradable, potentialy degradable and effectively degradable fractions of DM and nitrogen (Mlambo *et al*., 2011). Solvent extracted Soyabean meal has a rapidly degradable CP fraction of 8.1% whereas the expeller Soyabean meal and extruded Soyabean meal had the greatest slowly degradable crude protein fraction (Mjoun *et al*., 2010). The crude protein degradation rate is higher than 0.043 and 0.079/hr for cotton meal and soybean meal, respectively (Promkot and Wanapat, 2003). Watermelon seed cake has CP which is highly degradable in the rumen of steer with a degradation percentage of 82.2 at a rate of 0.20 (Mustafa and Alamin, 2012). Degradability values of 78, 52 and 57% were reported by Hussein and Jordan (1991) for crude protein of soybean meal, fish meal and corn, respectively.

Ngongoni *et al*. (2007) indicated that the nitrogen in sunflower is more degradable in the rumen (92%) than when it is in the commercial dairy concentrate. Cotton seed cake, Soybean meal and Palm seed meal has an effective degradability values in cows for DM of 41.9, 46.7 and 63.3

%, respectively (Promkot and Wanapat 2003). The effective CP degradability in cows of Cotton seed cake, Soybean meal and Palm seed meal are 49.6, 54.6, and 66.3% respectively (Promkot and Wanapat). Cotton seed cake incubated for 48-hours in the rumen has a crude protein degradability value of >940g/kg (Ndemanisho *et al.*, 2007). The literature review on the ruminal degradability of oil cakes/meals prove that most of the nutrients contained in these oil residues are highly degradable thus providing a bulk of their nutrients to the rumen microorganisms.

2.9 Apparent digestibility and Post-ruminal digestibility of seed/oil cakes

2.9.1 Apparent digestibility of seed/oil cake nutrients

The organic matter (OM) and gross energy (GE) digestibility decreased with addition of Macadamia nut in diets for sheep, however, CP and crude fat digestibility increases when Macadamia nuts are included at 12% of the diet but decreased when the nuts inclusion is increased beyond 12% of the diet (Sherrod and Ishizaki,1966). Contrary to their earlier findings Sherrod and Ishizaki (1967) reported that when Macadamia nuts are included in diets of lambs at 3% of the total diet, OM, CP and GE digestibility increased, however, when it is included at 12% of the diet digestibility of these nutrients decreased below that of the control diet (0% Macadamia nut).

The BSC inclusion in the diets of lambs decreases DM, CP, CF, EE, ADF and NDF digestibility of the total diets (Belewu and Ibikunle, 2009). Whole Baobab fruit meal inclusion in the diet of goats at 10% of the diet increases DM, CP, EE, and nitrogen free extract compared to 0% Baobab fruit diet (Ilori *et al.*, 2013). The differences may be attributed to the differences in the baobab products and probably animal species. The inclusion of Marula seed cake (MSC) in diets for goats decreases digestibility of OM, NDF and ADF compared to the goats fed Soybean meal, Sunflower cake and the protein unsupplemented diets (Mlambo *et al*., 2011). The different protein sources have varying effects on nutrient digestibility in animals (Khalid *et al*., 2012). The statement by Khalid *et al*. (2012) could provide the explanation of different digestibility observation of the study by Mlambo *et al*., (2011) which found differing digestibility trends when different oilcakes are used to supplement protein in the diets of goats. The high oil content of MSC could also be a contributing factor on the decrease of nutrients digestibility of a diet supplemented for protein with MSC. Higher quantities of unsaturated fatty acids in ruminants diets depress digestion (McDonald *et al*., 2011).

The apparent digestibility of crude protein was higher in steers given feed supplemented with Canola meal compared to the control feed (Leupp *et al*., 2006). Cotton seed meal inclusion in the diets of lambs does not affect DM, CP and fiber digestibility by lambs (Nelson and Watkins, 1967). Drackley *et al*. (1985) on the other hand found that a decrease in fiber digestion in steers fed diets containing sunflower seeds. This decrease in fiber digestibility may be attributed to the higher quantities of fiber and fat in sunflower seeds. Feeding of lambs with diets supplemented with Urea, Soybean meal and Corn gluten meal for protein in corn silage based diets result in higher DM and OM and lower nitrogen digestibility by lambs (Merchen *et al*., 1987). However, digestibility of DM, OM and CP increases when sheep fed grass hay-straw mixture are given protein sources as supplement (Swanson *et al*., 2000). The apparent digestibility of CP is not affected by whole cottonseed inclusion level in ruminants (Luginhuhl *et al*., 2000). The inclusion of Palm kernel cake up to 30% of the diet does not affect digestibility of nutrients, whereas inclusion of Rubber seed kernel above 20% results in a lower apparent digestibility of NDF and ADF compared to goats fed on 0 and 20% Rubber seed kernel (Chanjula *et al*., 2011). Concentrate feeds in general which are rich in protein content promote high rumen microbial population which facilitates rumen fermentation (McDonald *et al*., 2011). They went on to indicate that Cottonseed meal has CP digestibility of 77 – 86%. Supporting the findings of McDonald *et al*. (2011); Ash and Norton (1987) observed a higher CP digestibility in goats fed high protein compared to low protein diets.

The DM, OM and CP apparent digestibility in Sidama goats increased when they were supplemented with different levels of cottonseed meal compared to the non-supplemented goats but NDF and ADF digestibility was not affected by inclusion of cottonseed meal (Solomon *et al.,* 2008). Supplementing Menz sheep with Cottonseed meal, Leucaena or Sesbania do not affect the apparent digestibility of NDF and ADF by sheep (Bonsi *et al.,* 1996).

2.9.2 *In Vitro* digestibility of oil/seed cake

The MOC has a high *in vitro* OM digestibility value of 79.2% (Skenjana *et al*., 2006). Similarly, MNC has a high DM and GE digestibility values of 75.7 and 71.4% respectively when MNC is subjected to 3-step *in vitro* digestibility for pigs (Tiwari and Jha, 2016). This suggest that oil residues from macadamia nuts are highly digestible when they reach the small intestines of livestocks. Groundnut cake had a the highest true *in vitro* Organic matter digestibility (IVOMD; 90.2%) followed by wheat short (84.8%) and wheat bran (83, 2%) while grass hay had the lowest value (66.6%) (Mekasha *et al.*, 2011). The MSC has a high *in vitro* DM digestibility value of 83.3% comparable to 80% in vitro digestibility of Soyabean meal (Mdziniso *et al*., 2016).

2.10 Effect of Macadamia oil cake (MOC) and Baobab seed cake (BSC) on feed intake and growth performance of ruminants

According to Hayirli *et al*. (2002) DM intake can be influenced among other factors such as the fibre (NDF) and fat content of the feed. McDonald *et al*. (2011) argued that the amount of feed that animal consume per day has a positive effect on its daily production. The inclusion of MOC up to 20% to completely substitute soybean meal in the diets of feedlot cattle as a protein supplement does not affect daily feed intake and improves growth performance of the animals (Acheampong-Boateng *et al*., 2008). The inclusion of MOC in the diets of lambs up to 20% of the total diet as a protein supplement does not affect feed intake and growth performance of lambs (Acheampong-Boateng *et al*., 2017). The two studies (Acheampong-Boateng *et al*., 2008; Acheampong-Boateng *et al*., 2017) have confirmed that MOC can replace soyabean meal as protein supplement in the diets of ruminants without affecting feed intake and growth of the animals when it is added to constitute 10% of the total diet. The inclusion of feed-grade Macadamia nuts at 12% in the diets of sheep can substitute grains without adversely affecting feed intake and growth performance of the animals (Sherrod and Ishizaki, 1966). However, a follow up study by Sherrod and Ishizaki, (1967) revealed that feed-grade Macadamia nuts can be used in rations for ruminants to substitute some grains as long as its inclusion levels would not increase the crude fat content of the ration above 10% as these might interfere with the feed digestibility and energy utilization. The differences in the performances of animals between studies of Sherrod and Ishizaki (1966/7) and Acheampong-Boateng *et al*. (2008/17) may be attributed to the lower oil contents of the feeds the later compared to those of Sherrod and Ishizaki, (1967). The composition of the diets of lambs in the study by Sherrod and Ishizaki (1966/7) included oil rich products such as Soybean meal and Macadamia nuts which may be the sources of high oil contents of the diets.

The BSC may partially substitute Soyabean meal when it is included in the diets of lambs at 12.5% of the total diets without negatively affecting daily feed intake and growth performance of the animals (Belewu and Ikikunle, 2008). The BSC inclusion beyond 12.5% of the total diet to partially substitute Soyabean meal reduced feed intake and growth performance (Belewu and Ikikunle, 2008). The inclusion of BSC in the diets of lactating cows up to 15% of the total diet to partially substitute Cotton seed cake as a protein supplement promotes daily feed intake but reduces milk quality and quantity (Madzimure *et al*., 2011). The difference in the animal performances of the studies of Madzimure *et al*., (2011) and Belewu and Ibikunle (2009) may be attributed to animal species and the processing method of BSC. The inclusion of Whole Baobab fruit meal reduced daily feed intake but at 10% inclusion level, whole Baobab meal does not affect body weight gain in goats (Ilori *et al*., 2013). The reports of Belewu and Ibikunle (2008) and Ilori *et al*. (2013) implies that inclusion of baobab fruit products (meal/cake) as protein supplements at a level below 15% in the diets of sheep and goats might produce acceptable results but there is more room for research in this area to get a more conclusive finding. However, BSC may not be included from 10% and above in the diets of lactating cows as it reduces the milk quality and quantity.

2.11 Effects of feeding ruminants with other oil cakes as protein supplements on growth performance

Growing young ruminants require protein in their diets to satisfy their protein needs for growth. The supply of dietary protein is vital for growth in lambs (Khalid *et al*., 2012). Reduced CP intake may affect the growth performance of sheep (NRC, 1985). A provision of nutrients dense diet may be a better strategy to attain maximum growth rate (Arthington and Kalmbacher, 2003). Ruminant nutrition researchers (Economides, 1998; Irshaid *et al*., 2003; Nkosi *et al*., 2011) globally have indicated that conventional by-products oil cake like soybean meal can be successfully replaced with sunflower oil cake/meal in sheep rations. Cotton seed/cake can be used in ruminants' diets to condition the animals for slaughter without negatively affecting growth and carcass characteristics (Khidir *et al*., 1998; Absalan *et al*., 2011).

2.11.1 Feed intake

The DM intake may be affected by the dietary protein source as they affect the ability of the rumen to hold ruminal contents (Bandyk *et al*., 2001). Higher fiber contents like in Sunflower meal adversely affect the animal performance by decreasing intake and digestibility (Khalid *et al*. (2012). Feedlot weaners given a 13% inclusion of cold press Soybean oil cake showed a better feed intake (Chipa *et al.*, 2010). The inclusion of Marula seed cake (MSC) in diets of feedlot cattle does not affect feed intake of cattle (Mlambo *et al*., 2011). The inclusion of MSC to lactating dairy cows either as a sole protein supplement or partially substituting Soyabean meal as protein supplement does not affect feed intake (Mdziniso *et al*., 2016). The DM and CP intake of growing male goats fed hay-based diets decreased with an increase in the inclusion of whole cottonseed content (Luginhuhl *et al*., 2000). These findings of Luginhuhl *et al*., (2000) support the assertion that higher oil content of the feed negatively affect feed intake by animals.

Bulls fed diet of sunflower cake as protein source consumed more feed (DM) with a value of 8.45 kg/day followed by bulls fed cottonseed and groundnut cakes, respectively, and bulls fed Guar meal diets consumed less feed (6.92kg/day) (Turki *et al*., (2011). A 20% inclusion level of Rubber seed cake can be employed in fattening diets for goats without any adverse effects on feed intake (Rajan *et al*., 1990). Palm kernel cake may be used in fattening diets as protein supplement for ruminant animals without compromising feed intake (Abdullah *et al*., 1995). Feeding increased Palm kernel cake levels up to 30% of the diet does not affect feed intake whereas increasing rubber seed kernel levels (>20%) resulted in a slightly lower feed intake than in those goats fed 0 and 20% Rubber seed kernel (Chanjula *et al*., 2011). The inclusion of Licury cake in the diets of growing goats increased the fiber content of the diets but it does not affect DM and OM intake (Borja *et al*., 2010). The total DM intake of goats supplemented with cottonseed meal was higher (651.9 g/day) compared to non-supplemented goats (482.0 g/day) (Matiwos *et al*., 2008).

2.11.2 Body weight gain and feed conversion efficiency of ruminant animals

Feed efficiency is the measure of animal product output per unit of feed intake (Khalid *et al*., 2012). A better animal performance may be obtained by improving the feed efficiency (Kabir *et al*., 2004). An improved feed efficiency of 32.4% in lambs fed grass silage based diets supplemented with fish meal, canola meal and heat-treated canola meal as protein source was attained compared to those fed the unsupplemented control diet (Plaisance *et al*., 1997). Feeding Sunflower meal based diet to lambs reduced feed efficiency compared to the lambs on Soyabean meal based diet (Irshaid *et al*., 2003). The differences in the findings of Irshaid *et al*., (2003) and Plaisance *et al*., (1997) may be attributed to the species used to supplement the protein the diets of animals. This suggests that the species of an oil cake/meal has a significant effect of the utilization of the nutrient in the diets in which the protein supplement is incorporated. Indeed, the findings of Waller *et al*. (1980) who reported that lambs fed canola meal showed improved weight gain and feed efficiency compared to those fed cotton seed meal justifies that the species type, and protein quality do affect animal performance and utilization of the diets.

Sunflower seed supplementation in high concentrate diets improved feed conversion ratio of lambs (Ivan *et al*., 2004). Better feed utilization efficiency was observed in lambs fed diets containing soyabean meal and Canola meal compared to those fed cotton seed meal with the value of 8.98, 8.58 and 9.79, respectively (Khan *et al*., 1997). Feeding South African Mutton Merino lambs with diets containing full fat canola seeds reduced feed conversion ratio by as much as 21% (Brand *et al*., 2001). The literature of Khan *et al*., (1997) and Ivan *et al*., (2004) suggest that high oil content and probably higher fibre may negatively affect feed efficiency in animals. Similarly, Khalid *et al*. (2011) observed a significantly higher weight gain and better feed conversion ratio of lambs fed canola meal based diets compared to the lambs on cotton seed meal, corn gluten meal or sunflower meal based diets.

Mekasha *et al*. (2011) concluded that supplementing Ogaden bulls on hay diet with a groundnut cake based concentrate improved average daily body weight gain. Cattle feedlot weaners on diets containing 6% and 13% of cold press soyabean oil cake respectively had better average daily gains and feed conversion efficiencies (Chippa *et al*., 2010). The inclusion of 10 and 20% of sesame oil cake increased the average daily gains and feed conversion efficiencies of lambs compared to those on soybean meal (Omar, 2002). The differences may be attributed to the species and oil extraction methods of soyabean meal. The supplementation of lamb diets with cotton seed meal and corn gluten meal increased weight gain of lambs (Chakeredza, 2003). Supplementing cross bred lambs with canola meal and soybean meal as protein sources significantly increased live weight gain of lambs (Ponnampalam *et al*., 2005). Lambs fed fish meal based diets gained more weight than those fed sunflower diets (Nsahlai *et al*., 2002; Walz *et al*., 1998). The increase in weight gain of the lambs fed fish meal diets may be due to the high quality of the protein in fish meal and the fact that sunflower meal is less digestible due to its high fiber content. Higher weight gains were observed by Titi (2003) for kids fed sunflower meal with enzyme but no differences were observed on soybean meal and sunflower meal supplemented diets. Lambs fed soybean meal and canola meal had higher weight gains (244 and 233g/d) compared to 213g/d in lambs fed cotton seed meal diet (Khan *et al*., 1997). They (Khan *et al*., 1997) alluded the increase in weight gain of lambs on canola meal diet to the relatively high vitamins and minerals as well as high sulphur containing Amino acids (Methionine and Cystine) contents of canola meal.

Soybean meal may replace fish meal as protein source without affecting weight gain in growing lambs (Dabiri and Thonney, 2004). Groundnut meal may be replaced with decorticated sunflower meal at 0, 50 and 100% in the diets of lambs without influencing the final body weight and daily weight gain in Sudanese desert lambs. Similar animal response when fed groundnut meal or sunflower meal may be due to the high fiber contents of the two cakes as fibre can influence digestion of feed materials. Lambs fed either cotton seed meal or sunflower meal diets do not differ in their weight gains (Kandylis *et al*., 1999). Partial or whole substitution of urea nitrogen in the commercial fattening ration with MSC do not affect the average growth rate (1.62, 1.82 and 1.75 kg/day) and feed conversion efficiency (0.263, 0.255 and 0.258) of animals (Mlambo *et al*., 2011). Dairy cows have no changes in body weight gain when MSC is used as either a major or a urea's equal nitrogen supplement (Mdziniso *et al*., 2016).

The average daily gain of growing male goats fed hay-based diets decreases linearly when whole cottonseed is increased in the diets (Luginhuhl *et al*., 2000). When young lambs and goats are fed heat processed soyabean meal they increase their live-weight gain (Al-Jassim *et al*., 1991). Supplementing goats diet with cotton seed cake as a protein source increases body weight gain compared to the lambs fed maize stover supplemented with browse leaf meals (Ndemanisho *et al*., 2007). The supplementation of Sidama goats with cottonseed meal result in higher daily body weight gain (65.3 g/day) compared to un-supplemented goats (10.2g/day) (Matiwos *et al*., 2008). However, the feed conversion efficiency of goats is reduced (13.7) by cottonseed cake supplementation than the un-supplemented animals (47.9) (Matiwos *et al*., 2008).

Cattle and buffaloes fed palm kernel cake as protein supplements or basal diet generally showed improved growth performance (Hutagalung and Mahyuddin, 1985; Jelan *et al*., 1991). Bulls fed oilseed cakes have improved live weight gain of 1181g for cottonseed cake, 1113g for groundnut cake, 1077g for sunflower cake and 1056g for sesame cake (Turki *et al*, 2011). However, bulls fed diet with cottonseed cake as protein source had the most improved feed conversion efficiency compared to those on groundnut cake, sunflower cake and sesame cake (Turki *et al*., 2011).

2.12 Effect of Macadamia oil cake (MOC) and Baobab seed cake (BSC) on feed intake and growth performance of non-ruminants species

2.12.1 Poultry

The MOC can be included in the diets of broiler chickens up to 25% of the total ration to partially replace soybean meal without affecting the performance of chickens (Acheampong-Boateng *et al*., 2016). The MOC can be used in rations for indigenous chickens but it should not be fed alone as it contains high fibre content which reduces intake and growth of chickens (Phosa, 2009). The difference may be attributed to the extent of protein source replacement by MOC i.e. partial vs complete replacement.

BSC can be incorporated in rations for growing guinea fowl keets up to 5% of the total ration without adversely affecting feed intake and growth performance of the keets (Mwale *et al*., 2008). BSC can be included in broiler diets at 10% level of the diet without adversely affecting feed intake and growth performance (Chimvuramahwe *et al*., 2011). The difference in the inclusion level of BSC in the diets of birds may be attributed to the differences in species of the birds. Processed baobab seed meal (BSM) can be included in the diets of broiler chickens at 7.5% of the total diet to replace soyabean meal without deleterious effect on feed intake and growth performance of the chickens (Sola-Ojo *et al*., 2013a,b). The differences in the inclusion levels for optimal performance between Sola-Ojo *et al*. (2013a,b), Chimvuramahwe *et al*. (2011), and Mwale *et al*. (2008) may be attributed to the difference in the processing methods of the cakes. The BSM can be incorporated in the diets of laying hens at 5% of the total diet without any deleterious effects on daily feed intake, growth performance and egg quality (Sola-Ojo *et al.*, 2011). BSM can be incorporated in the diets of broiler chickens at levels up to 30% without adversely affecting feed intake and growth performance of the chickens (Bale *et al*., 2013). The performance of chickens on extremely higher inclusion level of BSM in their diets is surprising and difficult to explain since the literature has suggested an inclusion level of less than 20% of the baobab fruit products in the diets of birds if a satisfactory response is to be expected. It is, however, possible that the processing method may explain the differences in birds performance in this case.

2.12.2 Rabbits

The BSM can be included in rations for rabbits up to 15% of the total diet without compromising daily feed intake and growth performance (Oladunjoye *et al*., 2014). Similarly, rabbits can be supplemented with a combination of baobab pulp and seed meal in their diets without any deleterious effect on daily feed intake and growth performance of rabbits (Oladunjoye *et al*., 2014). Ezeagu (2005) working with albino rats indicated that supplementing rats with raw BSM at 10% level in their diet do not have any adverse effect on daily feed intake and growth performance of the rats.

2.13 Effects of Macadamia oil cake (MOC) and Baobab seed cake (BSC) on carcass characteristics of ruminants and non-ruminants

The inclusion of MOC at 10% of the total diet of feedlot cattle have negative effect on warm carcass weight compared to the cattle on soyabean meal diet but at 20% it does not have any deleterious effect on the warm carcass weight (Acheampong-Boateng *et al*., 2008). Dressing percentage of feedlot cattle carcasses is not affected by MOC inclusion in the cattle's diets (Acheampong-Boateng *et al*., 2008). The inclusion of MOC in the diets of feedlot cattle with the aim of replacing soyabean meal as protein supplement does not compromise the quality of the non-carcass components such as the liver (which sometimes get condemned in feedlot animals) suggesting that MOC did not have any toxic effect on the cattle (Acheampong-Boateng *et al*., 2008). Generally, the inclusion of MOC at 5% of the total diet of lambs as a protein supplement aimed at replacing soyabean meal improves the carcass characteristics of lamb carcasses compared to 10, 15, and 20% inclusion levels (Acheampong-Boateng *et al*., 2017). The 10, 15 and 20% MOC inclusion in the diets of lambs do not affect the carcass measurements of the lambs (Acheampong-Boateng *et al*., 2017) suggesting that soyabean meal can be successfully replaced with MOC at these levels. The differences in the inclusion levels of MOC in the diets of ruminants to optimize carcass measurements may be attributed to the species.

The inclusion of baobab pulp and seed meal up to 15% of the diet in rations for rabbits does not have any adverse effect on the carcass characteristics of the rabbits (Oladunjoye *et al*., 2014). They also found that the inclusion of these meals at this level does not compromise the mass of the visceral organs. BSM can be incorporated in diets of broiler chickens at 7.5% of the total diet without any adverse effect on the carcass characteristics of the chickens (Sola-Ojo *et al*., 2011).

2.14 Effects of other seeds/cake/meals on carcass characteristics on of ruminats

High energy and CP intake results in more muscle mass accretion (Hango *et al*., 2007). Different protein sources can affect carcass characteristics and meat composition (Khalid *et al.* (2012). The growth of muscle tissue and the extent and site of marbling in carcass affect the value and mass of meat (Mahgoub *et al*., 1978). Strategic supplementation may be helpful in achieving better carcass yield in small ruminants (Hogg *et al*., 1992). Higher dressing percentage might be due to higher slaughter weights (Lupton *et al*., 2008).

Supplementation of lambs with either expended sunflower seeds or sunflower meal has no effect on the carcass characteristics and quality of the carcass (Santos-Silva *et al.*, 2003). The addition of 15% olive cake in diets of lambs does not have any adverse effect on the carcass weight and dressing percentage of sheep carcasses (Mioč *et al*., 2007). The inclusion of palm kernel cake in diets for fattening goats could compromise carcass characteristics of the goats even though, dressing percentage and non-carcass components are not affected by the use of the palm kernel cake (Abubakar *et al*., 2012). Similarly, treating olive cake with alkali, ensilage or pelleting has an adverse effect on carcass characteristics of lambs compared to the untreated one (Abo Omar *et al*., 2011). Feeding lambs with diets supplemented with extrude soybeans and sunflower seeds do not affect hot and cold carcass weights of the lambs (Rizzi *et al.*, 2001). The differences in this regard may be attributed to the different species and protein supplements. Rizzi *et al*. (2001)'s findings are similar to the findings of Nagalakshmi *et al*. (2011); Obeidat *et al*. (2009); Silva *et al*, (2016); and Ítavo *et al*. (2016). Nagalakshmi *et al*. (2011) found that groundnut cake can be replaced with sunflower and karanj seed cake in diets for Nellore lambs without compromising carcass characteristics of the lambs, while Obeidat *et al*. (2009) indicated that sesame meal can be fed to Awassi lambs without any adverse effect on its carcass characteristics. Silva *et al*. (2016); and Ítavo *et al*. (2016) observed that incorporation of cotton seed cake and crambe meal respectively in diets for lambs has no adverse effect on their carcass characteristics. Protein concentrate supplementation in the diets of goat kids had no influence on the slaughter weight and slaughter and dissection data (Todaro *et al*., 2006).

Supplementing Ogaden bulls fed hay with groundnut cake at a 50:50 ratio improved empty weight and hot carcass weight compared to supplementing with wheat bran at a ratio of 25:75 and the control (T1-native grass hay) (Mekasha *et al.*, 2011). Higher slaughter weights and carcass weights were observed in lambs fed cotton seed diet compared to the lambs on Peanut meal (Nagalakshmi *et al*., 2002). Ground nut cake, sesame cake, cotton seed cake and sunflower seed cake used as protein source in the diets of fattening lambs have no effect on the proportion of muscle, bone, fat and trim tissues (Suliman and Babiker, 2007). Medium and high level cottonseed supplementation of Sidama goats result in higher body weight at slaughter, empty body weight and hot carcass weight than the un-supplemented goats (Matiwos *et al*., 2008). Supplementation with three levels of cottonseed meal led to higher dressing percentage and higher rib-eye muscle area compared to non-supplemented goats (Matiwos *et al*., 2008). However, in the same study Matiwos *et al*.(2008) observed that supplementation of goats with different levels of cottonseed meal do not affect the weights of small intestines and large intestine, reticulo-rumen, lungs and trachea and penis of the slaughtered animals. They went on to observe that the heart, head, omasum-abomasum, tail, abdominal fat and spleen weight were higher in goats supplemented with the medium level of cottonseed meal compared to the non-supplemented goats. Also in that study, medium and high levels of cottonseed meal supplementation resulted in higher liver and kidney weight than in the un-supplemented goats.

2.15 Conclusion

The chemical composition of oil cakes/seed meals is affected by environmental conditions, variety of the species, the species itself and the processing method. Macadamia oil cake produced in South Africa seem to vary in chemical composition which is due to inconsistency in the processing methods but the Macadamia products also differ depending on the country they are produced from and the processing methods as it is the case with those produced in South Africa and Hawaai. A similar trend applies for baobab products. However, these two products contents are rich in ether protein or energy to have a potential for use as nutrient supplements to replace the most commonly used and most often expensive sources of these nutrients for an improved profitable production of livestock.

Conventional and non-conventional oil cakes/meals are generally having high apparent nutrient digestibility when they are incorporated in diets of ruminants at different levels. They however, differ in their nutrient apparent digestibility within the same product or closely related products and products of different plant species, for example, the digestibility of nutrients for Macadamia nuts differed from one experiment to the other even though both experiments were carried out by the same people at the same place but two different years. High fiber meals seem to slightly negatively affect the digestibility of other nutrients even though the difference remains equal or above 50% value.

The *in vitro* digestibility of nutrients of the unconventional oil/seed cakes/meals are comparable to those of the likes of Soybean meals which implies that these products can be incorporated in the diets of both ruminants and non-ruminants as either protein or energy supplements.

Macadamia and baobab products from the literature demonstrate that they can be used in diets for both ruminants and non-ruminants to either completely or partially replace the conventional protein and energy sources without negatively affecting the growth and carcass characteristics of the animals. The choosing of the inclusion levels of these products, however, should be informed by scientific evidence; otherwise, the performance of the animals can be compromised.

CHAPTER 3: CHEMICAL COMPOSITION OF MACADAMIA OILCAKE AND BAOBAB SEED CAKE AS POTENTIAL FEED RESOURCES FOR FARM ANIMALS

3.1 Introduction

The search for alternative protein sources for animal feeding is an on-going exercise for many years, globally. South Africa as one of the tropical countries provides favorable environmental conditions for Baobab trees (*Adonsonia digitata*) to grow naturally and for commercial macadamia (*Macadamia ternifolia*) production. The plant oil industries extract oil from the macadamia nuts and baobab seeds and as a result, a considerable amount of residues/by-products is produced. The by-product of macadamia nut oil extraction is called macadamia oilcake (MOC) and that of baobab seed is baobab seed cake (BSC). These residues have been a subject of investigation as alternative protein/energy supplements for farm animals.

In South Africa, MOC have been used as protein supplements for cattle, broilers and sheep (Acheampong *et al*., 2008, 2016, 2017). Skenjana *et al*. (2006) in their study investigating the degradability of MOC and macadamia chips conducted in South Africa concluded that MOC has a potential as protein supplement for ruminants. A study conducted in Hawaii found that roasted Macadamia nuts can be incorporated into feedlot rations for sheep as an energy supplement (Sherrod and Ishizaki, 1966/7). Studies conducted in Zimbabwe (Madzimuri *et al*., 2011), and in Nigeria (Belewu and Ibikunle, 2009) concluded that BSC can be included in diets for lactating dairy cows and growing lambs, respectively. Ilori *et al*. (2013) in Nigeria found that baobab fruit can be included in goats' rations.

In South Africa research found that MOC can be incorporated in broiler diets without negatively affecting performance of the birds provided they are included at levels recommended by these researchers (Acheampong *et al*., 2016; Van Ryssen *et al*., 2014; Skenjana, 2011, Phosa, 2009). Studies conducted in Zimbabwe revealed that BSC can be incorporated in the diets for poultry (Chimvuramahwe *et al*., 2011 and Mwale *et al.*, 2008). Similar studies were conducted in Nigeria and found that BSC can be incorporated in poultry diets (Sola-Ojo *et al*., 2013; Bale *et al*., 2013; Sola-Ojo *et al*., 2011) as well as rabbits and rats (Olandunjoye *et al*., 2014; Ezeagu, 2005).

However, some of these (Macadamia and Baobab) by-products contain different quantities of nutrients. These differences are also evident in the cakes which were produced in the same country as well as those produced in other countries (Acheampong *et al*., 2016; Van Ryssen *et al*., 2014; Skenjana, 2011, Phosa, 2009; Chimvuramahwe *et al*., 2011 and Mwale *et al.*, 2008; Sola-Ojo *et al*., 2013; Bale *et al*., 2013; Sola-Ojo *et al*., 2011). This is an indication that there is a need to investigate the chemical constituents of these cakes especially those that are produced in South Africa so that those farmers who might be using the cakes to feed their animals can have the necessary scientific information to use during rations formulation. There is very little information on the chemical composition of Baobab seed cake produced in South Africa and this anomaly should be corrected as this cake is already being used by farmers to feed their animals. The objective of this study was to determine and compare the nutritional composition of MOC and BSC produced in South Africa.

3.2 Materials and methods

3.2.1 Study site

The study was carried out at the University of Venda, School of Agriculture experimental farm. University of Venda is in Vhembe district that is found in the far north of Limpopo Province under Thulamela local Municipality in Thohoyandou town. Thohoyandou is located approximately 70 km east of Makhado (formerly Louis Trichardt). Thohoyandou lies between latitude 22˚ 58' 23''S and longitude 30˚ 27' 30''E. The average summer temperatures range from 11˚C to 38˚C and the winter temperatures range from 11˚C to 27˚C (Kabanda, 2004).

3.2.2 Sample collection and processing

The MOC was bought from Royal Macadamia (Pty) Ltd in Levubu, a company which extracts oil from the Macadamia nuts which do not meet the requirements to be sold for human consumption. Baobab seed cake was bought from Ecoproducts in Louis Trichardt, a company which extracts oil from Baobab seeds. The cakes were brought to the university, dried, milled using a sample hammer mill to pass through a 1mm sieve and packaged in plastic ziplock sample bags and stored in a freezer at -20^{o}C to avoid spoilage especially fat racidity for future use.

3.2.3 Chemical composition determination

3.2.3.1 Nutrient analysis

3.2.3.1.1 Dry matter (DM) determination

The DM was determined according to the method of Associations of Official Analytical Chemists (AOAC), (2000). Five grams of each sample were dried in an oven at 60^0 C for until there was no weight change.

3.2.3.1.2 Ash determination and calculation of organic matter (OM):

The ash was determined by igniting the sample at 550^0C for 6 hours in a muffle furnace. Then OM was calculated from the ash content of the sample as follows:

% Organic matter on DM basis = 100% - % Ash on DM basis

3.2.3.1.3 Ether extract (EE) Determination

The EE was determined using the Tecator Soxtec System 1040 extraction unit (Soxtec method). Milled samples of MOC and BOC were subjected to fat extraction using petroleum ether in accordance with soxtec method.

3.2.3.1.4 Crude protein (CP) determination

The CP was determined according to the Kjeldahl method (AOAC, 2000) using Buchi Distilation Unit K-350. The samples of MOC and BSC were digested in Sulphuric acid.

3.2.3.2 Crude fibre (CF) determination

The CF was determined according to AOAC (2000) using the Fibertec 2010 machine. The samples of MOC and BSC were digested in sulphuric acid and sodium hydroxide solutions.

3.2.3.3 Determination of Neutral Detergent Fibre (NDF)

The determination of NDF was done according to the method of Robertson and van Soest, (1981). Samples of MOC and BSC were digested in neutral detergent solution and alpha-amylase solution.

3.2.3.4 Determination of Acid Detergent Fiber (ADF)

The ADF was determined according to the method of Goering and van Soest, (1970). Samples of MOC and BSC were digested in a pepsin-acid solution and acid detergent solution.

The NDF and ADF contain some ash which result in overestimation of the true NDF and ADF content of the cakes. You need to determine the ash free-NDF and ash free-ADF known as NDFom and ADFom respectively. This is now the acceptable current expression of the fibres in feeds. Redo the detergent fibre determination

3.2.3.5 Determination of Acid Detergent lignin (ADL)

The ADL was determined according to the method of Goering and van Soest, (1970). Samples of MOC and BSC were subjected to the ADF procedure except that the residue was further digested in a sulphuric acid.

3.2.3.6 Nitrogen free extractives (NFE)

The NFE was calculated as a percentage as follows:

%NFE = 100 – (%CP + %CF + %EE + % Ash)

3.2.3.7 Gross energy (GE)

The GE was determined by ignition of the sample using Bomb MC-1000 modular Calorimeter

3.2.3.8 Hemicellulose

Hemicellulose was calculated as a percentage as follows:

%Hemicellulose = %NDF - %ADF

3.2.3.9 Cellulose

Cellulose was calculated as a percentage as follows:

%Cellulose = %ADF - %ADL

3.2.3.10 Amino acid (AA) determination

Amino acid profiles of the MOC and BSC were determined according to the method of Spackman *et al*., (1958). The samples were digested in Hydrochloric acid and sculpture-containing AAs were digested in Performic acid. The AAs were separated using high performance liquid chromatography

3.2.3.11 Fatty acids (FA)determination

The FA profiles were determined according to Metcalf (1966) method using a Gas-liquid chromatography.

3.2.3.12 Mineral determination

The mineral composition of MOC and BSC samples were determined according to the method of Horwitz (2000).

3.2.4 Statistical analysis

Data on nutrient composition of cakes were analysed using 2-sample t-test (α <0.05) in Minitab 17 (Minitab, 2014) to determine whether or not the nutrients of the MOC and BSC were different. If the *P*-value was less than or equal to the α level, the null hypothesis (H_0) was rejected and it was concluded that there were significant differences in the nutritional value of the cakes.

3.3 Results

The nutrient composition of BSC and MOC are shown on Table 3.1. The MOC had significantly (*P<0.05*) higher moisture content than BSC, however, fat, hemicellulose and gross energy contents of BSC and MOC were not significantly (*P>0.05*) different. The BSC had significantly (*P > 0.05*) higher contents of ash, CP, ADL, Cellulose and NFE than MOC. However, MOC had significantly (*P<0.05*) high content of CF, NDF and ADF than BSC.

The sodium concentrations of BSC and MOC (Table 3.2) were not significantly (*P>0.05*) different. However, BSC had significantly (*P*<0.05) higher calcium, magnesium, potassium, phosphorus, zinc, and copper content compared to MOC. On the other hand, MOC had significantly (*P*<0.05) higher manganese and iron concentrations.

Table 3.3 shows the results of the AA profiles of BSC and MOC. The BSC had significantly (*P<0.05*) higher concentrations of Tryptophan, Cysteine, Arginine, Glutamic acid, Valine, Phenylalanine, Isoleucine, Leucine and Aspartic acid compared to MOC. However, the other Amino acids of BSC and MOC (Table 3.3) were not significantly different (P>0.05). In general BSC is richer in essential AAs (six out of the ten essential AA) compared to MOC.

Table 3.4 shows the FA contents of BSC and MOC. Out of the 23 individual FA of MOC and BSC analyzed, 14 FAs were significantly different (*P < 0.01*) and 9 FAs were not significantly different (P > 0.05). BSC had significantly higher (*P<0.01*) C16:0, and C17:1 contents compared to MOC. However, MOC had significantly (*P < 0.01*) higher C12:0, C14:0, C16:1,C18:0 C18:1n9c, C18:3n3, C20:1, C22:0, and C22:1n9 content. The MOC had significantly higher (*P<0.01*) saturated and mono-unsaturated fatty acids than BSC and on the other hand, BSC had significantly higher (*P<0.05*) polyunsaturated fatty acids content than MOC.

Table 3.1 Chemical composition (g/kg DM) of Baobab seed cake and Macadamia oil cake

Nutrients (g/kg DM)	Sample		SEM	Significance
	BSC	MOC		
Moisture (g/kg)	44±6.7	47±4.8	2.4	*
Ash	66±4.0	33±4.2	1.7	**
Fat	86±25.9	85±24.6	10.5	ns
Gross Energy (MJ/kg DM)	173±2.7	185±11.3	4.1	ns
Crude Protein	195±19.7	147±42.1	12.6	*
Crude Fiber	278±8.4	356±11.0	5.7	**
Acid Detergent Fiber	319±32.8	462±62.2	19	**
Neutral Detergent Fiber	415±23.5	554±56.6	16.3	**
Acid Detergent Lignin	154±5.7	72±3.0	2.5	**
Cellulose	165±33.4	389±62.3	19.5	**
Hemicellulose	96±25.6	92±38.2	13.0	ns
Nitrogen Free Extract	391±8.6	306±17.2	5.3	**

**: significantly different (P<0.01); *: significantly different (P<0.05); (ns) non-significant (P>0.05); BSC: Baobab seed cake; MOC: Macadamia oil cake; and (SEM) Standard error of means.

Table 3.2 Mineral composition of Baobab seed cake and Macadamia oil cake

Nutrients	Sample		SEM	Significance
	BSC	MOC		
Macro minerals (g/kg)				
Calcium	3.3±0.3	1.9±0.6	0.2	**
Magnesium	5.8±0.2	2.6±1.0	0.6	**
Potassium	15.3±1.2	5.8±1.8	0.6	**
Sodium	0.08±0.08	0.07±0.08	0.03	ns
Phosphorus	9.5±0.6	4.2±2.8	0.7	**
Micro minerals (mg/kg DM)				
Zinc	58.8±10.0	36.8±1.7	5.5	*
Copper	25.8±3.3	8.2±4.0	1.5	**
Manganese	21.7±2.3	51.7±14.2	3.4	**
Iron	130.0±50.5	234.0±78.7	26.5	*

**: significantly different (*P*<0.01); *: significantly different (*P*<0.05); ns: non-significant (*P*>0.05); BSC: Baobab seed cake; MOC: Macadamia oil cake; and SEM: Standard error of means.

Table 3.3 Amino acids profiles (g/kg DM) of Baobab seed cake and Macadamia oil cake

Amino acid	Sample		SEM	Significance
	BSC	**MOC**		
Tryptophan	2.1±0.02	1.4±0.03	0.02	**
Cysteine	8.5±0.8	1.3±0.3	0.31	**
Arginine	16.5±1.5	93±0.5	0.58	**
Serine	6.2±1.2	5.1±1.1	0.67	ns
Aspartic acid	11.3±1.5	8.4±0.6	0.62	*
Glutamic acid	27.8±2.5	14.1±1.1	1.02	**
Glycine	6.0±0.5	6.8±0.8	0.38	ns
Threonine	3.9±0.3	3.2±0.5	0.22	ns
Alanine	5.1±0.2	4.4±0.6	0.22	ns
Tyrosine	4.0±0.5	5.0±1.0	0.44	ns
Proline	4.8±0.1	4.7±0.1	0.06	ns
HO Proline	0.9±0.1	2.9±0.1	0.06	**
Methionine	0.9±0.3	0.9±0.2	0.15	ns
Valine	6.7±0.3	4.2±0.2	0.15	**
Phenylalanine	5.9±0.3	3.2±0.3	0.17	**
Isoleucine	4.8±0.4	3.4±0.1	0.14	**
Leucine	8.4±0.5	5.7±0.7	0.35	**
Histidine	4.6±0.4	4.4±0.2	0.18	ns
Lysine	8.1±1.1	6.5±0.5	0.47	ns

**: significantly different (*P*<0.01); *: significantly different (*P*<0.05); ns: non-significant (*P*>0.05); BSC: Baobab seed cake; MOC: Macadamia oil cake; and SEM: Standard error of means.

Table 3.4 Fatty acid profiles (g/kg DM) of Baobab seed cake and Macadamia oil cake

Fatty acids	Sample		SEM	Significance
	BSC	MOC		
C12:0	0.01±0.009	0.08±0.02	0.009	**
C14:0	0.1±0.09	0.8±0.04	0.04	**
C15:0	0.03±0.02	0.02±0.0	0.007	ns
C16:0	12.2±0.2	9.5±0.01	0.07	**
C16:1	0.1±0.01	23.2±0.09	0.03	**
C18:0	2.1±0.01	3.6±0.04	0.01	**
C18:1n9t	0.0±0.1	0.09±0.02	0.04	ns
C18:1n9c	16.6±0.04	69.9±0.	0.01	**
C18:2n6t	0.03±0.01	0.03±0.02	0.02	ns
C18:2n6c	14.9±0.01	3.0±0.02	0.02	**
C18:3n6	0.03±0.01	0.0±0.1	0.06	ns
C18:3n3	0.17±0.02	0.46±0.03	0.02	**
C20:0	0.4±0.3	0.29±0.01	0.09	**
C20:1	0.14±0.04	2.9±0.3	0.10	**
C20:2	0.01±0.009	0.007±0.006	0.004	ns
C21:0	0.03±0.01	0.02±0.01	0.006	ns
C22:0	0.2±0.03	1.1±0.1	0.04	**
C22:1n9	0.01±0.009	0.3±0.02	0.009	**
C24:0	0.2±0.01	0.3±0.04	0.01	**
C17:0	0.1±0.05	0.09±0.01	0.02	ns
C17:1	0.14±0.02	0.02±0.01	0.009	**
C20:4n6	0.007±0.006	0.003±0.006	0.003	ns
C23:0	0.02±0.02	0.02±0.01	0.009	ns
Saturated Fatty Acid	15.3±0.1	18.3±0.2	0.10	**
MONO-Unsaturated Fatty Acid	17.1±2.0	96.1±6.1	2.30	**
POLY-Unsaturated Fatty Acid	15.1±1.0	3.6±0.6	0.46	**
TRANS Fatty Acid	0.03±0.01	0.12±0.006	0.005	**
CIS Fatty Acid	31.3±1.0	74.3±5.2	1.79	**
OMEGA 3	0.18±0.03	0.48±0.03	0.02	**
OMEGA 6	15.05±0.2	3.06±0.06	0.06	**
OMEGA 9	16.8±1.3	70.5±0.6	0.57	**

**: significantly different (P<0.01); *: significantly different (P<0.05); ns: non-significant (P>0.05); BSC: Baobab seed cake; MOC: Macadamia oil cake; and SEM: Standard error of means

3.4 Discussion

3.4.1 Chemical composition analysis data

The significantly higher moisture content of MOC suggests that MOC may have a shorter shelf life than BSC because low moisture content has the potential to reduce the decay of feed materials as a result of microbial actions (Gadanya *et al*., 2014). The results of moisture content of MOC (47g/kg) of the current study disagreed with 60g of moisture/kg MOC reported by Acheampong-Boateng *et al*. (2008), and Van Ryssen *et al*. (2014), and 88g moisture/kg reported by Tiwari and Jha (2016). The differences with the first two researchers may be due to the inconsistency in production time as the cakes were produce at the same factory, and on the other hand, the difference with the later may be attributed to the difference in the production methods. Madzimure *et al*. (2011) and Oladunjoye *et al*. (2014) also reported moisture content of Baobab seed cake of 91g/kg and 92g/kg which were contradictory to the results of the current study. The differences in moisture content between those of the current study and the ones in the literature suggest that BSC and MOC of this study contained less moisture which would prolong the shelf life of the cakes. The oil extraction methods might have attributed to the differences in moisture content for BSC as those cited above were produced in other countries. However, the average 45.5g moisture/kg BSC and MOC in the present study was comparable to 39.6 g/kg of olive cake reported by Mioč *et al*. (2007).

The differences in ash content might be attributed to the plant species differences and the soil type where the two trees are found. Macadamia trees are planted along the Levubu valley which is characterized by reddish clay type of soils whereas baobab trees are found in abundance in the more dry areas of Vhembe district with a more sandy type of the soil as well as the species differences. The results of the ash content of BSC of the current study were higher than 45g ash/kg DM and 45.7g ash/kg DM BSC reported by Madzimure *et al*. (2011) and Oladunjoye *et al*. (2014), respectively. The 33g ash/kg DM of MOC in this study was higher than 28g ash/kg on as fed basis of MOC reported by Acheampong-Boateng *et al*. (2008) and Van Ryssen *et al*.,(2014) but lower than 48g ash/kg DM of sunflower oil cake reported by Nkosi *et al*., (2011). However, 33g ash/kg DM MOC in the present study is comparable to 37g ash/kg DM macadamia nut cake reported by Tiwari and Jha (2016).

The similar EE content of BSC and MOC in the present study may be due to the screw press method used to extract oil from the seeds and nuts, respectively since this method leaves a considerable amount of fat in the oil reisdue. The average 85.5g crude fat/kg DM in the present study is comparable to 91.7 g EE/kg DM of olive cake reported by Mioč *et al*. (2007). However, the EE content of MOC (85g/kg DM) in the present study was lower than 119g EE/kg DM, 228g/kg on fed basis for Macadamia nut cake and MOC reported by Tiwari and Jha (2016), and Van Ryssen *et al*. (2014), respectively. The differences in crude fat of MOC suggest that there might be inconsistencies with regards to the extent at which the oil is pressed from the nuts because MOCs were produced at Royal Macadamia (Pty) Ltd. The Macadamia varieties differences may also be attributed to these differences in the fat content of the nuts. Baobab seed cake fat content (86g EE/kg DM) in the present study was lower than 148g EE/kg DM for BSC reported by Oladunjoye *et al*., (2014). These differences may be due to the differences in the varieties and oil extraction methods used especially due to the fact that BSC was produced in different countries. The crude fat content of BSC and MOC in the present study was also lower than 308.4g EE/kg DM sunflower oil cake reported by Nkosi *et al*. (2011). These differences may be attributed to the different species and oil extraction methods.

The non-significant differences in gross energy contents of BSC and MOC in the present study may be attributed to the similar crude fat content of the cakes. It is widely accepted that fat contributes to the energy content of the feed. Numerically, the gross energy content of BSC (17.27 MJ/kg DM) was comparable to 17.21 MJ/kg DM of sesame oilcake and MOC (18.52 MJ/kg DM) was comparable to 18.55 MJ/kg DM of soybean oil cake reported by Udo and Umoren (2011). However, gross energy (17.27 MJ/kg DM and 18.52 MJ/kg DM) content of BSC and MOC in the present study were lower than the 20.6 MJ/kg DM of sesame oil cake reported by Nang Thu *et al*. (2011). The differences may be due to the higher crude fat content of the sesame oil cake. Tiwari and Jha (2016) reported that macadamia nut cake contained 23.36 MJ/kg DM which was higher than the gross energy of MOC in the present study. The higher gross energy content of macadamia nut cake (Tiwari and Jha, 2016) may be attributed to the high fat content of macadamia nut cake. The high energy contents of the two cakes suggest that they have potential to be good sources of energy for animals.

The differences in CP contents of BSc and MOC in this present study may be due to the differences in plant species. The higher protein and NFE contents of BSC may be due to the leguminous nature of baobab trees (Mshigeni and Hangula, 2001) because legumes are known for their higher protein contents. The protein content of BSC (195g CP/kg DM) was lower than 288.5g CP/kg DM raw baobab seed meal reported by Saulawa *et al*. (2014); and the differences could be attributed to either different baobab trees varieties or environmental conditions such as the amount of nitrogen in the soil where these trees grew. However, crude protein content of BSC (195g/kg DM) in the present study was higher than 169g CP/kg DM BSC and comparable to 204g CP/kg DM BSC reported by Madzimure *et al*. (2011) and Oladunjoye *et al*. (2014), respectively and it was lower than 376.3g CP/kg DM of baobab seeds reported by Sola-Ojo *et al.* (2011). The differences may be attributed to the different baobab varieties, geographical origin and oil extraction methods used. The NFE content of BSC (39.1g/kg DM) in the present study was lower than 49.9g NFE/kg DM of BSC reported by Oladunjoye *et al*. (2014). These differences may be due to variety, soil, processing method and the geographical location. The crude protein content of MOC (147g CP/kg DM) in the present study was comparable to 132g CP/kg as on fed basis of Macadamia oil cake meal and 133.82g CP/kg DM of Rice bran reported by Van Ryssen *et al*. (2014) and Udo and Umoren (2011), respectively, but lower than the 255g CP/kg DM of Macadamia nut cake reported by Tiwari and Jha (2016). However, the crude protein content of MOC in the present study was lower than 195g CP/kg DM of MOC and 203g CP/kg DM of MOC reported by Acheampong-Boateng *et al*. (2008) and Skenjana (2011), respectively. These differences may be due to the inconsistency in the addition of soybean hulls during oil extraction process, different macadamia varieties and prio-extraction of oil before crude protein determination for Skenjana’s findings. Sherrod and Ishizaki (1966/67) reported a crude protein content of 94g CP/kg DM and 99g CP/kg DM of roasted macadamia nut which was lower than the crude protein of MOC of the current study. The differences may be attributed to the differences in processing methods. Roasting is known to drastically reduce the protein content of seeds.

The significant differences in crude fibre content of the present study and the higher crude fibre of MOC might be due to high quantities of soyabean hulls added to macadamia nuts during oil extraction to mitigate against potential sticking of the cake to the sides of oil expeller due to the low fibre content of the nuts.

The 278g CF/kg DM of BSC in the present study was comparable with 256.1g CF/kg DM BSC reported by Madzimure *et al*. (2011). The 278g CF/kg DM of BSC in the present study was higher than 107.8g CF/kg DM and 104 g CF/kg DM baobab seed meal reported by Saulawa *et al*. (2014) and Oladunjoye *et al*. (2014), respectively. These differences may be due to different processing and oil extraction methods, the varieties of baobab trees and the geographical region at which these seeds were collected. The 278g CF/kg DM of BSC in the present study was higher than 142g CF/kg DM sunflower meal, 74g CF/kg DM soybean meal, 110 g CF/kg DM rice bran and 70g CF/kg DM sesame seed meal reported by Abdel-Hakim *et al*. (2008). These differences may be primarily due to the differences in plant species with environmental and method of oil extraction being other contributory factors.

The 356g CF/kg DM of MOC in the present study was comparable to 365 g CF/kg as on fed basis of MOC reported by Van Ryssen *et al*. (2014). These similarities may be attributed to the fact that these studies used the same source (Royal Macadamia (Pty)Ltd) of these cakes. However, crude fibre content of MOC (356g CF/kg DM) in the present study was higher than 252g CF/kg DM MOC, 249g CF/kg DM MOC and 286.9g CF/kg DM MOC reported by Tiwari and Jha (2016), Acheampong-Boateng *et al*., (2008) and Skenjana (2011), respectively. These differences may be attributed to varying amounts of soyabean hulls included during oil extraction process. The crude fibre content of MOC in the present study was also higher than 308g CF/kg DM of sunflower oil cake reported by Nkosi *et al*. (2011). The differences can be attributed to differences in plant species and inclusion of soyabean hulls during oil extraction.

The differences in ADF, NDF, ADL and cellulose contents of BSC and MOC in the present study may be due to the differences in their fibre contents and the chemical composition of the crude fibre. The higher values of ADF and NDF of MOC over those of BSC (Table 3.1) can be explained by the incorporation of soyabean hulls during oil extraction from the macadamia nuts. The higher NDF of MOC however, indicated that it may be highly degradable in the rumen of farm animals compared to BSC. The extremely high value of ADL and cellulose in BSC over those of MOC (Table 3.1) indicated that the CF in BSC was highly lignified and may not be easily digested/degraded by animals. The ADF and NDF of BSC obtained in the present study were higher than 370g ADF/kg DM of BSC and 276g NDF/kg DM of BSC reported by Belewu and Ibikunle (2009). The differences may be due to the differences in the processing methods, the plant varieties and the geographical location. The NDF and ADF of MOC (Table 3.1) obtained in the present study were higher than 498.4g NDF/kg DM and 400.4g ADF/kg DM of MOC reported by Skenjana (2011). Phosa (2009) also reported a 394.42g NDF/kg DM of MOC which was lower than that of the present study. The results of ADF, NDF, and ADL of the current study were higher than 280g/kg ADF and 358g/kg NDF reported by Tiwari and Jha (2016) for macadamia nut cake. The differences may be attributed to the inclusion of soyabean hulls during the oil extraction process and the presence of shell chips in the cracked nuts. Hemicellulose and cellulose contents of MOC in the present study were lower than 98.9g hemicellulose/kg DM and 267.1 g cellulose/kg DM of MOC, respectively reported by Skenjana (2011). These differences may be due to the inconsistency in the inclusion levels of soyabean hulls during the oil extraction process.

The significantly higher calcium, phosphorus, magnesium and potassium values of BSC compared to those of MOC may be due to the differences in plant species and the geographical location. According to Mshigeni and Hangula (2001) *Adansonia digitata L* (baobab tree) is a legume and legumes are rich in protein and minerals (McDonald *et al*., 2011). This explains these high mineral values of BSC compared to MOC. The 3.3g Calcium/kg DM of BSC in the present study was comparable to 3g calcium/kg DM of BSC reported by Saulawa *et al*., (2014) for raw Baobab seed meal. The calcium and potassium contents of BSC in the present study were comparable to 4.4 g calcium/kg DM and 15g potassium/kg DM of BSC reported by Babiker (2012). Phosphorus, Magnesium and Potassium values of the present study were higher than 3g phosphorus/kg DM, 3g magnesium/kg DM and 4g potasium/kg DM of BSC, respectively reported by Saulawa *et al*. (2014) and also 5g calcium/kg DM, 4.3g magnesium/kg DM and 4.3g potasium/kg DM of BSC reported by Babiker (2012). The Phosphorus content of the present study was higher than 2.4g phosphorus/kg DM and 5g phosphorus/kg DM of BSC reported by Saulawa *et al*. (2014) and Babiker (2012). The differences may be due to the differences in the baobab varieties and the geographical location of the trees. The processing method especially the oil extraction method may also affect the mineral content of the feed material. The non-significant difference in Sodium content of BSC and MOC of the present study (Table 3.2) suggested that these two cakes possed similar quantities of sodium and their lower values of sodium meant that both cakes were poor sources of this mineral.

The 2.6g magnesium/kg DM content of MOC in the present study was comparable to 2.4g magnesium/kg DM of MOC reported by Skenjana (2011). However, calcium, sodium and potassium contents of MOC in the present study were lower than 3.3g calcium/kg DM, 1.8g sodium/kg DM and 13.9g potasium/kg DM all for MOC reported by Skenjana (2011) but his findings of Phosphorus (3g/kg DM of MOC) was lower than 4.2g phosphorus/kg DM of MOC in this study. Acheampong-Boateng *et al*. (2008) reported 2.4g calcium/kg DM of MOC which was comparable to 1.9g calcium/kg DM of MOC found in this study but he also found lower Phosphorus value of 2.9g/kg DM of MOC content to that of this study. Van Ryssen *et al*. (2014) reported a 1.6g cacium/kg as on fed basis of MOC which was comparable to that of the present study. However, van Ryssen et al. (2014) reported a phosphorus value of 2.3g/kg as on fed basis of MOC which was lower than that of the present study. The differences may be due to the differences in the year of production and the varieties of macadamia nuts.

The significantly higher zinc, copper and lower manganese and iron contents of BSC (Table 3.2) as compared to their respective MOC values may be attributed to the differences in plant species with baobab being a legume and macadamia as non-legume trees. The iron, zinc, and copper concentrations of BSC in this study were higher than 50.1mg iron/kg DM, 41.1mg zinc/kg DM, and 18mg copper/kg DM of BSC reported by Saulawa *et al*. (2014).

The MOC concentrations of Copper, Iron, and Manganese in the present study were lower than 13.7mg copper/kg DM, 248.9mg iron/kg DM, and 267.2mg manganese/kg DM of MOC reported by Skenjana (2011) for MOC but zinc concentration (Skenjana, 2011) was higher at 59.0mg/kg DM of MOC to 55.6mg zinc/kg DM of MOC in the current study. The differences in concentrations of these micro-minerals in MOC may be due to the differences in the year in which they were produced, the Macadamia varieties and the inclusion levels of soybean hulls.

3.4.2 Amino Acids profiles

The significantly higher concentrations of essential Amino acids of BSC compared to those of MOC (Table 3.3) in the present study suggest that BSC contains protein of good quality. However, the similar and lower methionine values for both BSC and MOC (Table 3.3) make them poor sources of this essential Amino acid. The findings of the present study were in agreement with the report of Osman (2004) who indicated that baobab seeds contained relatively higher concentrations of essential Amino acids. However, numerically the essential Amino acids concentrations of BSC in the present study were lower than those of baobab seeds reported by Osman (2004). The differences may be attributed to the differences in variety, soil, geographical region and oil extraction method.

BSC and MOC in the present study contained similar concentrations of non-essential Amino acids except for cysteine, aspartic acid and glutamic acids which were significantly higher in BSC. The essential and non-essential Amino acids concentrations of both BSC and MOC were lower than those of fish meal, jatropha kernel meal, and soybean meal reported by Akinleye *et al*. (2011). These differences may be due to the differences in species, soil, and geographical location. The AA concentrations of MOC in the present study were lower than those reported by Skenjana (2011) for macadamia oil cake meal except for histidine concentration which was higher for the present study. These differences may be due to differences in the seasons, macadamia varieties, soil, and soyabean hulls inclusion. The AA profile of macadamia nut cake reported by Tiwari and Jha (2016) show that 7.0g lysine/kg DM and 4.5g histidine/kg DM contents were comparable to those of MOC in the present study, however, a methionine (3.4g/kg DM), threonine (7.9g/kg DM), tryptophan (2.1g/kg DM), phenylalanine (7.5g/kg DM), valine (9.5g/kg DM), isoleucine (7.7g/kg DM), leucine (13.8g/kg DM), arginine (25.7g/kg DM), cysteine (6.0g/kg DM), proline (10.3g/kg DM), glutamic acid (43.6g/kg DM), tyrosine (8.5g/kg DM) and serine (9.0g/kg DM) of macadamia nut cake were all higher than those of MOC in the present study. The differences may be attributed to the differences in the oil extraction process because macadamia nut cake production did not include soyabean hulls as it is the case with MOC. The macadamia varieties, soil and environmental conditions may be contributory to the differences in the Amino acids profiles of the macadamia cakes because Macadamia nut cake used by Tiwari and Jha (2016) was produced in Hawaai.

3.4.3 Fatty acid (FA) composition of Baobab seed cake and Macadamia oil cake

The significantly higher concentrations of fatty acids for MOC compared to those of BSC in the present study suggest that despite the two cakes having similar concentrations of EE the composition of the fat/oil is different. The higher concentration of saturated fatty acids (lauric, myristic and stearic acids) and unsaturated fatty acids (oleic and linolenic acids) in MOC compared to those of BSC was an indication that MOC is rich in both classes of fatty acids. The two cakes are both rich in one of the two essential fatty acids with MOC being rich in linolenic acid and BSC rich in linoleic acid. The use of the two cakes can be useful in ruminants' diets because according to McDonalds *et al*. (2011) ruminants cannot synthesize linolenic and linoleic acids. The BSC in the present study was also rich in palmitic acid which was in agreement with the findings of Osman (2004) who indicated that baobab seeds were rich in palmitic and linoleic fatty acids and that they form part of their major fatty acids. In the present study MOC was a major source of mono-unsaturated fatty acids whereas BSC was rich in poly-unsaturated fatty acids. These results were in agreement with the findings of Oman (2004) who argued that baobab seeds were a major source of mono-and poly-unsaturated fatty acids. The values of myristic, palmitic, stearic, elaidic, oleic, linoleic, linolenic, arachidonic, saturated, mono-unsaturated, and poly-unsaturated fatty acids of the current study were lower than those of MOC as reported by Skenjana (2011) and macadamia nut cake reported by Tiwari and Jha (2016), however, erucic fatty acid value of the current study was higher than that of the later. The differences may be due to the differences in the varieties, the processing method and environmental conditions.

3.5 Conclusion

It can be concluded that BSC is richer in most nutrients than MOC especially crude protein, essential Amino acids, NFE, minerals and polyunsaturated fatty acids. MOC contains high fibres, saturated and mono-unsaturated fatty acids. Baobab seed cake has a potential to be used in rations formulations as a protein supplement especially for ruminants. The low protein content of MOC makes it an intermediate protein supplement falling in the same group with rice bran and wheat bran. Baobab seed cake, however, contained high acid detergent lignin which may be problematic during digestion as it is the most indigestible component of the fibre. The high fibre content of MOC may cause reduction in feed intake by animals and if it is included in higher quantities in diets for animals this should be taken into consideration. Baobab seed cake and MOC were both good sources of plant fat/oil especially the unsaturated fatty acids which may be beneficial to consumers of the meat of animals fed these cakes if the fatty acids can be able to alter the fatty acid composition of the fat of the meat. As a mitigating factor, the highly saturated fats of beef can be altered through the introduction of unsaturated fatty acids rich feed materials in the diets of beef cattle (Vahmani *et al*., 2015). Sunflower seeds in the diets of beef cattle increased the unsaturated FAs of their carcasses which could have health benefits in humans (Mapiye *et al*., 2015).

Based on their nutritional analysis, these cakes can be used in diets for both ruminant and non-ruminant animals as energy and to a lesser extend as protein supplements provided their fibre and Amino acid concentrations are taken into consideration when formulating rations especially for non-ruminants animals.

CHAPTER 4: RUMINAL DEGRADATION OF DRY MATTER, CRUDE PROTEIN AND AMINO ACIDS OF BAOBAB SEED CAKE AND MACADAMIA OIL CAKE

4.1 Introduction

According to FAO (2002) global meat production and consumption will increase from 233 x10^6 metric tonnes (in 2002) to 300x10^6 metric tonnes in 2020. The increase in meat demand is probably among other factors related to population increase which in turn is positively related to reduce grazing land and, poses serious challenges in animal production systems. In South Africa, like many other developing countries globally, the use of unconventional plant oilseeds by-products produced from horticultural industries as nutrient supplements for ruminant animals has become one of the options used to satisfy the nutrient requirements of the animals. The use of these by-products is driven by amongst other factors like the shortages of grazing pastures during the dry season, high costs of cereal by-products due to competition between the animal and human feed manufacturing industries, and the increasing demand for red meat globally due to an ever increasing human population. Tropical and subtropical countries experience a decline in the quality and quantity of forages annually during the dry season (Noula *et al*., 2004).

Baobab seed cake (BSC) and Macadamia oil cake (MOC) produced in South Africa along the Soutpansberg Mountain in Vhembe district are by-products of the plant oil industry. These cakes are being used by livestock farmers in this region to feed their animals as a way to mitigate the problems of feed shortages during the dry season and for the purposes of conditioning of animals for slaughter. However, information on the nutritional value of these two cakes in South Africa is limited and as a result there is a need to establish the extend at which they are degraded in the rumen and their subsequent digestion post- ruminally. The nutritional information, in particular, that of Baobab seed cake produced in other countries cannot be relied on due to the disparities in the production methods (Marghazani, 1998) and environmental factors. The importance of rumen degradation studies is that it provides information on the quantity of protein degraded in the rumen for the purposes of microbial protein synthesis.

According to NRC (2001) the sources of utilizable protein for ruminants are the microbial protein discharged from the rumen, rumen undegraded dietary protein and endogenous protein. Moreover, according to Schwab *et al*. (2005) microbial proteins provide the majority of Amino acids which are also of high quality for digestion in the small intestines of ruminants. The provision of protein from microbial protein may not be sufficient to meet the requirements for this nutrient by animals especially for the high producing animals. It is then imperative to include in ruminants rations protein sources/supplements which provide a source of rumen undegradable protein to supplement the quantity of protein provided by microbial protein.

Rumen undegradable protein provides a good measure of protein value of feed materials (Aufrère *et al*., 2001). The formulation of rations for ruminant animals should be based on the feed ingredients' amounts of rumen degradable protein and rumen undegradable protein of the ration (NRC, 2001). A diet formulated in this way will be able to provide the animal with sufficient protein to meet both the microbial and animal requirements. However, proteins of most solvent oil extracted seed meals are highly degraded in the rumen (Wright *et al*., 2005) thereby leaving very little rumen undegradable protein for digestion in the small intestines and subsequent utilization by the animal. Heat treatment can lower rumen protein degradation through the process of denaturing and Maillard reactions of proteins (Moshtaghi Nia and Ingalls, 1995). It is therefore hoped that the generation of heat during the screw press production of BSC and MOC can reduce their protein degradation in the rumen. The objective of this study was therefore, to evaluate rumen degradability of dry matter, crude protein and Amino acids of BSC and MOC.

4.2 Materials and methods

4.2.1 Study site

The experiment site description was the same as in 3.2.1.

4.2.2 Sampling of Baobab seed and Macadamia oil cakes

The samples of MOC and BSC were obtained as indicated in 3.2.2.

4.2.3 Animals and feeds

Three 18 months old Bonsmara males (average weight of 395 kg) each fitted with permanent rumen-fistula (13 cm internal diameter; Bar Diamond, USA) were used to determine the degradability of BSC and MOC. At the beginning of the study but initiation of data collection, animals were kept in one pen and fed with a commercial cattle finisher diet (Table 4.1) at the rate of 5 kg per day. Fresh water was supplied *ad libitum*.

Table 4.1: Chemical composition of commercial complete cattle finisher diet used in the study

Composition	**g kg^{-1}**
Protein (min)	120
Calcium (max)	8
Phosphorus (min)	3
Moisture (max)	120
Fibre (max)	200
Fat (min):	25
Urea (max):	1.25
% Derived from Urea	29.9%
	mg kg^{-1}
Monensin NA	30
Zinc Bacitracin	50

*Supplied by Driehoek feeds (Vaalwater, Waterberg, Limpopo, South Africa)

4.2.4 Sample preparations

The samples of MOC and BSC collected from Royal Macadamia (Pty)Ltd and Ecoproducts were first analyzed for DM (see 3.2.3.1.1), CP (see 3.2.3.1.4) and AA (see 3.2.3.9) before the incubation in order to have the initial chemical composition of the cakes. After the DM, CP, and AA of BSC and MOC were analyzede, another set of samples of MOC and BSC were ground to pass through a 2 mm sieve and placed in nylon bags for the purposes of this study.

4.2.5 The *in situ* degradation (nylon bag) method

The nylon bag technique (Mehrez and Ørskov, 1977) was used. The Dacron bags (Nitex, B.O.M: B3A03001010200) of an effective size of 5 cm x 10 cm and pore size 41 μm containing 5 grams of each of air dried sample, milled through a 2.5 mm screen was used. The bags were attached about 2 cm below the top using plastic bands, to flexible vinyl plastic tubes, about 40 cm long and of 6 mm outer diameter, and then suspended in the rumen of the cannulated animals for incubations of 0, 2, 4, 6, 8, 12, 16, 24, 36, 48 and 72 hours (NRC,2001). The bags were incubated in the rumen in duplicates per incubation period. The insertion of bags was done before the morning feeding time. After each incubation time, the bags were immediately withdrawn from the rumen, placed in cold water to prevent further fermantation and washed under running tap water until effluent water remained clear. The zero hour bags (control) were washed without incubation in the rumen. The washed bags were dried in a forced air oven at

60°C until the weight of the sample remains constant (24 hours), allowed to cool and then weighed to determine DM disappearance and the residues subjected to further nutrient analysis (Crude protein and Amino acids).

4.2.6 Laboratory analysis

The residual DM in nylon bags were analyzed for CP as described in 3.2.3.1.4 and Amino acid disappearance was determined as described in 3.2.3.9. Then the nutrients degradation were calculated by the difference between the amount in control sample and degraded residues.

4.2.7 Mathematical calculations

The degradability of dry matter, crude protein, and Amino acids with time for each sample were described using the mathematical model of Ørskov and McDonald (1979):

$$P = a + b\,(1 - e^{-ct})$$

Where P = Dry matter disappearance at time

a = zero time intercept

b = slowly degradable fraction

c = rate of degradation

Potential degradability (PD) was estimated as (a + b). Effective degradability (ED) was calculated at rumen fractional outflow rates (k) of 0.02, 0.05 and 0.08 per hour according to Ørskov and McDonald (1979):

$$ED = a + bc/(k+c)$$

The degradability constants were estimated using the Neway Excel version 6 (The Rowett Research Institute, Aberdeen, UK).

4.2.8 Statistical analysis

Data on dry matter, crude protein and Amino acid disappearance, and degradation constants (Model I) were subjected to analysis of variance (ANOVA) using the General Linear Model of Minitab software version 17 (2014). The treatment means were compared using Tukey's Studentised multiple range test at 5% significance level.

$Y_{ijk} = \mu + A_i + C_j + \Sigma_{ijk}$ Model I

Where, Y_{ijk} = the observation, ruminal degradability of DM, CP and Amino acids, and ruminal kinetics;

μ = overall mean common to all observations;

A_i = fixed animal effect, i = 1, 2 or 3;

Cj = effect of j^{th} cake, j = 1 or 2;

Σ_{ijk} = Random error

4.3 Results

The rumen disappearance values of DM and CP of MOC and BSC are shown in Table 4.2. The MOC had a significantly (*P<0.01*) higher DM washing loss than BSC. However, BSC had a significantly (*P<0.01*) higher CP washing loss than MOC. The DM disappearance of MOC and BSC did not differ significantly at all the incubation periods indicated in Table 4.2. The CP disappearance of MOC and BSC did not significantly differ over the first 12 hours of incubation but thereafter, BSC had significantly higher (*P<0.01*) CP disappearance percentages over the incubation range of 72 hours inclusive.

The characteristics of rumen degradation are shown in Table 4.3. The MOC had significantly (*P<0.01*) higher soluble fractions (a) values of DM than that of BSC. However, the CP soluble fraction in BSC was significantly (*P<0.01*) higher than that of MOC. The percentage insoluble but potentially degradable fractions (b) and the outflow rate of degradation (c) of both MOC and BSC for DM and CP were not significantly (*P>0.05*) different.

The potential rumen degradability (a+b) of DM in MOC and BSC were not significantly different however, BSC had a significantly (P<0.01) higher potentially degradabable CP than MOC.

Effective degradability percentage of DM was significantly (P>0.05) different in both MOC and BSC calculated at an outflow rate of 2% per hour. However, BSC had a significantly (P<0.05) higher percentage of effective degradability of DM at an outflow rate of 5% per hour whereas MOC had a significantly (P<0.05) higher percentage value of effective degradability at an outflow rate of 8% per hour. There were significant (P<0.05) differences in percentage effective degradability values of CP of MOC and BSC calculated at three out flow rates (2, 5, and 8%h^{-1}). At out flow rates of 2, 5, and 8% per hour, BSC had significantly (P < 0.05) higher percentage of effective CP degradability values than MOC.

The AA degradability profiles of MOC and BSC incubated in the rumen for 0, 12, 16, 24, and 48 hours are presented in Table 4.4. In the case of washing loss, MOC had significantly higher (P<0.05) values for arginine, threonine (essential Amino acids), aspartic acid, glutamic acid and proline (non-essential Amino acids) whereas the other Amino acids were not significantly different (P>0.05). There were no significant (P>0.05) differences in the degradability of methionine of both MOC and BSC incubated in the rumen of the steers at 0, 12, 16, 24 and 48 hours. At the 12th hour of rumen incubation MOC had significantly higher (P<0.05) values for Arginine, Threonine, Phenylalanine, Leucine, Lysine (all essential Amino acids), Aspartic acids, Glutamic acid, Glycine, and Proline. Baobab seed cake had significantly higher (P<0.05) values for Valine, and Proline compared to MOC after 12 hours of ruminal incubation. The degradability values of Isoleucine, Histidine, Alanine, and Tyrosine for both MOC and BSC incubated for 12 hours were not significantly different (P>0.05). At 16 hours incubation period, MOC had significantly higher values for Arginine, Phenylalanine, Histidine (all essential AA), Glycine, and Tyrosine whilst BSC had significantly higher (P<0.05) degradability values for Valine, Isoleucine, Leucine, Lysine (all essential AA), Aspartic acid, Glutamic acid, Alanine, and Proline. Like Methionine, Threonine degradability values were not significantly (P>0.05) different between MOC and BSC incubated in the rumen for 16 hours. After 24 hours of samples incubation, BSC had significantly higher (P<0.05) degradability values of Arginine, Valine, Phenylalanine, Lysine (all essential AA), Aspartic acids, Glutamic acid, and Proline. Like Methionine, the degradability values of Threonine, Isoleucine, Leucine, Histidine (all essential Amino acids), Glycine, Alanine, and Tyrosine were not significantly different between MOC and BSC incubated for 24 hours in the rumen of steers. BSC had significantly higher (P<0.05) degradability values for the entire AA except for methionine compared to MOC at an incubation period of 48 hours.

Table 4.2 *In sacco* dry matter and crude protein disappearance (%) of macadamia oil cake and baobab seed cake

Incubation h	DM				CP			
	Sample		SEM	Significance	Sample		SEM	Significance
	Baobab	Macadamia			Baobab	Macadamia		
0	21.28	27.26	1.102	ns	30.79[a]	6.55[b]	0.224	**
2	22.85	27.88	2.812	ns	34.62	33.4	1.145	ns
4	29.26	32.33	1.182	ns	34.34	37.16	1.214	ns
8	36.49	35.72	1.096	ns	37.21	36.201	1.058	ns
12	36.71	34.75	1.729	ns	39.44	38.3	0.813	ns
16	39.84	38.00	1.385	ns	51.37[a]	39.03[b]	0.658	**
24	46.68	43.47	1.031	ns	62.72[a]	40.88[b]	0.251	**
36	53.29	47.35	4.557	ns	64.44[a]	40.59[b]	0.835	**
48	66.72	63.93	3.260	ns	67.21[a]	41.43[b]	1.047	**
72	74.91	72.85	0.371	ns	69.2[a]	42.95[b]	0.224	**

**: P <0.01; ns: non-Significant (P > 0.05); [ab] :Row means with different superscripts differ significantly at P <0.05; Row means without [a] and [b] as superscripts are not significantly different at (P>*0.05*); DM: dry matter; CP: crude protein; SEM: standard error of means

Table 4.3 *In sacco* rumen degradability constants of Macadamia oil cake and Baobab seed cake

		DM				CP			
		Sample				Sample			
		BSC	MOC	SEM	Significance	BSC	MOC	SEM	Significance
Degradability constants	a	21.27^{b}	27.27^{a}	1.105	**	30.77^{a}	6.57^{b}	0.041	**
	b	73.87	70.5	1.952	ns	69.23	69.77	1.285	ns
	c	0.005	0.015	0.003	ns	0.001	0.001	0.0003	ns
	a+b	95.13	97.77	1.252	ns	100^{a}	76.33^{b}	1.321	**
ED(%) at three outflow rates	0.02	72.83	78.84	1.336	ns	80.17^{a}	37.24^{b}	0.084	**
	0.05	63.23^{a}	56.81^{b}	1.400	*	65.35^{a}	28.03^{b}	0.072	**
	0.08	48.2^{b}	54.83^{a}	1.427	*	57.37^{a}	28.08^{b}	0.064	**

**: P <0.01; *: P <0.05; ns: non-Significant (P > 0.05); ^{ab} :Row means with different superscripts differ significantly at P <0.05; Row means without ^{a} and ^{b} as superscripts are not significantly different at ($P>0.05$); DM: dry matter; CP: crude protein; a: soluble fraction (%); b: insoluble but potentially degradable fraction (%); c: outflow rate of degradation (h-1), and k: rumen outflow rate (h-1); MOC: Macadamia oil cake; BSC: Baobab seed cake. SEM: standard error of means

Table 4.4 *In situ* ruminal degradation of essential Amino acids of Macadamia oil cake and Baobab seed cake

Essential Amino acids	Sample means	Incubation hours				
		0	12	16	24	48
Arginine	Baobab	9.50^{b}	12.77^{b}	27.07^{b}	72.12^{a}	71.52^{b}
	Macadamia	33.33^{a}	49.46^{a}	50.22^{a}	52.33^{b}	92.83^{a}
	SEM	1.771	1.329	1.343	2.085	1.116
	Significance	**	**	**	**	**
Threonine	Macadamia	17.95^{a}	23.08^{a}	23.08	25.64	28.21^{b}
	Baobab	3.92^{b}	11.76^{b}	19.61	43.14	56.86^{a}
	SEM	2.636	1.318	1.186	6.589	1.318
	Significance	*	**	ns	ns	**
Methionine	Macadamia	10.19	22.22	33.33	25.93	44.44
	Baobab	7.24	21.03	20.96	41.67	44.44
	SEM	4.603	4.847	4.548	19.256	6.415
	Significance	ns	ns	ns	ns	Ns
Valine	Macadamia	1.19	2.38^{b}	2.38^{b}	11.91^{b}	14.29^{b}
	Baobab	5.97	11.94^{a}	20.90^{a}	38.81^{a}	49.25^{a}
	SEM	2.294	1.147	1.032	5.736	1.147
	Significance	ns	**	**	*	**
Phenyalanine	Macadamia	10.53	18.42^{a}	21.05^{a}	21.05^{b}	28.95^{b}
	Baobab	2.12	3.39^{b}	5.08^{b}	47.46^{a}	54.24^{a}
	SEM	2.184	1.278	1.150	6.389	1.278
	Significance	ns	**	**	*	**
Isoleucine	Macadamia	3.13	3.13	6.25^{b}	6.25	18.75^{b}
	Baobab	0.00	4.17	14.58^{a}	31.25	43.75^{a}
	SEM	3.067	1.533	1.380	7.667	1.533
	Significance	ns	ns	*	ns	**
Leucine	Macadamia	3.51	8.77^{a}	10.53^{b}	12.28	17.54^{b}
	Baobab	0.00	3.57^{b}	28.57^{a}	38.10	42.86^{a}
	SEM	1.731	0.866	0.779	4.328	0.866
	Significance	ns	*	**	ns	**
Histidine	Macadamia	3.39	8.70	15.22^{a}	19.57	26.09^{b}
	Baobab	3.03	4.17	8.70^{b}	15.22	32.61^{a}
	SEM	1.543	1.229	1.130	6.276	1.255
	Significance	ns	ns	*	ns	*
Lysine	Macadamia	3.51	8.77^{a}	10.53^{b}	12.28^{b}	17.54^{b}
	Baobab	0.00	3.57^{b}	28.57^{a}	38.10^{a}	48.86^{a}
	SEM	1.731	0.866	0.779	4.328	0.8
	Significance	ns	*	**	*	**

*: $P < 0.05$; **: $P < 0.01$; (NS) Non-Significant: $P > 0.05$. ^{ab} column means with different superscripts differ significantly at $P < 0.05$; column means without ^{a} and ^{b} as superscripts are not significantly different at ($P > 0.05$) ; SEM: standard error of means

Table 4.5 *In situ* ruminal degradation of non-essential Amino acids of Macadamia oil cake and Baobab seed cake

Non-Essential Amino acids	**Sample means**	**Incubation hours** 0	12	16	24	48
Aspartic acids	Baobab	7.40^{b}	7.38^{b}	43.33^{a}53.39^{a}		80.53^{a}
	Macadamia	23.81^{a}	25.00^{a}	24.64^{b}	24.21^{b}	25.79^{b}
	SEM	1.833	1.490	1.050	2.246	1.392
	Significance	**	**	**	**	**
Glutamic acid	Macadamia	26.95^{a}	33.33^{a}	34.75^{b}	40.43^{b}	43.26^{b}
	Baobab	2.16^{b}	19.42^{b}	66.55^{a}	66.55^{a}	75.18^{a}
	SEM	0.649	0.325	0.292	1.623	0.325
	Significance	**	**	**	**	**
Glycine	Macadamia	1.02	26.80^{a}	26.80^{a}	29.90	32.99^{b}
	Baobab	3.90	15.58^{b}	22.08^{b}	22.08	63.64^{a}
	SEM	1.349	0.677	0.609	3.385	0.677
	Significance	ns	**	**	ns	**
Alanine	Macadamia	6.82	9.09	13.64^{b}	15.91	22.73^{b}
	Baobab	3.33	11.67	25.49^{a}	27.45	43.14^{a}
	SEM	2.301	1.151	1.103	6.127	1.225
	Significance	ns	ns	**	ns	**
Tyrosine	Macadamia	12.00	14.00	34.00^{a}	38.00	50.00^{b}
	Baobab	5.00	17.50	20.00^{b}	25.00	65.00^{a}
	SEM	2.614	1.307	1.176	6.535	1.307
	Significance	ns	ns	**	ns	**
Proline	Macadamia	14.89^{a}	17.02^{b}	19.15^{b}	23.40^{b}	23.40^{b}
	Baobab	4.55^{b}	24.23^{a}	30.29^{a}	45.54^{a}	60.61^{a}
	SEM	1.848	0.963	0.871	5.058	0.930
	Significance	*	**	**	*	**

*: $P < 0.05$; **: $P < 0.01$; ns: Non-Significant: $P > 0.05$. ^{ab} column means with different superscripts differ significantly at $P < 0.05$.; column means without ^{a} or ^{b} as superscripts are not significantly different at ($P > 0.05$); SEM: standard error of means

4.4 Discussion

There is very little information on the data of rumen degradability of MOC and BSC produced in South Africa. In fact there is only one (Skenjana *et al*., 2006) published paper in a peer review journal on the degradability of MOC produced in South Africa. The study of Skenjana *et al*., (2006) was conducted using sheep but no South African literature exists on the use of cattle (steers) to evaluate the degradability parameters of MOC. This dearth of information, presents challenges when attempting to formulate beef cattle rations that incorporate MOC or BSC. This situation prevails despite the fact that in Vhembe district (where BSC and MOC are produced) these cakes are widely used across a range of animal species on an *ad hock* basis. Rumen degradability literature for BSC is very scarce internationally and within South Africa especially from reliable sources such as peer reviewed journals. Research that had been done outside South Africa and published in peer reviewed journals is of the general opinion that these cakes can be used as protein supplements.

4.4.1 The Washing loss of Dry matter and Crude protein disappearances

The significantly higher washing loss of MOC can be attributed to higher water soluble constituents of the DM compared to those of BSC. This assertion was supported by the higher degradability constant (a) value representing the soluble fraction of the DM. The DM washing loss of MOC in the present study agreed with the 27.8% of rice polishing, 25.4% of rice bran reported by Habib *et al*. (2013) and 27.6% for sunflower meal as well as 25% of cotton seed meal reported by Gao *et al*. (2015). The DM washing loss of BSC was similar to 21.9% of sunflower meal as well as the 21.5% of maize oil cake reported by Habib *et al*. (2013). However; the results of the washing loss for both macadamia oil cake and baobab seed cake were lower than the 30.6% for rape seed meal and 33.7% for cotton seed meal reported by Habib *et al*. (2013). The differences could be attributed to the washing methods because Habib *et al*. (2013) used a washing machine whereas a running tap water was used to rinse the sample feed materials contained in the bags.

Comparatively, the significantly higher CP washing loss of BSC compared to that of MOC suggest that BSC had higher water soluble protein as it is consistent with a significantly higher soluble fraction (a) value. Crude protein washing loss of MOC and BSC were comparable to

7.3% of distillers dried grains and 28% of sunflower seed meal respectively, reported by Gao *et al*. (2015).

The trend in dry matter disappearance from 2 - 72 hours of incubation with respect to the increase in the disappearance was similar for both MOC and BSC. This trend was also similar to that reported by Gao *et al*. (2015) for the disappearance of both DM and CP for cotton seed cake meal, sunflower seed meal, and distiller dried grains. Comparatively, the significantly higher crude protein degradability of BSC compared to MOC from 16 hour incubation suggest that the longer the cakes stay in the rumen, the CP disappearance of BSC continues at an even higher rate. The findings of the present study were in agreement with the findings of Homolka *et al*. (2007) in their study of CP degradability after incubating rapeseed and rapeseed meal in the rumen for 16, 24, and 48 hours and observing significant differences in the disappearance of CP accross the full range of incubation time. However, contrary to non-significant differences in protein disappearance in the present study after 2, 4, 8, and 12 hours of incubation, the findings of Homolka *et al*. (2007) showed that rapeseed and rapeseed meals when incubated in the rumen for 2, 4, and 8 hours had significant differences in protein disappearance.

4.4.2 Rumen degradability characteristics

The significantly differences in the rapidly soluble fractions (a-values) for DM of MSC and BSC could be attributed to the differences in the lignin content of the two cakes. The soluble fraction (a- value) of MOC in the present study for dry matter was lower than the 47.6 % reported by Skenjana *et al*. (2006) in their trial with sheep also conducted in South Africa. The difference might be attributed to the differences in the particle sizes, the bags' pore sizes and the washing methods as the information on these factors was not indicated in the study conducted by Skenjana *et al*. (2006). The potentially degradable fraction (b-value) of the DM in the present study for MOC cake was higher than the 36.7% reported by Skenjana *et al*. (2006). These differences suggest that there could be inconsistencies in the production of MOC because the samples of the cakes were obtained from the same producer; however, factors such as particle sizes and the addition of soybean hulls which contribute to the high fibre content of MOC are likely to contribute to differences. The a+b values for MOC is also higher than the 84% reported by Skenjana *et al*. (2006). The effective degradability of MOC in the present study calculated at 5% outflow rate was lower than the 64.6% reported by Skenjana *et al*. (2006). The differences may in part be attributed to the differences in the animal species used in the two experiments because the later used sheep whilst cattle were used in the current study. The present findings, unlike those of Skenjana *et al*. (2006), suggest that there might be differences in the degradability of feed stuffs between sheep and cattle and that MOC in cattle has a potential of retaining an extra 10% of its DM for the post ruminal digestion in cattle. The non-significant difference in the c-value for dry matter observed in the current study was comparable to 0.07 avocado meal and 0.04 Macadamia oil cake reported by Skenjana *et al*. (2006). However, crude protein c-values for baobab seed cake and MOC of the current study were lower than 0.09 for avocado meal and 0.19 for Macadamia oil cake reported by Skenjana *et al*. (2006). The differences may be attributed to incubation in rumen of different animal species.

The effective degradability of MOC in the present study calculated at 5% outflow rate was comparable with the 52.9% for Avocado meal reported by Skenjana *et al*. (2006). Effective degradability of DM for MOC in the present study calculated at $0.08h^{-1}$ was comparable to 54.4% for Rape seed cake, 49% for Sunflower meal and 58.7% of maize oil cake reported by Habib *et al*. (2013).

The crude protein soluble fraction (a-value), potentially degradable fraction (a+b), and effective degradability calculated at 0.05^{h-1} outflow rate observed in the present study for MOC were lower than 73.5%, 92.2%, and 88.2% respectively reported by Skenjana *et al*. (2006). The potentially degradable fraction (b-value) of crude protein for MOC observed in the present study was higher than the 18.7% reported by Skenjana *et al*. (2006). According to Kendall *et al*. (1991) higher heat production during the production process of the oil cakes has the potential to bind the protein content of the cakes with its fibre components thereby reducing the availability of the protein to microbial action during rumen degradation. This assertion offers a plausible explanation for the differences in degradation kinetics of MOC as originating from the same source.

The effective degradability calculated at outflow rate of $0.02h^{-1}$ for DM of MOC and BSC in the present study was comparable to 75.9% for Rape seed meal and 72% for Extruded Rape seed meal reported by Barchiesi-Ferrari and Anrique (2011). It is also comparable to 76% of Wheat distillers dried grains calculated at 0.025, h^{-1} reported by Lee *et al*. (2016). However, Barchiesi-Ferrari and Anrique (2011) reported higher effective degradability values ranging from 61 – 79.5% calculated at 0.05 and 0.08 h^{-1} for the same meals compared to the findings of the current study. The differences could be attributed to the differences in the fibre contents and the heat treatment during processing. According to Barchiesi-Ferrari and Anrique (2011) higher ADF and ADIN concentration have the potential to reduce the degradability of DM in feed materials.

4.4.3 The Amino acids disappearance of Macadamia oil cake and Baobab seed cake

The ruminal degradation values of AA for MOC and BSC emulate the same order to that of the CP of these cakes. The results of crude protein disappearance of MOC and BSC showed little differences from 0 hours to 12 hours but from the 16th hour BSC showed significantly higher values of which the same trend was observed with their respective AA. This kind of protein and its Amino acid ruminal degradation relationship was supported by Mjoun *et al*. (2010) whose assertion that the characteristics of a protein in a feed material influence the rumen degradation of its Amino acids. Therefore, the differences in Amino acid disappearance may be due to the existence of differences in the protein characteristics of MOC and BSC.

4.5 Conclusion

In conclusion BSC has higher rumen degradable DM, CP and AA than MOC during the early hours of incubation but as the cakes remain in the rumen beyond 16 hours MOC degradation increases at an accelerating rate. Baobab seed cake and MOC have a potential to provide a ruminant animal with considerable quantities of protein for utilization by rumen microbes which are necessary for production and supply of the animal with good quality rumen microbial protein. These two cakes also have potential to supply the animal with a considerable amount of rumen undegradable protein and AA for the benefit of the animal through supply of absorbable true protein.

CHAPTER 5: APPARENT AND *IN VITRO* DIGESTIBILITY OF MACADAMIA OIL CAKE AND BAOBAB SEED CAKE

5.1. Introduction

Globally, most of the protein sources for livestock come from the agronomical products and by-products such as soybean meal, sunflower meal, groundnuts meal, cotton seed meal etc. However, these common protein sources/supplements for livestock may be very expensive for small-scale farmers and in some instances their production is limited to areas whereby these crops are produced which makes their accessibility to be problematic for farmers who are in non-producing areas. Animal feeds account for over 70% of animal production costs (Sindhu *et al*., 2002). This challenge can therefore be mitigated by the use of lesser known locally produced horticultural by-products. Vhembe and Mopani districts as well as other lowveld areas in South Africa are known to be the least producers of the commonly used agronomical crops which dominate the animal feed industry as protein sources/supplements. However, these areas are known for producing subtropical fruits and nuts. Two such subtropical trees are baobab (*Adansonia digitata*) and macadamia (*Macadamia ternifolia*) trees.

Baobab trees grow naturally in the wild and the rural people use the bark for making ropes and weaving due to its high fibre content, the leaves as vegetables (Venter and Witkowski, 2013) and the white powder (pulp) from the dry fruit is used as a food ingredient (Sidibe and Williams, 2002). The seeds of the baobab fruit are crushed, roasted and eaten by local communities and recently small-scale plant oil producers press the seed for oil which is used in the cosmetic industry (Venter and Witkowski, 2013). The residue from oil production or ground whole seed meal has a potential to be used as a protein supplement. Several researchers (Ilori *et al*., 2013; Madzimure *et al*., 2011; Chimvuramahwe *et al*., 2011; Belewu and Ibikunle, 2009) have used these by-products to feed animals either as a protein source or supplement. None of these research works were done in South Africa and, therefore, there is a need to evaluate the locally produced product for nutritive value.

South Africa is probably one of the major macadamia nut producing country with the Lowveld of Limpopo, Mpumalanga and Kwazulu-Natal provinces being the highest producing regions (DAAF, 2012). Macadamia nuts produced in these provinces are destined for the Asian (especially China), the USA and European market. Acheapong-Boateng *et al*. (2008) indicated that nuts which could not be sold for human consumption are used for oil production. Macadamia nut products can be used as feed ingredients for livestock (Acheampong-Boateng *et al*., 2016; Tiwari and Jha, 2016; Van Ryssen *et al*, 2014; Acheampong-Boateng *et al*., 2008; Skenjana *et al*., 2006; Sherrod and Ishizaki, 1966/7).

The following researchers concentrated on the growth performance and milk production of animals when baobab fruit and macadamia nut products are included in the diets of the animals (Acheampong-Boateng *et al*., 2016; Acheampong-Boateng *et al*., 2008; Madzimure et al., 2011). Skenjana *et al*., (2006) evaluated the rumen degradability of dry matter (DM) and crude protein (CP) using sheep and the *in vitro* digestibility of DM; whilst Tiwari and Jha (2016) evaluated the *in vitro* DM and energy digestibility of Macadamia nut cake (MNC) for pigs. The apparent nutrient digestibility of these products were also evaluated by Sherrod and Ishizaki 1966/7 for macadamia nut in sheep, and Belewu and Ibikunle (2009) and Ilori *et al*. (2013) for baobab seed products in sheep and goats, respectively. It is, therefore, very important to determine apparent nutrient digestibility of both Macadamia oil cake (MOC) and Baobab seed cake (BSC) based diets for CP and Amino acids (AA) digestibility of locally produced cakes. The apparent and *in vitro* digestibility of nutrients has an added advantage in that the two methods are accomplished without surgical operations on animals. Furthermore, the *in vitro* post-ruminal digestion of feed ingredients provides both academics and farmers with information about the amount of nutrients which are available for the animal to utilize for maintenance and production. The objective of these experiments were, therefore, to determine the apparent nutrient digestibility of BSC and MOC based sheep diets and the *in vitro* post-ruminal digestion of DM, CP and AA of these two cakes produced in South Africa.

5.2. Material and methods

5.2.1. Experimental site

The apparent digestibility data were collected at Grey and Grey farm, South Africa (S 26 38971; E 29 47 468. Elevation: 1639m). The farm is managed by a subsidiary company called GiyaMlimi Ltd which is owned by the Greys and the local community. The farm is located in the Southern Highveld of Mpumalanga province about 30 km west of Ermelo town and 20 km east of Morgenzon town along the R39 road which connects the two towns. The chemical composition of the samples was analyzed at the University of Venda.

5.2.2 Animal management and experimental design

The apparent digestibility trial was conducted during the last ten days of the growth trial using a completely randomized design arranged in a 2 x 2 factorial with the two cakes and two inclusion levels regarded as factors with 10% MOC diet also serving as control. The 10% MOC diet was chosen as the control diet because it has been proven that it can substitute soyabean meal without affecting the performance of feedlot sheep and cattle (Acheampong-Boateng *et al.*, 2017/2008). Four male lambs in each of the four treatments (10 % and 15% of both Baobab and MOC diets) were fitted with faecal bags and adapted to carrying the faecal bags for three days before the actual data collection could start. The animals were housed in an individual metabolism cages. The lambs were fed daily at 09.00 h in the morning on an *ad libitum* basis and clean ball valve controlled running water was available to the lambs at all times.

5.2.3 Data collection

The adaptation period of three days was followed by seven daily collections of faeces, urine, feed samples and feed refusals. The daily collected urine of each animal was measured, sampled and stored as indicated by Chen and Gomez (1992). The faeces and feed refusals were weighed everyday immediately after collection and about twenty percent of the faeces were sampled and pooled per animal over the collection period. The feed, urine and faecal samples were stored in a freezer at -20 ^{0}C for future chemical analysis at the University of Venda.

5.2.4 Laboratory analysis

Prior to chemical analysis the faeces and feed samples were thawed and dried in a forced air oven at 60 ^{0}C for 48 hours and ground to pass through a 1 mm sieve. The dried feed and faecal samples provided the DM content of the respective samples.

The Organic matter (OM) of both the feed and faecal samples were estimated by ashing the samples in a furnace at 500^{0}C over night (until all carbon has been removed from the ash) and its ash content subtracted from the DM content of the respective samples. In order to estimate the nutrient intake, digestibility and nitrogen retention the feed and faecal samples were analysed for OM, NDF, acid detergent fibre (ADF), acid detergent lignin (ADL), and nitrogen.

The urine samples were analysed for nitrogen and Allantoins. Organic matter and Nitrogen were determined using AOAC (2000) method. Allantoins were determined using the method described by Chen and Gomez (1992). The ADF and NDL of the samples were determined using Robertson and van Soest (1981), and Goering and van Soest (1970) respectively. The apparent digestibility of nutrients were calculated as indicated in 5.2.5

5.2.5 Calculations and statistical analysis

Nutrient apparently digested = nutrient consumed (g/kg) – nutrient in faeces (g/kg)
Apparent nutrient digestibility = [nutrient apparently digested (g)/ nutrient consumed (g)]*100 (to convert to apparent digestibility percentage)
The Nitrogen retention was determined as the difference between total Nitrogen intake and the Nitrogen lost through faeces and urine as follows:

Nitrogen retention (g/day) = total N consumed – (N in faeces and urine)

The quantity of digestible organic matter fermented in the rumen (DOMR), equivalent amounts of purine absorbed (P_a) by the animal, total purine derivatives (PD) excreted (PD_e mmol/d) were calculated using the equations of Chen and Gomes (1992). Microbial nitrogen (MN) yield was calculated using equation of ARC (1984).

The data collected were subjected to analysis of variance using General Linear Model of Minitab software version 17 (2014). The treatment means were compared using Tukey's multiple range test at 5% significance level.

The linear statistical model for the analysis of variance used was of the form:
$Y_{ijk} = \mu + C_i + L_j + (CL)_{ij} + E_{ijk}$

Y_{ijk}= Observation on the l^{th} dependent observation having the i^{th} cake type and j^{th} level of cake inclusion;
μ = Overall mean or population constant common to all observations;
C_i = Effect of i^{th} cake type; i=1 or 2 (MOC, BSC);
L_j = Effect of j^{th} level of cake inclusion; j=1 or 2 (10%, 15%);
$(CL)_{ij}$ = Interaction between the i^{th} cake type and j^{th} level of cake inclusion;

E_{ijk} = Random error term-assumed to be normally and independently distributed with 0 and variance equal to δ^2.

5.3. 3-step *In vitro* post-ruminal digestibility of rumen undegraded protein (RUP) and Amino acids (RUAA).

5.3.1 Experimental site

See 3.2.1 for the site description

5.3.2. Animals and diets

Three Bonsmara steers fitted with permanent rumen-fistulae were used to determine the degradability of BSC and MOC. The animals were kept in one pen and fed hay *ad libitum* and 5kg of a complete commercial concentrate diet once a day at 9h00 am. Fresh water was always available for the animals at all times. The chemical composition of complete commercial cattle finisher diet used in the study is provided in Table 4.1.

5.3.3 Experimental procedure

The 3-step *in vitro* procedure described by Gargallo *et al*., (2006) was used to determine the intestinal digestibility of DM, CP and AA nutrients. The standard/traditional (Gao *et al*. 2015) incubation time of 16 hours was used to determine the rumen undegraded protein (RUP) and rumen undegraded Amino acid (RUAA). Five grams of each sample were weighed and put into a nylon bag (The Dacron bags “Nitex, B.O.M: B3A03001010200” of an effective size of 5 cm x 10 cm and pore size 41 μm) so that 15 bags contained one of the two cakes. Ten bags (five for each cake type) were incubated in each one of the three steers. After drying rumen undegraded residues (RUR) were removed from the bags by cutting off the top of the bags and manually removing the residues. The RURs were composited by the steer, dried and ground to pass through a 1 mm sieve. The DM, CP, and AA contents of the RUR were determined using the methods described in 3.2.3.1.1 for DM, 3.2.3.1.4 for CP and 3.2.3.9 for AA to calculate their respective rumen degradabilities.

For the subsequent pepsin plus pancreatin digestion trial (pepsin-HCL method) a total of 30 bags containing 1.0 g of RUR with 15 bags containing one of the two cakes were introduced into each incubation bottle which contained 2 L of a 0.1 N HCl solution adjusted to pH 1.8 with 1.0 g/L of P7000-100G pepsin (Sigma, St. Louis, MO, USA), and were incubated for 1 hour in a constant - temperature (39^{0}C) water bath shaker. After incubation, the bags were rinsed with tap water and introduced into the incubation bottles containing 2L of a pancreatin solution of 0.5 M KH_2PO_4 buffer adjusted to pH 7.8, containing 50 ppm of thymol and 3 g/L of P7545-100G, Sigma, St. Louis, MO, USA, and then further incubated for 24 hours in a constant temperature (39^{0}C) water bath shaker. After the incubation, the bags were rinsed with tap water until the runoff was clear. The final residues in all bags were dried at 60^{0}C for 48 hours and subsequently analysed for DM, CP, and AA contents by the methods described under 5.3.4.

5.3.4 Chemical analysis

The residual DM in nylon bags were analyzed for nitrogen as provided in 3.2.3.1.4. The residual DM were also analyzed for AA content as provided in 3.2.3.9.

5.3.5 Calculations

The post-ruminal or intestinal dry matter, crude protein and Amino acid digestibility were calculated by the difference between the amount in rumen undegradabed residue and amount in residue after digestion.

IND (g/kg nutrient) = (RUN – NRD) / RUN * 1000

Where IND = Intestinal nutrient digestibility, RUN = Rumen undegraded nutrient, NRD = Nutrient remaining after digestion.

5.3.6 Statistical analyses

Data on apparent digestibility (Model I) and *in vitro* digestibility (Model II) were subjected to analysis of variance (ANOVA) using the General Linear Model of Minitab software version 17 (2014). The treatment means were compared using Tukey's Studentised multiple range test at 5% significance level.

$Y_{ijk} = \mu + C_j + L_j + (CL)_{ij} + \Sigma_{ijk}$ Model I

Where, Y_{ijk} = the observation, apparent DM, N retention, OM, NDF, ADF and allantoins;

μ = overall mean common to all observations;

C_i = effect of i^{th} cake, i = 1 or 2;

L_j = effect of j^{th} levels of cake inclusion, j = 1 or 2;

(CL) = interaction between i^{th} cake and j^{th} levels of cake inclusion

Σ_{ijk} = Random error

$Y_{ijk} = \mu + A_i + C_j + \Sigma_{ijk}$ Model II

Where, Y_{ijk} = the observation, and *in vitro* DM, CP and Amino acids digestibility;

μ = overall mean common to all observations;

A_i = fixed animal effect, i = 1, 2 or 3;

Cj = effect of j^{th} cake, j = 1 or 2;

Σ_{ijk} = Random error

5.4. Results

5.4.1 Chemical composition of four animal feeds

The chemical composition of the diets (10% MOC, 15% MOC, 10% BSC, 15% BSC) is presented in Table 5.1. The nutrient compositions of the diets were for most part similar between the diets, however, there was no statistical analysis carried out to determine the significance differences amongst the means.

Table. 5.1: The chemical composition of the four diets used to feed the lambs

Nutrients (%)	10% BSC diet	15% BSC diet	10% MOC diet	15% MOC diet
Dry matter	96.33	96.30	95.92	95.93
Crude protein	14.31	14.22	14.59	14.45
ADF	17.03	17.39	16.26	20.10
NDF	31.81	31.81	38.07	34.10
ADL	4.02	4.23	3.35	2.66
Ether extracts	5.47	5.87	7.08	8.58
Gross energy (MJ/kg)	17.70	17.89	18.11	18.33

BSC: Baobab seed cake; MOC: Macadamia oil cake; ADF: Acid detergent fibre; NDF: neutral detergent fibre; ADL: Acid detergent lignin

5.4.2 Nutrient intake and faecal output

Data on crude protein, organic matter (OM), neutral detergent fibre (NDF), and acid detergent fibre (ADF) intake for the four groups of lambs is presented in Table 5.3. The results show that the inclusion of MOC and BSC both at 10% and 15% did not affect (P>0.05) the total Crude protein, Organic matter, NDF, and ADF intake by lambs.

Data on faecal output (g/day) of nitrogen (N), OM, NDFand ADF for the four groups of lambs is presented in Table 5.3. The inclusion of MOC and BSC at 10 and 15% in the diets did not affect (P>0.05) the faecal excretion of nutrients by lambs. The total N, OM, NDF, and ADF in the faeces ranged from 0.30 – 0.40 g/day, 190.5 – 268.5 g/day, 331.2 – 391.5 g/day and 167.13 – 200.91 g/day, respectively. The urinary N (g/day) and Allantoins (ml/l) were also not affected

(P>0.05) by the inclusion of MOC and BSC both at 10 and 15% and their values ranged from 0.77 – 1.12 g/day and 19.70 – 20.99 ml/l, respectively.

5.4.3 Nutrient digestibility and N retention

Data on OM, NDF, ADF digestibility and nitrogen retention of the diets for the four groups of lambs is presented in Table 5.4. Macadamia oil cake and BSC inclusion at 10 and 15% of both cakes did not increase or decrease (P>0.05) the apparent digestibility of the diets by the lambs. The OM, NDF and ADF values ranged from 687.0 – 764 g/kg, 426.2 – 493.1 g/kg and 383.6 – 586.1 g/kg, respectively. There was diet x inclusion level interaction (P<0.05) for the data on N retention. Nitrogen retention by lambs was significantly affected (P<0.05) by the inclusion of MOC and BSC at the two levels mentioned earlier with lambs on 15% MOC diet having retained more N, followed by lambs on BSC diets and the least N retention being by the lambs on 10% MOC. A textbook interaction was noted in that when BSC was increased in the diet, N-retention significantly (P<0.05) decreased and when MOC was increased in the diet N-retention increased significantlt (P<0.05) too.

Data on the quantity of digestible organic matter fermented in the rumen (DOMR), purine derivatives (absorbed and excreted), and microbial nitrogen yield (MN) is presented in Table 5.5. The inclusion of MOC or BSC at 10 and 15% in the diets of lambs did not significantly (P>0.05) affect DOMR, purine derivative absorbed or excreted, and MN of the lambs.

5.4.5 Ruminal and Post- ruminal digestion of components of BSC and MOC

Table 5.6 contains the dry matter and crude protein digestibility after 16 hours of incubation as well as an *in vitro* dry matter and crude protein digestibility of Baobab seed cake and Macadamia oil cake. The results show that there was no significant (P>0.05) difference in the degradability of dry matter and crude protein of both cakes. According to the results on table 5.6 below, baobab seed cake have significantly (P<0.05) higher intestinal digestibility of dry matter and crude protein than macadamia oil cake.

The rumen degradability and post-ruminal digestibility of essential amino acids of Baobab seed cake and Macadamia oil cake after 16 hours of cake incubation in the rumen are shown in Table 5.7. There were no significant differences (P>0.05) in both essential and non-essential Amino acids (Table 5.8) disappearance of baobab seed cake and macadamia oil cake. However, the results of intestinal digestibilities of Amino acids of baobab seed cake and macadamia seed cake were significantly (P<0.05) different except for essential Amino acid arginine and two non-essential Amino acids serine and proline which were not significantly different. In the case of essential Amino acids Baobab seed cake had significantly higher intestinal digestibility values of Amino acids than those of Macadamia oil cake. The intestinal digestibility values of non-essential Amino acids followed the same trend/pattern to that of the essential Amino acid with Baobab seed cake having the highest values.

5.4.6 Ruminal degradation (16hours) and Post- ruminal digestion of components of BSC or MOC supplemented diets

The results on the rumen degradation and post-ruminal digestion of nutrients in BSC or MOC based diets is presented in Table 5.9. The 15% MOC based diet had a significantly higher (P<0.05) crude protein disappearance compared to 10% MOC, 10% BSC and 15% BSC diets. The crude protein disappearance for 10% MOC, 10% BSC and 15% BSC diets were not significantly different (P>0.05). Aspartic acid disappearance after 16 hours of rumen incubation was significantly different (P<0.05) amongst the four diets with 10% BSC diet having the highest disappearance of this Amino acid. The 15% BSC, 10% MOC and 15% MOC diets were not significantly different (P>0.05) from each other in aspartic acid disappearance after 16 hours of incubation in the rumen of steers. Arginine, threonine, methionine, valine, phenylalanine, isoleucine, leucine, histidine, lysine, serine, glutamine, glycine, alanine, tyrosine and proline disappearances were not significantly different (P>0.05) amongst the four diets.

The *in vitro* digestibility values of crude protein from residues of a 16 hour incubation in the rumen of steers of the four diets were not significantly different (P>0.05). The 10% MOC diet had the highest (P<0.05) digestibility values of threonine, methionine, histidine, glycine, and tyrosine than 15% MOC supplemented diets. The 15% MOC diet had a significantly higher (P<0.05) values of: arginine than the other three diets; phenylalanine than 15% BSC diet;, histidine than both 10% BSC and 15% BSC diet , and alanine than 15% BSC diet digestibility than those of the other diets. . The 15% BSC diets had the highest (P<0.05) digestibility values of lysine than 10% BSC and aspartic acid was significantlt higher than those of the other diets. Valine, isoleucine, leucine, serine, glutamic acid and proline were not significantly different (P>0.05) amongst the four diets.

Table 5.2 Intake of nutrients by lambs on Macadamia oil cake or Baobab seed cake based diets

Protein source	Inclusion level (%)	No of Animals	Nutrients intake (g/day)			
			CP	OM	NDF	ADF
BSC	10	4	13.8	936.3	654.4	405.0
	15	4	12.9	935.3	665.4	359.8
MSC	10	4	14.6	936.5	625.8	347.3
	15	4	14.5	942.2	626.6	358.9
SEM			3.89	7.36	12.56	30.61
Protein source means						
BSC		8	13.4	935.8^{a}	659.9	382.4
MOC		8	14.5	939.4^{b}	626.2	353.1
SEM			2.75	5.20	9.16	21.64
Inclusion level means (%)						
10		8	14.2	936.4	640.1	376.1
15		8	13.7	938.8	646.0	359.3
SEM			2.75	5.20	9.16	21.64
Significance						
Protein source (D)			ns	*	ns	ns
Inclusion level (L)			ns	ns	ns	ns
DxL			ns	ns	ns	ns

*: *P<0.05*; ns: *P>0.05*. ^{ab}: within a section of each column, means with different superscripts are significantly different (*P<0.05*); SEM: standard error mean; BSC: Baobab seed cake; MOC: Macadamia oil cake; N: nitrogen; OM: Organic matter; NDF: Neutral detergent fibre; ADF: Acid detergent fibre; ns: Non-significant: P>0.05. and SEM: Standard Error Mean; column means without ^{a} and or ^{b} as superscripts are not significantly different at (*P>0.05)*

Table 5.3 Nutrients out-put from faecal and urine of lambs fed different levels oof macadamia oil cake or baobab seed cake supplemented diets

Protein source	Inclusion level (%)	No of Animals	Faecal output (g/day)				Urine	
			N	OM	NDF	ADF	Urinary N	Allantoin (mℓ/ℓ)
BSC	10	4	0.30	268.5	331.2	167.13	0.84	19.70
	15	4	0.38	232.2	391.5	200.91	0.78	19.04
MSC	10	4	0.37	190.5	358.5	174.2	1.12	20.66
	15	4	0.40	210.5	345.0	194.7	0.77	20.99
SEM			0.050	33.76	23.244	9.318	0.104	0.952
Protein source means								
BSC		8	0.34	250.4	361.3	184.0	081	19.37
MSC		8	0.38	200.5	351.8	184.4	095	20.82
SEM			0.035	23.87	16.507	6.589	0074	0.673
Inclusion level means								
	10	8	0.33	229.5	344.9	170.7^{b}	098	20.18
	15	8	0.39	221.4	368.3	197.8^{a}	077	20.01
SEM			0.035	23.87	16.507	6.589	0074	0.673
Significance								
Protein source (D)			ns	ns	ns	ns	ns	ns
Inclusion level (L)			ns	ns	ns	*	ns	ns
DxL			ns	ns	ns	ns	ns	ns

*: *P<0.05*; ns: *P>0.05*. ^{ab}: within a section of each column, means with different superscripts are significantly different (*P<0.05*); SEM: standard error mean; BSC: Baobab seed cake; MOC: Macadamia oil cake; N: nitrogen; OM: Organic matter; NDF: Neutral detergent fibre; ADF: Acid detergent fibre; ns: Non-significant: P>0.05. and (SEM) Standard Error Mean; column means without ^{a} and or ^{b} as superscripts are not significantly different at (*P>0.05)*

Table 5.4 Apparent nutrient digestibility and nitrogen retention by lambs fed different levels of macadamia oil cake or baobab seed cake supplemented diets

Protein source	Inclusion level (%)	No of Animals	Digestibility (g/kg DM)			N retention (g/kg)
			OM	NDF	ADF	
BSC	10	4	687.0	493.1	586.1	1.07[ab]
	15	4	723.9	567.8	383.6	0.92[ab]
MSC	10	4	764.1	426.2	497.8	0.85[b]
	15	4	745.0	450.5	451.9	1.14[a]
SEM			34.66	80.975	66.800	0.100
Protein source means						
BSC		8	705.5	530.5	484.8	0.99
MSC		8	754.5	438.4	474.8	0.99
SEM			24.51	57.258	47.234	0.071
Inclusion level means						
	0.1	8	725.5	459.7	542.0	0.96
	0.15	8	734.4	509.2	417.7	1.03
SEM			24.51	57.258	47.234	0.071
Significance						
Protein source (D)			ns	ns	ns	ns
Inclusion level (L)			ns	ns	ns	ns
DxL			ns	ns	ns	*

(BSC) Baobab seed cake; (MOC) Macadamia oil cake; (N) nitrogen; (OM) Organic matter; (NDF) Neutral detergent fibre; (ADF) Acid detergent fibre; **: P<0.01; (ns) Non Significant: P>0.05. [ab] within a column, means with different superscripts are significantly different (P < 0.05).,and (SEM) Standard Error Mean; column means without [a] and or [b] as superscripts are not significantly different at (*P>0.05)*

Table 5.5 Effects of two inclusion levels of macadamia oil cake or baobab seed cake in diets for lambs on digestible organic matter fermented in the rumen (DOMR), purine derivatives and microbial nitrogen yield by lambs

Protein source	Inclusion level (%)	DMOR (kg/d)	Microbial N Yield (g/d)	Purine Absorbed (mmol/d)	PD Excretion (mmol/d)
BSC	10	0.70	22.48	30.93	27.98
	15	0.75	24.00	33.02	29.73
MOC	10	0.80	25.73	35.39	31.72
	15	0.64	20.45	28.14	25.63
SEM		0.06	1.92	2.64	2.22
Protein source means					
BSC		0.73	23.24	31.97	28.86
MOC		0.72	23.09	31.76	28.68
SEM		0.04	1.36	1.87	1.57
Inclusion level means					
	10	0.75	24.10	33.16	29.85
	15	0.69	22.23	30.58	27.68
SEM		0.04	1.36	1.87	1.57
Significance					
Protein source (D)		ns	ns	ns	ns
Inclusion level (L)		ns	ns	ns	ns
DxL		ns	ns	ns	ns

**: *P<0.01*; *: *P<0.05*; ns: *P>0.05*; [ab]: within a section of each column, means with different superscripts are significantly different (*P<0.05*); SEM: standard error of means; ns: not significant (*P>0.05*); BSC: Baobab seed cake; MOC: Macadamia oil cake; DOMR: Digestible organic matter fermented in the rumen; DxL: diet X inclusion level; Column means without [a] and or [b] as superscripts are not significantly different at (*P>0.05)*

Table 5.6 Ruminal degradation and *in vitro* digestibility of dry matter and crude protein (g/kg DM) ofr baobab seed cake and macadamia oil cake)

Component	16 hour rumen incubation		*In vitro* digestibility	
	RDMD	RCPD	IVDMD	IVCPD
BSC	379.4	456.8	748.2^{a}	626.2^{a}
MOC	376.8	467.6	633.9^{b}	418.7^{b}
SEM	18.74	33.75	20.06	12.31
Significance	ns	ns	**	**

**: P<0.01; (ns) Non-significant at *P>0.05*; ^{ab} means within a column with different superscripts are significantly different (*P < 0.05*); IVDMD: *In vitro* dry matter degradability, IVCPD: *In vitro* crude protein digestibility; and SEM: Standard error of means; BSC: baobab seed cake; MOC: macadamia oil cake; RDMD: rumen dry matter degradability; RCPD: rumen crude protein degradability; Column means without ^{a} and or ^{b} as superscripts are not significantly different at (*P>0.05)*

Table 5.7 Ruminal degradability and 3-step *In vitro* digestibility of essential Amino acids (g/kg DM) of macadamia oil cake and baobab seed cake

Amino acid	RD		SEM	Significance	IVD		SEM	Significance
	BSC	MOC			BSC	MOC		
Arginine	345.5	483.9	41.41	ns	750.0	770.8	16.07	ns
Threonine	128.2	187.5	59.50	ns	637.3[a]	551.3[b]	11.41	**
Methionine	277.8	111.1	92.82	ns	517.2	583.3	125.42	ns
Valine	199.0	87.3	49.80	ns	714.3[a]	487.0[b]	22.80	**
Phenylalanine	169.5	93.8	51.22	ns	768.7[a]	586.2[b]	22.34	**
Isoleucine	152.8	156.9	46.53	ns	680.3[a]	534.9[b]	35.73	*
Leucine	158.7	128.7	49.45	ns	750.0[a]	597.3[b]	16.75	**
Histidine	159.4	113.6	102.66	ns	453.6	521.4	161.48	*
Lysine	349.8	297.4	6.86	**	531.6[a]	328.5[b]	44.37	*

RD: Ruminal degradability; IVD: *In vitro* digestibility; BSC: Baobab seed cake; MOC: Macadamia oil cake; *: $P < 0.05$; **: $P < 0.01$; ns: Non-significant at $P > 0.05$; [ab] Row means with different superscripts differ significantly at $P < 0.05$. SEM: Standard error of means; Row means without [a] and or [b] as superscripts are not significantly different at ($P>0.05$)

Table 5.8 Ruminal degradability and 3-step *In vitro* digestibility of non-essential Amino acids (g/kg DM) of macadamia oil cake and baobab seed cake

Amino acid	RD		SEM	Significance	IVD		SEM	Significance
	BSC	MOC			BSC	MOC		
Serine	263.4	196.1	64.64	ns	430.7	325.2	72.83	ns
Aspartic acid	265.5	345.2	45.53	ns	682.7[a]	581.8[b]	12.65	**
Glutamic acid	383.7	472.8	75.92	ns	714.0[a]	583.0[b]	28.69	*
Glycine	255.6	83.3	47.00	ns	447.8[a]	240.6[b]	38.39	*
Alanine	320.3	416.7	128.02	ns	480.8[a]	324.7[b]	31.72	*
Tyrosine	387.5	346.7	29.13	ns	886.6[a]	459.2[b]	11.47	**
Proline	152.8	248.2	36.93	ns	491.8	349.1	37.10	ns

RD: Ruminal degradability; IVD: *In vitro* digestibility; BSC: Baobab seed cake; MOC: Macadamia oil cake ; *: $P < 0.05$; **: $P < 0.01$; ns: Non-Significant: $P > 0.05$. [ab] Row means with different superscripts differ significantly at $P < 0.05$.: Row means without [a] and [b] as superscripts are not significantly different at ($P>0.05$)

Table 5.9 Ruminal degradability and 3-step *in vitro* digestibility of nutrients (g/kg DM) of Macadamia oil cake or Baobab seed cake supplemented diets

components	Rumen Degradation (16 Hour)				SEM	Significant	*In vitro* digestibility				SEM	Significant
	MOC 10%	MOC 15%	BSC 10%	BSC 15%			MOC 10%	MOC 15%	BSC 10%	BSC 15%		
CP	211.8^{b}	375.8^{a}	221.5^{b}	206,0^{b}	23,79		570,4	603,9	576,3	601,9	25,37	ns
Arg	253,7	247,1	230,8	224,8	22,63	ns	420,0^{c}	632,2^{a}	550,0^{b}	489,7^{bc}	17,41	*
Thr	204,5	285,7	255,8	255,3	24,57	ns	476,9^{a}	320,0^{b}	511,6^{a}	468,1^{a}	24,34	*
Met	238,1	214,3	263,2	300,0	26,69	ns	666,7^{a}	545,5^{b}	684,2^{a}	650,0^{ab}	25,60	*
Val	215,7	250,0	203,4	196,4	18,76	ns	568,6	613,6	627,1	589,3	26,27	ns
Phe	173,9	212,8	218,2	208,3	17,41	ns	608,7^{ab}	702,1^{a}	654,5^{ab}	583,3^{b}	25,64	*
Isol	285,7	171,4	186,0	214,3	32,31	ns	595,2	628,6	581,4	619,0	28,02	ns
Leu	232,6	166,7	193,2	218,4	22,07	ns	616,3	621,2	613,6	655,2	24,83	ns
His	417,8	260,9	260,9	279,1	77,17	ns	714,3^{a}	764,7^{a}	500,0^{b}	580,6^{b}	29,35	*
Lys	230,8	204,5	259,3	260,0	16,62	ns	648,6^{ab}	514,3^{ab}	500,0^{b}	648,6^{a}	30,97	*
Ser	166,7	187,5	166,7	173,1	29,17	ns	520,8	538,5	500,0	519,2	30,68	ns
Asp	230,8^{b}	220,8^{b}	321,8^{a}	270,6^{ab}	17,37	**	551,3^{b}	580,6^{b}	474,6^{b}	822,6^{a}	23,54	*
Glu	233,1	184,6	230,8	184,6	17,85	ns	709,1	688,7	616,7	848,5	105,78	ns
Gly	320,8	319,1	300,0	303,6	23,35	ns	415,1^{a}	187,5^{b}	228,6^{b}	410,7^{a}	19,62	*
Ala	419,4	428,6	416,7	367,6	25,05	ns	596,8^{a}	357,1^{a}	616,7^{a}	676,5^{b}	24,99	*
Try	315,8	343,8	312,5	333,3	23,43	ns	701,8^{a}	333,3^{c}	583,3^{b}	616,7^{ab}	20,21	*
Pro	226,1	235,3	210,5	206,3	23,61	ns	490,6	461,5	422,2	476,2	21,81	ns

Cys: Cysteine; Thr: Threonine; Met: Methionine; Val: Valine; Phe: Phenylalanine; Isol: Isoleucine; Leu: Leucine; His: Histidine; Lys: Lysine; Ser: Serine; Asp: Aspartic acid; Glu: Glutamic acid; Gly: Glycine; Ala: Alanine; Trp: Tryptophan; Pro: Proline; BSC: Baobab seed cake; MOC: Macadamia oil cake; *: P < 0.05; **: P <0.01; ns:Non-significant at P > 0.05; ^{ab} Row means with different superscripts differ significantly at P <0.05; SEM: Standard error of means; : Row means without ^{a} and or ^{b} as superscripts are not significantly different at (P>0.05)

5.5 Discussion on Apparent digestibility trial

5.5.1 Nutrient intake

The non-significant difference in crude protein intake of the lambs given the four diets mirror the protein content pattern of the diets since the MOC lambs consumed numerically higher crude protein. The diets with slightly higher protein content seem to have a positive effect on protein intake in the animals. The results of the current study are in agreement with the findings of Gionbelli *et al*. (2012) who reported that an increase in concentrate feed level did not increase the crude protein intake of Nellore heifers. The findings were attributed to similar protein composition of the diets. Similar protein content of the diets was probably the reason the current study also had similar crude protein intake. The results of OM intake in the current study contradicted those of Mlambo *et al*., (2011) who reported that inclusion of Marula seed cake in the diets of goats decreased significantly the OM intake. They attributed the decrease in OM intake to the high level of fat in Marula seed cake however, the cakes in the present study contained lesser fat content compared to that of the Marula seed cake. Overall, the results on nutrient intake (CP, OM, NDF, and ADF) in the current study were contradictory to Mlambo *et al*. (2011) who found significant differences in intake of nutrients between diets. The differences can be attributed to the relatively large differences in nutrient content of diets used in their studies whereas the diets for the current study had a lot more similar nutrient contents.

The results of nutrient intake of the current study are similar to the findings of Sherrod and Ishizakki (1967) who reported that dry matter intake was not significantly affected by inclusion of Macadamia nut in lamb rations. However, in their previous study Sherrod and Ishizakki (1966) reported that dry matter intake decreased with an increase in Macadamia nut inclusion in the diets of lambs which is in contradiction to the results of the current study. The differences could be attributed to the higher oil content of the nuts and the range of inclusion levels of Macadamia products.

The nutrients (CP, OM, NDF, ADF) intake of lambs on BSC diet in the present study was in disagreement with the report of Belewu and Ibikunle (2009) who indicated that increasing BSC to 15% in the diet of lambs decreased nutrient (DM, CP, ADF, NDF) intake. The diets of lambs with different inclusion levels of BSC in the study of Belewu and Ibikunle (2009) had different nutrient composition which could have affected nutrient intake by lambs which was not the case in the present study.

The non-significant differences in faecal output of nutrients in the current study suggest that the digestion and absorption of nutrient were similar for all the diets. This is in contrast with the findings of Mlambo *et al*., (2011) who evaluated the digestibility of Soybean meal, Marula seed cake and Sunflower cake and found that the nutrients in the faecal output where significantly different. The differences can be attributed to differences in the ration formulations because the diets of the current study had more balanced nutrient contents whereas those of Mlambo *et al*. (2011) were not balanced due to the use of unsupplemented grass hay as the basal diet whereas the marula cake, sunflower cake and soybean cake diets were formulated to meet the animals' nutrient needs. The same can be said about the urinary N differences in the two studies. The non-significant differences in the Allantoins content of the urine of the lambs assigned to the four diets in the current study suggest that the inclusion of Baobab seed cake or Macadamia oil cake in diets of lambs does not affect the metabolism of nutrients/protein differently. Similar results on Allantoin were reported by Gionbelli *et al*. (2012) who did not find any differences in Allantoin concentrations in the urine of heifers fed different concentrate levels.

5.5.2 Digestibility of the nutrients

The non-significant differences in the digestibility values of OM, NDF, and ADF suggest that the differences in nutrient composition of the two cakes, as these were the only feed materials which were different in the diets, are not significant enough to have a significant effect on their digestibility. The study conducted by Mlambo *et al*. (2011) using three different protein sources (Soyabean meal, Sunflower seed cake and Marula seed cake) found differences in the digestibility of OM, ADF, NDF which is contrary to the results of the present study. These differences might be attributed to the differences in the nutrient composition of the diets employed in the two studies.

The nutrient digestibility of Baobab seed cake in the present study are in disagreement with the results of nutrient (DM,CF, EE, NFE) digestibility reported by Ilori *et al*. (2013) who fed goats containing Baobab fruit at different levels. However, their results were similar to those of the present study when Baobab fruit was included in the diets up to 20%, but when Baobab fruit inclusion increased to 30% the digestibility of the diet dry matter increased significantly which is contrary to the current findings. The differences between the results of the current study and those of Ilori *et al*. (2013) might be attributed to the higher levels of Baobab fruit inclusion (30%) which has a potential to have increased the oil content of the diets to levels which negatively interfered with the activities of rumen microbes. Even though crude protein digestibility was not determined in the current study Ilori *et al*., (2013) found no significant different in the CP digestibility of the goats given diets supplemented with Baobab fruit. Belewu and Ibikunle (2009) also reported results which disagree with those of the current study. Using a control diet containing 25% soyabean, they reported that replacement of 50% or 100% of the soyabean component of the diet with Baobab seed cake significantly increased digestion of dry matter, NDF, ADF, etc by fattening lambs. The difference may be due to the inclusion levels of the Baobab seed cake in the diets between the two studies.

Macadamia oil cake digestion results for the present study are in disagreement with the results reported by Sherrod and Ishizakki (1967/6) who found that there were differences in nutrient digestion when Macadamia nuts were included in the diets of lambs at different levels. The differences might be attributed to the processing (roasting) of the nuts which could have had the effect especially if heat treatment was not consistent and additionally, the high oil content of the nuts compared to the cake used for the present study could also have contributed to the differences.

The differences in nitrogen retention amongst lambs fed the four different diets followed a trend that was a reverse of the trend observed for urinary nitrogen. The 10% MOC diet had numerically higher urinary nitrogen which resulted in the lambs having a significantly lower nitrogen retention compared to lambs on 10% and, 15% BSC diets as well as those on the 15% MOC diet. The 10% MOC diet had also numerically higher crude protein content than the rest of the diets which could be another reason the lambs on this diet had lower N retention. This is supported in part by the assertion of Sangare *et al*. (2000) who indicated that low nitrogen retention may be due to high urinary nitrogen output by the animals. The results on nitrogen retention of all the lambs in the four diets however, shows that the animals had positive nitrogen retention which according to Mlambo *et al*. (2011) means that the animals retained the digester long enough to allow for nitrogen absorption and not excrete it in the faeces and urine. This also suggests that there was a good balance between protein and energy of the diets since a lack of good balance thereof results in higher urinary nitrogen excretion (Mishra and Rai, 1996).

Generally, the results of the current study were in contrast with the results reported by Mlambo *et al*., (2011) because they found that the goats on the diet without protein supplements had a negative nitrogen retention which was to be expected since grass hay has low protein content to support the protein needs of the animal.

The results of the present study were similar to those reported by Sherrod and Ishizakki (1966/7) who found that lambs on Macadamia nut based diets had significant different nitrogen retention values and were all positive.
The non-significant differences in DOMR, purine derivatives either excreted or absorbed and MN yield of the present study were contradictory to the report by Khandaker *et al*. (2011) who found that an increase in the inclusion level of Mustard oil cake in the diets of cattle significantly increased the quantities of these parameters. The differences may be attributed to the different species used in the two experiments.

5.5.3 Post-ruminal *in vitro* digestibility of crude protein and Amino acids of BSC and MOC

There is lack of information about the small intestine digestibility of Baobab seed cake and Macadamia oil cake for dry matter, crude protein, and Amino acids. The significant differences in dry matter intestinal digestibility between the two cakes can be attributed to the differences in the physical properties (such as solubility) and fibre constituents of the two cakes. Furthermore, the fact that the expeller method of oil extraction was used for both cakes leads to the possibility of different levels of heat produced in the process. The negative effects of excessive heat treatment on protein digestibility are well documented (McDonald *et al.*, 2011). Another potential contributing factor in the differences in digestibility values of these cakes is the fact that they were produced by two different companies as indicated in the introduction. The intestinal digestion of Amino acids followed the same pattern as that of the crude protein whereby Baobab seed cake had higher crude protein digestibility as well as those of Amino acids. This implies that protein digestibility is positively related to its subsequent Amino acid digestibility.

The 633.9 g/kg dry matter digestibility value of Macadamia oil cake in the present study was lower than 79.2% of *in vitro* organic matter digestibility reported by Skenjana *et al*., (2006) but the differences may be attributed to the differences in nutrients as only organic matter was considered whereas the entire dry matter was determined in the current study. There was a possibility that some constituents of the inorganic matter would have been less digestible. The other possibility could be that of the differences in fibre content of Skenjana's Macadamia oil cake compared to that of the present study. An *in vitro* dry matter digestibility value of 633.9 g /kg DM for Macadamaia oil cake arrived at in this study was also lower than 75.5 % for Macadamia nut cake reported by Tiwari and Jha (2016). The lower dry matter digestibility in the current study could be due to the high fibre level of Macadamia oil cake which came about as a result of the inclusion of soybean hulls in the oil extraction process compared to that of Macadamia nut cake which did not contain any soyabean hulls. However, dry matter digestibility of Baobab seed cake of 748.2g/kg in the current study was comparable to those reported by Skenjana (2006) for Macadamia oil cake; and, Tiwari and Jha (2016) for Macadamia nut cake. Mdziniso *et al*. (2016) reported an 833.3g/kg DM *in vitro* dry matter digestibility of Marula seed cake which was higher than those of the current study for both Baobab seed cake and Macadamia oil cake. This was strange since it is widely understood that high fat negatively affect digestibility of nutrients and Marula seed cake was reported by the same author to contain 28.96% of fat compared to 8.6% and 8.5% for Baobab seed cake and Macadamia oil cake, respectively.

The crude protein post-ruminal *in vitro* digestibility value of 626 g/kg DM for Baobab seed cake in the current study was comparable to 625 g/kg DM for Lupin, and Sunflower seed (protected), and 628g/kg for Soypass reported by Hippensteil *et al*. (2015) and Maskal'ov'a *et al*. (2014) respectively but lower than 81.46% Nitrogen digestibility reported by Mdziniso *et al*, (2016). The differences may be due to different *in vitro* digestion methods used in these studies, and the nature as well as chemical composition of the protein supplement (e.g. presence of antinutritional factors can lower protein/nitrogen digestibility values).

The higher essential Amino acid digestibility of Baobab seed cake (ranged from 453.6 – 768.7g/kg DM) in the current study was comparable to the average of 657g/kg DM of row soyabean, 629g/kg DM of Soypass, and 763g/kg DM of brewers grains reported by Maskal'ov'a *et al*. (2014).

5.5.4 Ruminal degradability and post-ruminal in vitro digestibility of crude protein and Amino acids of MOC or BSC supplemented diets

The significant differences in the crude protein degradability is consistent with the findings of Gao *et al*. (2016) who incubated three different total mixed rations in the rumen for lambs at with each ration being incubated in the rumen for a different time period (27 h TMR-1, 28 h TMR-2, 25 h TMR-3). The non-significant differences in the degradability of Amino acids are contrary to the degradability of crude protein which was found to be significant amongst the four diets. This is contrary to the findings of Gao *et al*. (2016) who indicated that both nitrogen and Amino acids degradability have shown similar trends. The differences may be attributed to different components of the total mixed rations used in the two studies. However in the present study alanine was numerically highly degradable in the rumen which contradicts the findings of Gao *et al*. (2016) and Lee *et al*. (2012) who reported that histidine was highly degraded in the rumen of dairy cows. The higher histidine degradability in the present study agreed with the previous findings. The high alanine degradability value observed for 10% MOC based diet implied that it too is highly degradable in the rumen . The significant differences in aspartic acid degradability observed in the present study agreed with the findings of Goa *et al.* (2016) who also reported a difference in the degradability of this Amino acid. It is however, important to indicate that most (more than 60%) of the Amino acid in the study by Gao *et al.*, (2016) were not significantly different from each other. This observation suggests that most Amino acids in total mixed rations were not affected differently by the actions of rumen microbes.

The non-significant differences in crude protein digestibility in the current study was contrary to the findings of Gao *et al.* (2016) who found significant differences in crude protein digestibility(3-step *in vitro* digestibility). The differences may be attributed to the differences in compositions of total mixed rations.

The significantly different digestibilities of Amino acid in the present study was in agreement with the findings of Gao *et al.* (2016). This suggested that the extent in which individual Amino acids which had escaped rumen degradation are digested in the small intestines is not the same.

5.6 Conclusion

It can be concluded that nutrient digestibility data in the present study show that the 10% and 15% inclusion levels of Baobab seed and Macadamia oil cake as protein supplements supported the nitrogen requirements of lambs for maintenance and growth. This was demonstrated by a positive nitrogen retention observed in this study. This meant that sheep farmers especially the feedlotters with access to one or two of these cakes can incorporate them in the diets of their animals during ration formulation given that these cakes have a potential to promote nutrients intake and utilization for the benefit of the animals. In comparison however, Baobab seed cake had a higher nutrient digestion compared to Macadamia oil cake which implies that inclusion of Macadamia oil cake at higher level (15%) could result in a slight decrease in the performance of the animals due to its lower crude protein and Amino acid digestion. This is supported by the fact that the results of the current study on DOMR, purine derivatives either excreted or absorbed and MN yield provide similar trend of the least numerical values of these parameters which may explain the least animal performance for those on the 15% MOC based diet.

CHAPTER 6: GROWTH PERFORMANCE AND CARCASS CHARACTERISTICS OF SOUTH AFRICAN MUTTON MERINO FED DIETS WITH DIFFERENT LEVELS OF MACADAMIA OIL CAKE OR BAOBAB SEED CAKE

6.1 Introduction

South Africa being one of the many countries across the globe which are found within the tropics experiences a decline in the quantity and quality of naturally growing plant feed materials particularly due to long non-rainy season (Noula *et al*., 2004). Most South African regions receive sufficient rains to support proper pasture growth only in the summer season. Feeding of ruminant livestock generally becomes a challenge to farmers during the dry season but due to their small herds the small scale farmers are the hardest hit given the high feed costs, especially energy and protein sources. Resource poor rural communities in South Africa do not only derive income from livestock farming but they also use them as a source of savings (Stroebel *et al*., 2011). Most small-scale sheep farmers in South Africa, like their commercial counterparts, fatten their lambs in a quest to fetch good prices for their animals on the market. Stroebel (2004) argued that it is becoming a common practice for small-scale sheep farmers in South Africa to fatten their animals before selling them. With feed accounting for 70-80% of the total production costs in ruminant feedlotting (Hanning, 1999), cheaper feed materials ought to be sought so that production can be sustainable to small-scale farmers. The most expensive constituents of feedlot rations are the energy and protein sources (Mustafa and Alamin, 2012). High costs and lack of availability of the conventional energy and protein sources, particularly in less industrialized regions of South Africa, exacerbate the problem of sourcing these products by small-scale farmers. Conventional protein supplements such as Soybean meal are extensively used in feedlots in South Africa but are usually too expensive and often not readily available to small-scale farmers (Nkosi *et al*., 2011). The problem of feed shortages can be addressed by the use of unconventional feedstuffs provided they can be easily sourced, are nutritious and affordable (Skenjana, 2006). Similar views were expressed by Acheampong-Boateng (2008) who argued that this problem can be mitigated through the use of locally produced good quality alternative non-conventional feed materials.

Horticultural by-products produced in agro-processing industry such as citrus pulps, potato hash have been proved to offer some solution to this challenge of scarcity and affordability of conventional energy and protein sources (Oni *et al.*, 2008; Nkosi and Meeske, 2010). Along the

Levubu valley in Vhembe district of the Limpopo Province there are several agro-processing factories that produce considerable by-products which can be used to feed ruminants' livestock. These by-products include Macadamia oil cake and Baobab seed cake which are the focus for this research. Macadamia were produced in South Africa for the first time in the lowveld areas of Limpopo and Mpumalanga provinces following the initiation of the macadamia orchards (Peace *et al*., 2005). The macadamia oil is produced by pressing oil from the insects damaged or cracked nuts. The residues of macadamia oil extraction are referred to as macadamia oil/nut cake meal.

Baobab trees grow wild in Limpopo province and other provinces in South Africa even though the production of baobab fruits is considerable but limited to older trees (Venter and Witkowski, 2013). The fruits are often collected by women and sold to processors (Venter and Witkowski, 2010). The seeds are then removed from the pulp which is then packaged and sold for human consumption or use in the cosmetic industry. The seeds are dehulled and then oil is extracted mechanically from the dehulled seeds using the screw press technology. The residual product after oil extraction is referred to as Baobab seed cake.

Currently baobab seed cake is produced in Vhembe district of Limpopo province by Ecoproducts whereas Macadamia oilcake/meal is produced by Royal Macadamia Ltd (Pty) and other small macadamia oil producers in the lowvelds of Limpopo and Mpumalanga provinces. These two by-products of the plant oil industry are produced using the screw pressing method during the extraction of oil from the seeds and nuts. There is a growing trend in both local and international markets for organic products of baobab fruit such as the baobab oil and powder (Venter and Witkowski, 2013)
Several studies have been undertaken to evaluate the feeding potential of macadamia oil cake and baobab seed cake. Macadamia oil cake/meal can be included in broiler diets at low levels without affecting growth (van Ryssen *et al*., 2014; Acheampong-Boateng *et al.*, 2016).

Macadamia oil residues have a potential to be used as components of the diets of ruminants (Skenjana *et al*., 2006). Macadamia nuts can be used as an energy supplement for sheep provided the fat content of the diet remains within the 10% range (Sherrod and Ishizaki, 1966 and 1967). The inclusion of 10% of Macadamia oil cake as protein supplement in diets of feedlot cattle can be used to substitute soyabean meal without affecting the performance of the animals (Acheapong-Boateng *et al*., 2008). Lambs can be finished off with the inclusion of 10%

macadamia oil cake in their diets to replace soyabean meal as protein supplement without affecting the growth performance of the lambs (Acheapong-Boateng *et al*., 2017).

Baobab seed cake can be used as a protein supplement in diets for lactating dairy cows (Madzimure *et al*., 2011) whereas Belewu and Ibikunle (2009) reported that *Adansonia digitata* seed meal has a potential to be a protein supplement for sheep. Whole Baobab fruit meal can be included in diets for goats (Ilori *et al*., 2013). Baobab seed meal/cake has a potential to be used as a protein supplement in diets for poultry (Bale *et al*., 2013; Sola-Ojo *et al*., 2013; Babiker, 2012; Sola-Ojo *et al*., 2011; Mwale *et al*., 2008;;). According to Ezeagu (2005) in the study investigating the growth performance of albino rats, baobab seed meal has a potential as a source of nutrients for livestock. Oladunye *et al*. (2014) reported that Baobab seed meal and a combination of baobab pulp with baobab seed meal can be incorporated in diets for rabbits.

From the literature it is evident that there is very limited research done on the growth performance and carcass characteristics of sheep using macadamia oil cake and baobab seed cake as protein supplements. The problem is further compounded by lack of such research studies in South Africa using the cakes produced in this country as it is common knowledge that climate, soil type as well as processing method have an effect on the nutritional content of the horticultural by-products. In support of the later statement, the findings of Madzimure *et al*. (2011) pertaining to the chemical composition of baobab seed cake in percentages (CP=16.9; EE=5.26; CF=25.61) were different from those of Oladunye *et al*. (2014) for baobab seed meal (CP=20.4; EE=14.8; CF=10.4). The objective of this study was to compare the growth performance and carcass characteristics of South African Mutton Merino lambs fed on four different concentrate diets containing two levels (10 or 15%) of baobab seed cake and macadamia oil cake.

6.2 Materials and methods

6.2.1 Experimental site

The experiment was conducted at Grey & Grey farm, South Africa (S 26 38971; E 29 47 468. Elevation: 1639m). The farm is managed by a subsidiary company called GiyaMlimi Ltd which is owned by the Greys and the local black community which is part of the land restitution programmes of the government. The farm is located in the Southern Highveld of Mpumalanga province about 30 km west of Ermelo town and 20 km east of Morgenzon town along the R39 road which connects the two towns.

6.2.2 Experimental design

Five to six months old (16 males and 16 females) South African Mutton Merino lambs which were housed individually were used in a completely randomized block design arranged in a 2 x 2 factorial (2 cake types x 2 inclusion levels and blocked by sex/gender). Eight lambs consisting of four males and four females were randomly allocated to each of four experimental diets (10% BSC diet, 15% BSC diet, 10% MOC diet, and 15% MOC diet). The 10% MOC diet also served as the control as it has been proven that it can replace soybean meal without compromising the performance of the animals (Acheampong-Boateng *et al.,* 2017; 2008)

6.2.3 Animal management

Thirty-two South African Mutton Merino lambs (16 males and 16 females) aged between five and six months and each weighing on average ±30 kg at the beginning of the trial were used in the experiment. The lambs were individually housed in 57 x 118cm metabolism cages under a well-ventilated house with a corrugated iron roof facing in an easterly direction. Experimental feed and water were provided for the lambs daily *ad libitum*. The lambs received feed every day at 9 am. At the beginning of the trial the lambs were injected subcutaneously with 2ml of MULTIVAX-P-PLUS for vaccination against enterotoxaemia (pulpy kidney) and after two weeks they were injected with 0.5 ml of IVOTAN for treatment of internal parasites bought from NTK .

6.2.4 Diets formulations

Four iso-nitrogenous and iso-energetic diets were formulated to contain 10 % and 15% of either Baobab seed cake or Macadamia oil cake (Table 6.1.). The diets were formulated in so as to be able to meet 15 – 16% crude protein and 12 MJ ME/kg required by growing lambs.

Table 6.1 Four sheep diets with either Macadamia oil cake or Baobab seed cake as protein supplements

Feed ingredient	feed 1 (10% BSC)	feed 2 (15% BSC)	feed 3 (10% MOC)	feed 4 (15% MOC)
BSC %	10	15	0	0
MOC %	0	0	10	15
Hominy Chop %	41.9	37.35	41.4	36.6
Wheaten Bran %	15	15	15	15
Molasses meal %	10	10	10	10
Lucerne %	10	10	10	10
E. curvula hay %	10	10	10	10
Feed grade Urea %	0.5	0.15	1	0.9
Feed grade ammonium %	0.6	0.5	0.6	0.5
Feedlime %	1.5	1.5	1.5	1.5
Salt %	0.5	0.5	0.5	0.5
Calculated nutrient density of diets				
Energy%	10.24	9.62	10.7	9.52
EE %	5.60	5.69	5.26	5.18
CP %	15.93	15.89	15.93	15.89
CF %	14.05	14.75	14. 52	15.45
NDF %	14.05	14.75	14.52	14.45
ADF %	30.89	31.89	32.57	34.42
Calcium	3.20	4.80	4.80	7.20

BSC: Baobab seed cake; MOC: Macadamia oil cake; EE: Ether extracts; CP: Crude protein; CF: Crude fibre; NDF: Neutral detergent fibre; ADF: Acid detergent fibre

6.2.5 Chemical analysis of feed materials

The feed samples (macadamia oil cake and baobab seed cake based diets) samples were determined as indicated in chapter 3, section 3.2.3

6.2.6 Growth measurements

This experiment was conducted for 67 days. The lambs were adapted for a period of fourteen days before data collection commenced. During and after the adaptation period the animals were fed and watered *ad libitum*. Feed remaining (feed refusals) in the troughs was removed and weighed every day before feeding. The animals were weighed at the beginning of the trial and weekly on Friday mornings. The weight of the feed refusals was subtracted from the amount of feed offered to each lamb to determine the average daily feed intake. The weights of the animals taken weekly were used to calculate the weekly weight gains which were in turn used to compute the average daily gain (ADG) by dividing these values by seven. Feed conversion ratio (FCR) was calculated for each animal by dividing feed intake by average daily gain. At the end of the trial the animals were weighed and their weights were used to determine the total weight gain by subtracting the initial weight from the final weight.The animals were then transported to a local commercial abattoir in Ermelo for slaughter. One of the lambs had to be withdrawn from the trial due to elongated belly which is a common condition in sheep feedlotting as it found it difficult to eat and drink water.

At the abattoir, the animals were stunned by means of a captive bolt pistol, their throats cut immediately and the skin, head, offal and the feet were removed. The carcasses were identified by means of a plastic tag attached to their hind leg using a cable tie. Each carcass was weighed (hot dressed mass) before the carcasses were transferred to the cold room where they were kept for twenty four hours.

The following day the carcasses were transported by a cold room truck to a local butchery where they were weighed to determine the cold dressed mass for each carcass. After the weighing of the carcasses, the tails were removed at their bases and the carcasses were split along the midline. The left side was further cut horizontally between the 12^{th} and the 13^{th} rib to expose the ribeye area which was then traced on a tracing paper for the determination of the ribeye area. The backfat thickness was measured on the 13^{th} rib using a digital caliper. The carcass length was measured using a flexible plastic tape measure.

6.2.7 Statistical analysis

Analysis of variance was performed on the growth parameters data (Model I) using General Linear Model of SAS version and the means were compared using Duncan's multiple range test (due to small differences in values expected in the results), using 95% level of confidence.

$Y_{ijkl} = \mu + C_j + L_j + (CL)_{ij} + \beta_k + \Sigma_{ijkl}$ Model I

Where, Y_{ijkl} = the observation, IBW, BWG, FBW, FI, FCR and carcass characteristics;

μ = overall mean common to all observations;

C_i = effect of i^{th} cake, i = 1 or 2;

L_j = effect of j^{th} levels of cake inclusion, j = 1 or 2;

(CL) = interaction between i^{th} cake and j^{th} levels of cake inclusion;

β_k = the fixed block effect of k^{th} sex, k = 1and 2; and

Σ_{ijkl} = Random error

6.3 Results

6.3.1. Feed intake, average daily gain and feed conversion efficiency of lambs

The results of this study show that there were protein supplement source (BSC/MOC) x level of inclusion interactions (Table 6.2). Significant protein supplement source x level of inclusion interactions were detected for: average daily feed intake (P<0.01), average daily gain, total weight gain, and final body weight (P<0.05).

Average daily feed intake (ADFI) for lambs fed diets supplemented with 10% BSC, 15% BSC, and 10% MOC were similar (P>0.05). However, lambs fed 15% BSC and 10% MOC supplemented diets consumed significantly more (P<0.05) feed than lambs on the 15% MOC supplemented diet. Feed consumption by lambs fed the 10% BSC supplemented diet was similar (P>0.05) to that of lambs on the 15% MOC supplemented diet.

Average daily gain (ADG), final body weight (FBW) and total weight gain (TWG) of lambs in this study mirrored the feed consumption patterns as reported in the preceding paragraph. Lambs which were fed diets supplemented with either 10% BSC, 15% BSC, and 10% MOC had similar (P>0.05) average daily gain (ADG), final body weight (FBW) and total weight gain (TWG) at the end of the feeding trial, however, lambs fed 15% BSC and 10% MOC supplemented diets had significantly higher ADG, FBW and TWG (P<0.05) than lambs on a 15% MOC supplemented diet. Lambs which were fed the 15% MOC supplemented diet had similar (P>0.05) ADG, FBW and TWG to lambs fed the 10% BSC supplemented diet.

The two different protein sources (MOC, BSC) and the two inclusion levels (10%, 15%) did not have any significant effect on ADFI, ADG, TWG, FBW and FCR values.

Sex of lamb affected performance for several parameters investigated in this study with male lambs performing significantly (P<0.05) better than female lambs for FBW, TWG, ADFI, and ADG, but gender did not have a significant effect on FCR values (P>0.05).

Table 6.2 Effects of supplementation with different levels of baobab seed cake or macadamia oil cake on feed intake and growth performance of South African Mutton Merino lambs

Protein source	Inclusion level (%)	IBW (kg)	FBW (kg)	TWG (kg)	ADFI (kg)	ADG (kg)	FCR
BSC	10	30.53	46.73[ab]	16.20[ab]	1.53[ab]	0.21[ab]	7.34
	15	30.88	48.13[a]	17.25[a]	1.65[a]	0.22[a]	7.39
MOC	10	31.00	48.00[a]	17.00[a]	1.65[a]	0.22[a]	7.53
	15	30.63	45.13[b]	14.50[b]	1.47[b]	0.19[b]	7.97
SEM		0.30	0.58	0.85	0.03	0.008	0.28
Protein source means							
BSC		30.7	47.4	16.73	1.59	0.22	7.36
MOC		30.8	46.6	15.75	1.56	0.20	7.75
SEM		0.21	0.41	0.43	0.02	0.006	0.20
Inclusion level means							
	10	30.8	47.4	16.60	1.59	0.21	7.44
	15	30.8	46.6	15.88	1.56	0.21	7.68
SEM		0.21	0.41	0.43	0.02	0.006	0.20
Sex means							
Male		31.06	48.88[a]	17.81[a]	1.71[a]	0.23[a]	7.42
Female		30.45	45.12[b]	14.66[b]	1.45[b]	0.19[b]	7.70
SEM		0.21	0.41	0.43	0.02	0.01	0.28
Significance							
Protein sourcet (D)		ns	ns	ns	ns	ns	ns
Inclusion level (L)		ns	ns	ns	ns	ns	ns
Sex		ns	**	**	**	**	ns
DxL		ns	**	**	**	**	ns

**: *P<0.01*; *: *P<0.05*; ns: *P>0.05*. [ab] within a section of each column, means with different superscripts are significantly different (P < 0.05): SEM: standard error of means; ns: non-significant; IBW: initial body weight; FBW: final body weight; TWG: total weight gained; ADG: average daily gain; ADFI: average daily feed intake; FCR: feed conversion ratio; Column means without [a] or [b] as superscripts are not significantly different at (*P>0.05)*

6.3.2. Carcass characteristics and non-carcass components of the lambs

The results on carcass characteristics (Table 6.3) show that lambs fed with 10% BSC, 15% BSC and 15% MOC supplemented diets had similar (P>0.05) warm carcass mass (WCM) and cold carcass masses (CCM). Lambs fed with 15% BSC and 10% MOC supplemented diets had similar (P>0.05) WCM and CCM. However, lambs fed with 10% MOC supplemented diet had significantly (P<0.05) heavier WCM and CCM than the lambs fed 15% MOC and 10% BSC supplemented diets.

The carcasses of lambs fed with 10% BSC, 15% BSC, 10% MOC and 15% MOC supplemented diets did not have significantly differ (P>0.05) in their dressing percentage (DP), carcass length (CL), neck weight (NW), fat thickness (FT), body width (BWT) and rib eye area (REA). There were significant protein supplement x inclusion level interaction effects on warm carcass mass and cold carcass mass (both at P<0.05).

The results of protein source means show that lambs on MOC supplemented diets had significantly (P<0.05) higher DP than the lambs on BSC supplemented diets. The lambs fed diets supplemented with BSC and MOC at 10% inclusion level had significantly (P<0.05) higher fat thickness than the lambs supplemented with BSC and MOC at 15% inclusion level. The results of the carcass characteristics of lambs in the current study indicated that carcasses from male lambs had heavier (P<0.05) WCM, CCM, CL, and NW than carcasses from their female counterparts. The carcasses of female lambs had thicker (P<0.05) FT and BWT than the carcasses of male lambs. Sex did not significantly affect DP and REA of the carcasses (P>0.05).

The results on non-carcass components are shown in Table 6.4. The results show significant (P<0.05) diet x inclusion level interaction on skin and spleen weights of the lambs. While skin weight increased significantly (P<0.05) with increasing levels for BSC, a similar trend was not observed for MOC. Lambs on the 15% BSC had significantly heavier (P<0.05) skin that lambs feed a 15% MOC or 10% BSC diet. The lambs which were fed 10% BSC, 10% MOC and 15% MOC supplemented diets had similar (P>0.05) skin weights. Lambs fed 15% BSC and 10% MOC supplemented diets had similar (P>0.05) skin weights..

The supplementation of lamb diets with BSC and MOC at 10% and 15% inclusion level did not have any significant (P>0.05) effect on the weight of, the rumen plus intestines, liver, lungs, trotters, head, heart, and trachea. Lambs on the 15% BSC had significantly lighter spleens that those on the 10% MOC diet, no other significant differences in means for this parameter were present.

Lambs fed with BSC supplemented diets had heavier (P<0.05) trotters than lambs on MOC supplemented diets. However, the means for skin, rumen plus intestines, liver, lungs, head, heart, and trachea weights were not significantly (P>0.05) influenced by the source of protein (BSC or MOC) used to supplement the diets. Inclusion levels of BSC and MOC in diets for lambs did not have significant (P>0.05) effects on non-carcass components of lambs evaluated in the present study (Table 6.4).
Sex of the lambs in the current study had no significant effects (P>0.05) on the weights of non-carcass components of the lambs.

Table 6.3 Effects of supplementation with different levels of baobab seed cake or macadamia oil cake on carcass characteristics of South African Mutton Merino lambs

Protein source	Inclusion level (%)	WCM (kg)	CCM (kg)	DP %	CL (cm)	NW (kg)	FT (mm)	BWT (mm)	REA (cm^2)
BSC	10	21.85[b]	21.65[b]	46.76	64.16	1.06	4.48	23.19	13.45
	15	22.90[ab]	22.75[ab]	47.58	63.98	1.13	3.74	24.33	13.26
MOC	10	23.41[a]	23.13[a]	48.85	66.58	1.22	4.41	24.12	12.77
	15	21.85[b]	21.61[b]	48.44	65.23	1.14	3.41	22.39	13.54
SEM		0.35	0.35	0.60	0.78	0.04	0.33	1.22	0.48
Proein source means									
BSC		22.38	22.20	47.17[b]	64.07	1.10	4.11	24.26	13.36
MOC		22.63	22.37	48.64[a]	65.90	1.18	3.90	23.25	13.16
SEM		0.24	0.24	0.42	0.55	0.03	0.23	0.86	0.34
Inclusion level means									
	10	22.63	22.39	47.80	65.37	1.14	4.44[a]	24.15	13.11
	15	22.38	22.18	48.01	64.60	1.14	3.58[b]	23.36	13.40
SEM		0.24	0.24	0.42	0.55	0.03	0.23	0.86	0.34
Sex means									
Male		23.33[a]	23.12[a]	47.72	66.26[a]	1.21[a]	3.50[b]	21.95[b]	13.10
Female		21.68[b]	21.45[b]	48.09	63.71[b]	1.06[b]	4.52[a]	25.56[a]	13.41
SEM		0.24	0.01	0.42	0.54	0.03	0.23	0.85	0.34
Significance									
Protein source (D)		ns	ns	*	ns	ns	ns	ns	ns
Inclusion level (L)		ns	ns	ns	ns	ns	*	ns	ns
Sex		**	**	ns	**	**	**	**	ns
D x L		**	**	ns	ns	ns	ns	ns	ns

*: *P<0.05*; ns: *P>0.05*; [ab] within a section of each column, means with different superscripts are significantly different (*P<0.05*); SEM: standard error of means; ns: not-significant (P>0.05); WCM: warm carcass mass; CCM: chilled carcass mass; DP: dressing percentage; CL: carcass length; NW: neck weight; FT: fat thickness; BWT: body weight thickness; REA: rib eye area. Column means without [a] or [b] as superscripts are not significantly different at (*P>0.05)*

Table 6.4 Effects of supplementation with different levels of baobab seed cake or macadamia oil cake on non-carcass components of South African Mutton Merino lambs

Protein source	Inclusion level (%)	Skin (kg)	Rumen + Intestine(kg)	Liver (kg)	Spleen (kg)	Lungs (kg)	Trotters (kg)	Head (kg)	Heart (kg)	Trachea (kg)
BSC	10	4.76[b]	9.41	0.70	0.121[ab]	0.52	1.21	2.48	0.31	0.113
	15	5.53[a]	9.72	0.76	0.118[b]	0.52	1.22	2.47	0.32	0.122
MOC	10	4.88[ab]	9.56	0.72	0. 181[a]	0.53	1.20	2.46	0.29	0.121
	15	4.79[b]	9.20	0.68	0.174[ab]	0.49	1.18	2.42	0.30	0.109
SEM		0.2	0.23	0.02	0.02	0.02	0.01	0.03	0.01	0.01
Protein source means										
BSC		5.14	9.57	0.73	0.12[b]	0.52	1.21[a]	2.48	0.31	0.11
MOC		4.83	9.38	0.70	0.18[a]	0.51	1.19[b]	2.44	0.30	0.12
SEM		0.13	0.16	0.02	0.01	0.01	0.01	0.02	0.01	0.01
Inclusion level means										
	10	4.81	9.49	0.71	0.15	0.52	1.20	2.47	0.30	0.11
	15	5.16	9.46	0.72	0.15	0.51	1.20	2.45	0.31	0.11
SEM		0.13	0.16	0.02	0.01	0.01	0.01	0.02	0.01	0.01
Sex means										
Male		5.04	9.43	0.74	0.16	0.52	1.20	2.46	0.31	0.12
Female		4.94	9.52	0.69	0.14	0.50	1.20	2.46	0.30	0.11
SEM		0.12	0.16	0.02	0.01	0.01	0.01	0.02	0.01	0.01
Significance										
Protein source (D)		ns	ns	ns	**	ns	*	ns	ns	ns
Inclusion level (L)		Ns	ns	ns	ns	ns	ns	ns	ns	ns
Sex		ns	ns	ns	ns	ns	ns	ns	ns	ns
D x L		*	ns	ns	*	ns	ns	ns	ns	ns

**: *P<0.01*; *: *P<0.05*; ns:non-significant (*P>0.05)*; [ab] within a section of each column, means with different superscripts are significantly different (*P < 0.05*); SEM: standard error of means; BSC: baobab seed cake; MOC: macadamia oil cake. Column means without [a] or [b] as superscripts are not significantly different at (*P>0.05)*

6.4 Discussion

6.4.1 Average daily feed intake

The differences in average daily feed intake in this study may be due to the difference in ether extracts contents of the four diets (Table 5.1). The higher ether extracts content of food negatively affect daily feed intake in Awassi lambs (Haddad and Younis, 2004). The reason behind the reduction in feed intake could be due to the fact that high unsaturated fatty acids in the diet reduces fibre digestibility which is caused by an antimicrobial effect of these fatty acids (Palmquist and Jenkins, 1980). This could be a contributory factor for the lower average daily feed intake of lambs on the 15% MOC diet. Increasing the inclusion level of MOC from 10% to 15% resulted in an increased ether extract content of the diet which had resulted in reduced feed intake. Anti-nutritional factors such as tannins have a repellent effect on feed intake of livestock (McDonald *et al*., 2011) however, Madzimure *et al*., (2011) indicated that as long as the feed materials which contain tannins are fed to the animals dry, the feed intake cannot be affected by their presence. This implies that, had MOC and BSC contained tannins, they could not have any influence on feed intake as these two cakes are produced and fed dry. However, it is important to indicate that regardless of the differences in average daily feed intake, the lambs on the four diets consumed more feed than the 0.9 kg feed per animal per day as indicated by McDonald *et al*. (2011). This implies that the inclusion of MOC and BSC in diets for lambs does not have a deleterious effect on feed intake.

The decrease in average feed intake when MOC was increased from 10% to 15% in the diets observed in the present study was similar to the report of Sherrod and Ishizakki (1966/7) who found that increasing Macadamia nuts above 12% in the diets of sheep reduced their feed intake. This decrease in average daily feed intake for lambs on 15% MOC supplemented diet could be attributed to the high fibre content of MOC (Table 3.1) coupled with increased EE which could have interfered with the digestion of fibre fractions of the diet as alluded to by Wanapat *et al*. (2011). According to the findings of Acheampong-Boateng *et al.* (2008) the inclusion of MOC in diets of feedlot cattle in excess of 10% reduces daily feed intake even though the difference was not significant. The average daily feed intake of lambs on the MOC diets fall within 1.39 to 1.59 kg/day DM range when MOC was included at 5%, 10%, 15% and 20% in the diets of S.A. mutton merino lambs (Acheapong-Boateng *et al*., 2017).

The findings of Oladunjoye *et al*. (2014) were also in agreement with the results of the current study on BSC data because they reported that rabbits can be given a diet containing 15% baobab pulp and seed meal without affecting feed intake. The same results were also reported by Beken and Sahin (2011) who indicated that Olive cake inclusion up to 20% in diets for lambs did not have a negative effect on feed acceptability by lambs. This is an indication that on average 15% BSC inclusion level in diets of ruminants and rabbits does not negatively affect acceptability of feed by these animals. Contrary to the findings of the current study on BSC feed intake, Madzimure *et al*. (2011) reported that increasing BSC inclusion levels in the diet of lactating dairy cows from 5% to 15% decreased the stover intake. Ilori *et al*. (2013) and, Belewu and Ibikunle (2009) also found the results contrary to those of the current study. Ilori *et al*. (2013) found that average daily feed intake decrease in WAD goats fed whole baobab fruit as supplement to wheat offal. Belewu and Ibikunle (2009) found that average daily dry matter intake was lower in sheep fed 25% BSC compared to those on 0% and 12.5% BSC. The differences in average daily feed intake findings between the results of the current study and those of the researchers mentioned above might be due to differences in animal species, the high fibre content of baobab fruit shell as argued by Ilori (2013) and the very high inclusion level of 25% in the case of Belewu and Ibikunle (2009). BSC being an oil cake does contain reasonably high oil content (86g/kg) hence a decline in feed consumption due to the negative effect fat has on rumen fermentation which then affect feed intake especially if oil is not removed which might be the case with the BSC of the researchers mentioned above.

6.4.2 Total weight gain

The total weight gain differences amongst the lambs on the four diets in this study may be due to the differences in their average daily feed intake. It is widely accepted that feed intake is positively related to body weight gain and this is evident from the results on table 6.2 in that lambs which ate more feed gained more weight/day.

The results of the overall body weight gain for lambs on the 15% MOC diet in this study were in agreement with the report on South African Mutton Merino lambs fed Sunflower oil cake as a protein supplement (Nkosi *et al*., 2011). However, the lambs on 10% BSC, 15% BSC, and 10% MOC diets in this study (16.43-17.25 kg) performed better than those reported by Nkosi *et al*. (2011) in South Africa and Irshaid *et al*. (2003) who investigated the effect of Sunflower meal on the growth performance of Awassi lambs in Jordan. They both indicated a total body weight gain ranging from 10.55-15.72 kg for the entire experimental period. The differences in total weight gain could be attributed to the difference in the length of trials amongst these studies. Beken and Sahin (2011) reported an average total weight gain of 10.1 kg for lambs fed 20% Olive cake as protein supplement which is significantly lower than the results of the current study. These differences may be attributed to a better MOC and BSC utilization by the lambs. The differences between the current study and those of Nkosi *et al*. (2011) and Irshaid *et al*. (2003) may also be attributed to the use of different protein supplements and lamb breed (Awassi) for the later. Different protein supplements were likely to have different nutritive values and different breeds of lambs may respond differently to a particular diet.

Contrary to the results of this study several researchers have reported that Baobab seed cake/meal cannot be included beyond 15% in the diets of ruminants because such inclusion level reduces animal performance (Ilori *et al*., 2013; Madzimure *et al*., 2011; Belewu and Ibikunle, 2009). According to Madzimure *et al*. (2011) 15% inclusion of Baobab seed cake in the diets of Guernsey cows reduced milk production. Ilori *et al*. (2013) reported that WAD goats performed better when whole baobab fruit is incorporated in the diet at a level not exceeding 10% whilst, Belewu and Ibikunle (2009) indicated that Baobab seed meal cannot be included in the diets of sheep in access of 12%. The findings of this study also disagrees with the report of Acheampong-Boateng *et al*., (2008) who found that MOC can be included in the diets of feedlot cattle up to 20% of the diet. These differences may be attributed to the use of different ruminant species and possibly differences in fibre content (24.9% CF, for Acheampong-Boateng *et al*., 2008 and 35.6% CF for the current study) of the different cakes.

6.4.3 Average Daily Gain (ADG)

The differences in ADG in the present study may be attributed to the differences in feed intake because the animals which ate more feed gained more weight. Feed intake is positively related to body weight gain (McDonald *et al*., 2011). However, it is worth noting that the lambs with the least ADG in the present study were comparable to the lambs (South African Mutton merino) with the highest ADG reported by Nkosi *et al*. (2011) in their study where they fed the animals with sunflower oil cake. This indicates that even though the ADG of lambs on 15% MOC was lower than the rest of the groups in the present study, their performance is still within acceptable levels. The lambs on BSC diets and those on 10% MOC diets performed much better than those on 15% MOC. The performance of lambs indicates that, in this case, the anti-nutritional factors (Tannins) in BSC and MOC reported by Madzimure *et al*. (2011) and Skenjana (2011) were not sufficient to cause any negative effect on animal performance. The oil extraction process has probably roasted the cake efficiently to deactivate or destroy the tannins in BSC and MOC produced in South Africa as suggested by Belewu and Ibikunle (2008). The least performance of lambs associated with the 15% MOC diets might be attributed to increased fibre content of the diet which in turn might have reduced its utilization by the young lambs (Villamide and San Jaun, 1998). The other reason for the least performance of the 15% MOC lambs may be attributed to low feed intake of these animals as (McDonald, 2002) feed intake is positively related to body weight gain. Generally, the results of the current study for average daily gain and the findings of Sherrod and Ishizaki (1966) follow a similar pattern whereby the lambs gained less weight as the level of MOC/Macadamia nuts was increased. The inclusion of 5%, 10%, 15% and 20% MOC in diets of S.A. mutton merino lambs had no significant effect on average daily gain of lambs (Acheampong-Boateng *et al*., 2017) which was contrary to the findings of the current study. However, in the current study, average daily gains of the lambs on MOC diets were higher than 71.5, 70.9, and 55g/day (Sherrod and Ishizaki, 1966) with lambs on 10% MOC having average daily gain value falling within 0.22 – 0.24 kg/day range (Acheampong-Boateng *et al*., 2017). The differences may be attributed to differences in the inclusion levels although even those inclusion levels falling within the same ranges of the two studies have different gains. The high oil content of Macadamia nuts (Sherrod and Ishizaki, 1966), could have suppressed feed intake through decreased rumen degradability of the fibre of the diet. High oil content interferes with the proper functioning of the rumen by preventing microbes from attaching themselves on the cell wall of ration components thereby reducing degradation and digestion of nutrients (Mlambo *et al*., 2011).

The results of this study are in agreement with the findings of Oladunjoye *et al*. (2014) who reported that rabbits fed Baobab seed meal plus pulp up to 15% of the total diet had an increased weight gain. This means that the utilization of BSC by rabbits and sheep was similar hence the same growth trends. Like Oladunjoye *et al.* (2014) and Ilori *et al*. (2013) found that WAD goats fed 10% whole Baobab seed meal recorded higher average daily gains which were comparable to those of sheep on 10% BSC diet. Contrary to the results of the current study were the findings of Acheaompong-Boateng *et al*. (2008) who reported that fattening cattle performed better (2.008 kg/day ADG) when MOC was included at 20% level, and, Belewu and Ibikunle (2009) reporting that the lambs gained less weight (56 g/day per lamb) when BSC in incorporated at above 12.5% level. These differences might be attributed to the species differences in the case of MOC and the processing method for BSC.

6.4.4 Feed Conversion Efficiency (FCR)

The non- significant differences in FCR in the present study was consistence with the findings of several researchers (Oladunjoye *et al.*, 2014; Souza *et al*., 2013; Beken and Sahin, 2011; Nkosi *et al*., 2011; Belewu and Ibikunle,2009; Koyuncu, 2008) who in their different research work with different livestock species reported that FCR was not affected by diets. However the results of this study show a lower FCR (7.38-7.97) value compared to most of the findings of the researchers mentioned above. Nkosi *et al*. (2011) reported FCR ranging from 6.1 – 6.9 of SA mutton merino fed Sunflower oilcake as protein supplement in South Africa whilst Souza *et al*. (2013) found FCR of 3 for lambs (Dorper x Santa Ines or Brazilian Somali sheep) fed a total mixed ration mixed to achieve a 0.3 kg/day. Oladunjoye *et al*. (2014) reported FCR values ranging from 5.98 – 6.02 for rabbits fed Baobab pulp and seed meal as protein and energy supplements whereas Belewu and Ibikunle,(2009) found a range of 0.1 – 0.14 FCR for lambs fed BSC as protein supplement. Beken and Sahin (2011), and, Koyuncu, (2008) reported FCR ranges of 6.9 – 7.2 and 5.56 – 5.96 for Awassi lambs fed Olive cake,. These differences may be attributed to the differences in nutritive value of the test feeds.

Contrary to the results of this study (FCR range of 7.34 – 7.97) on MOC, Acheampong-Boateng *et al*. (2008/2017) in their study with cattle and sheep given MOC as protein supplement reported a significant different in FCR values among the treatments with a range from 4.814 – 5.729 and 5.97 – 7.24 respectively. Shirima *et al*. (2014) in their study of the influence of age and concentrate feeding (with Cotton seed cake as protein supplement) on the performance of Tanzanian long-fat-tailed sheep also reported that the lambs had significantly different FCR values. However, FCR values in this study were less than 8.5, 8.1, and 8.3 reported by Sherrod and Ishizaki (1966) when they included Macadamia nuts in the diets of lambs which explains the lower weight gains of their lambs compared to those of the current study. These differences may be due to species and high oil content of the nuts.

Lambs in the current study used more feed to produce a kilogram of meat compared to the findings of most of the researchers cited above with some exceptions from the findings of Shirima *et al*. (2014). The source of such differences might be attributed to the different feed materials and mixtures, the age and type of species or sheep breeds as well as climatic conditions. It is, however, important to highlight that the lambs in the current study performed better than almost all the lambs reported by the researchers mentioned above in terms of ADG except those reported by Acheampong Boateng *et al*. (2017).

The better growth performance of male lambs when compared to the female lambs in the current study was not suprising as it is known that males out-perform females. These results were in aggrement with the findings of Sen et al. (2011) and Kashani and Bahari (2017) who found that male lambs out-performs their female counterparts in terms of growth.

6.4.5 Carcass Characteristics of South African Mutton Merino Lambs

6.4.5.1 Warm and cold carcass mass

Carcass characteristics measurements are important for both the producer (farmer) and the retailers as these serve as determinants of the quality of the meat and the price the retailers are going to pay for the carcass. It also gives an indication of the amount of meat one can expect from a given carcass.

The significant differences on the warm carcass weight (WCM) and cold carcass weight (CCM) of the lambs in the current study might be attributed to the differences in the cakes and their inclusion levels in the diets of the lambs. The WCM and CCM values followed the same pattern as those of FBW, TWG, ADFI and ADG which was an indication that these carcass masses were positively influences by feed intake and body weight gain. It is not strange that lambs on 15% MOC diet performed poorly in terms of carcass weights compared to the lambs on the other diets because they were also lightest of the four groups. The weights of stomach contents and the other non- carcass components might have contributed to these changes in weights of the carcasses of the lambs because if the lambs on 15% BSC diet had more stomach and intestines contents as well as heavier skins (with wool) for an example can reduce their carcass weights.

The results of this study were in agreement with the findings of Acheampong-Boateng *et al*. (2017), who reported significant differences in warm and cold carcass masses of lambs fed diets supplemented with MOC as protein supplement. Warm carcass masses of feedlot cattle fed Soybean oil cake and two levels of MOC as protein supplements significantly differed from each other (Acheampong-Boateng *et al*., 2008), which was similar to the findings of the current study. The results of the current study on the WCM and CCM were similar to the findings of Shirima *et al*., (2014) who reported a significant difference in the two parameters for Tanzanian long-fat-tailed sheep. The current results were also consistence with the findings of Mioc *et al*. (2007) who reported a significant difference in the carcass weights of lambs fed olive cake as a protein supplement. However, the WCM and CCM of the current study ranged from 21.85 – 23.41 kg and 21.65 – 23.13 kg, respectively, which are heavier than the 19.1 – 21.1 kg (warm carcass weight) and 18.6 – 20.6 kg (cold carcass weight) reported by Acheampong-Boateng *et al*. (2017). The differences may be attributed to the difference in slaughter weight and age of the animals..

The diet x inclusion level interaction for the warm and cold carcass traits can be explained by a reversal increase in these traits when the inclusion levels of the two cakes are increased. At 10% BSC the two traits values are lower than the values of 15% BSC inclusion but the reverse was the case with MOC. At 10% MOC the values of the two traits were higher compared to 15% MOC diet. These differences may be due to the nature of the fatty acid of which Osman (2004) indicted that Baobab oil is stable and can be useful as food oil.

6.4.5.2 Dressing percentage

The results of dressing percentage in the current study were consistent with the findings of Acheampong-Boateng *et al*. (2008) who reported a non-significant difference in dressing percentage in feedlot cattle fed two levels of MOC as protein supplement. Similar findings were reported by Oladunjoye *et al*. (2014) who also found no significant difference in dressing percentage of growing rabbits fed Baobab pulp and seed meal as both energy and protein supplement. Koyuncu (2008) reported that the dressing percentage of Kivircik and Karacabey Merino breeds were not significantly different which is in agreement with the results of this study. However, the dressing percentage values reported by Acheampong-Boateng *et al*., (2008) and Oladunjoye *et al*., (2014) were higher (53.4 – 55.1% and 56.1 – 57.9% respectively) than those of the current study (46.74 – 48.85%), but were comparable to the findings of Koyuncu (2008) who reported dressing percentage ranging from 47.1 – 49.2%. The 46.74 – 48.85% range in dressing percentage of the current study was comparable to 46.5 and 49.5 % for Nellore lambs fed groundnut cake and sunflower cake diets (Nagalakshmi *et al*., 2011) who also found that the addition of these cakes do not affect the dressing percentages of the lambs. Similar findings were also reported by Rizzi *et al*. (2002). According to Ustuner *et al*. (2012) the inclusion of sunflower and soybean meals in diets for lambs either pelleted or not did not affect the dressing percentage of lambs which was similar to the findings of the present study.

Acheampong-Boateng *et al*. (2017) working with South African mutton merino lambs reported that dressing percentage was significantly influenced by the addition of different levels of MOC in the lambs' diets which disagrees with the results of the current study. Contrary to the results of the current study are the findings of Mioc *et al*. (2007) who reported that inclusion of Olive cake in different levels in the diets of lambs significantly affected the dressing percentage of the lambs. However, the study of Mioc *et al*. (2007) found dressing percentage values of 41.29 – 43.85% which were lower than the values of this study. The differences might be attributed to differences in the breeds, age at slaughter and cakes used in the two studies. Most of the dressing percentage values for the current study fall within 47.2 – 48.7 kg range reported by Acheampong-Boateng *et al*. (2017) except the 46.76 for the lambs on the 10% BSC diet.

The non-significant difference in carcass length found in this study due to the inclusion of different levels of BSC and MOC were similar to the finding of Cabral *et al*. (2013) and Macome *et al*. (2011) in their studies involving the feeding of lambs with Peach-Palm by-products and Palm kernel cake respectively. However, the range of carcass length values (63.34 – 66.58 cm) in the present study was higher than a range of 55.44 – 59.90 cm reported by the previous researchers. These differences may be due to the differences in slaughter weights and the breed of lambs. Acheampong-Boateng *et al*. (2017) reported a significant differences in carcass length of lambs fed diets supplemented with different inclusion levels of MOC which was contrary to the results of the current study. However, the carcass length values between the current study and that of Acheampong-Boateng *et al*., (2017) have similar values with a range from 62.9 – 66.58 cm.

The non-significant differences in neck weight found in this study were similar to the finding of Cabral *et al*. (2013) and Oliveira *et al*. (2012). However, Cabral *et al*. (2013) and Oliveira *et al*. (2012) found the weights of the lamb's necks ranging from 0.26 – 0.39kg and 0.45 – 0.5kg, respectively which were lower than the range of 1.07 – 1.22kg for the present study. These differences may be due to the differences in weight of the animals at slaughter and the breed. Contrary to the findings of the present study on the weight of the neck, Souza *et al*. (2013)

found that cross breed lambs had significantly difference in neck weights but the neck weight values (average of 1kg) were comparable to the findings of the current study. Their findings may have been influenced by the differences in the breeds of the lambs as their focus was on the effect of genotype.

The non-significant difference associated with different levels of BSC and MOC on fat thickness and body wall thickness found in this study are similar to the finding of Flakemore *et al*. (2015) who reported a fat thickness range of 3.8 – 4.5 mm from a study involving the supplementation of lambs with low and high Rice bran. However, the body wall thickness of the current study ranged from 22.39 – 24.33 mm which was higher than the range of 14.2 – 17.1 mm reported by the previous authors. The differences may be due to breed differences. The fat thickness range of 3.41 – 4.41 mm in the present study was lower than 6 – 6.5 mm range for Awassi ram lambs reported by Ustuner *et al*. (2012). The differences may be due to the differences in the lamb breeds and or the feed because some breeds have a propensity to put on more fat and some feed formulations support deposition more than others. State of physiological maturity has been documented to have an effect on fat deposition (Brand *et al.*, 2017; van der Westhuizen *et al.*, 2010).

The significantly different body wall thickness associated with the level of inclusion of the cakes suggests that 10% inclusion of both BSC and MOC affects this attribute. These differences may be due to the fact that when the inclusion level is increased to 15% the fat content of the feed was also increased thereby affecting the proper functioning of the rumen. According to Van der Walt *et al*., (2014) unsaturated oil promotes more efficient use of metabolizable energy which could be the case in the present study. Another scenario may be that increased oil content of the feed depressed fibre digestibility (Hess *et al*., 2008) which may be the reason why the 15% cake inclusion recorded lower body wall thickness values.

The non-significant differences in the rib eye area in the present study is similar to the findings of Flakemore *et al*. (2015), Ustuner *et al*. (2012), and Koyuncu (2008). Contrary to the results of the present study were those of Acheampong-Boateng *et al.* (2017) who reported that different inclusion level of MOC in the diet of lambs significantly affected the rib eye area of the carcass. The differences may be due to the differences in the nutrient composition of the diets of the lambs in the two studies as well as the slaughter age.

The superior carcass characteristics of male lambs in the current study over their female counterparts were in agreement with the findings of Sen et al. (2011). These results were expected because male lambs out-performed the female lambs in terms of growth.

6.4.6 Non-carcass components of S.A. Merino lambs

The significantly different skin weight values in the present study contradicts the report by dos Santos Cabral *et al*. (2013), Oliveira *et al*. (2013) and Koyuncu (2008) who found no significant difference in the skin weights of the lambs fed Peach-Palm by-products. The skin weights in this study on average were higher than those of the two researchers. The differences may be due to breed differences, slaughter weights and the wool quantity in the skins of the present study which could have contributed in the differences in the skin weights.

The non- significant differences in rumen+intestines, liver, lungs, trotters, head, heart and trachea in the present study were in agreement with the findings of da Silva Elias *et al*. (2015), dos Santos Cabral *et al*. (2013) and Koyuncu (2008) who reported a non- significant differences for the same traits. These similarities suggest that these protein supplements from plant oil cakes do not have negative effects on these traits. The significant difference in spleen weights in this study contradicts those of da Silva Elias *et al.* (2015), dos Santos Cabral *et al*. (2013) and Koyuncu (2008) who found no differences in spleen weights. The differences may be due to the differences in the oil cakes, breeds of sheep and weight at slaughter.

The differences in spleen and trotters weights associated with the dietary differences in the present study may be due to the differences in the nutritive values of the two cakes. According to Skenjana *et al*. (2006) MOC is highly degradable in the rumen and this may result in most of its nutrients being used by microbes in the rumen leaving very little for the animal itself hence the lighter weights of these traits. The diet x inclusion level interaction was attributable to a textbook case of a swapping of ranks in spleen and skin weights associated with feeding the different diets. These suggest that whenever the animals are supplemented with any of the two cakes at these two levels there will be no linear increase in these traits.
The non-significant differences in the non-carcass characteristics of male and female lambs in this study suggest that the inclusion of BSC and MOC at different levels do not have any effect on these traits.

6.5 Conclusion

It is therefore concluded that 15% MOC incorporation into the diets of finishing lambs decreases feed intake and growth perofrmance of the lambs which results in lower carcass yields. BSC can be incorporated in the diet of lambs at an inclusion level of up to 15% without negatively affecting feed intake and growth performance and carcass characteristics of the animals. Generally the non-carcass components of the lambs are not affected by the inclusion of BSC and MOC in the diets of the animals.

CHAPTER 7: GENERAL DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS

6.1 General discussions

The low protein contents of Macadamia oil cake and Baobab seed cake makes these cakes intermediate protein supplements. This means that on their own they cannot supply enough protein to meet the animals' requirements for production such as growth, milk production, wool production, egg production etc. but they are best suitably used in combination with urea in ruminants diets or some high protein sources like Soybean meal in monogastrics. In case of ruminants animals the use of urea with Macadamia or Baobab cake as a protein supplement can help achieve the reduction of high costs associated with use of conventional oil cakes. Reduction in cost in this case is mainly because urea is generally cheaper than the Soybean meal which dominates the animal feed industry especially in South Africa. Baobab seed cake in particular contains good quantities of essential Amino acids which make it a good quality protein supplement compared to Macadamia oil cake.

From the chemical analysis carried out for this study, Macadamia oil cake and Baobab seed cake contain 18.5 and 17.3% of GE, respectively which is comparable to some of the cereal grans making them good sources of energy. Their considerably high fat content (average of 8.5% EE) gives them an added advantage as oil contributes double the energy of the carbohydrates (McDonald *et al.*, 2011). This is supported by the fact that during the growth trial in this study the diets were formulated excluding maize meal as an energy source and only hominy chop was used as the main energy source for the animals. In case of monogastrics, the inclusion of these two cakes in their diets should be done in such a way that the cakes do not increase the fat content of the diets above 10% because as any other plant oils they are rich in unsaturated fatty acids which have the ability to alter the fatty acids composition of the meat with undesirable effects such as soft pork in pigs. Soft body fat in monogastrics can negatively affect the consumer acceptability of the meat which will also reduce the price the retailers will pay for such meat.

The mineral composition of the two cakes in particular the macro elements were fair enough to meet the animals' needs with very little supplementation required. Of the two cakes Baobab seed cake was richer in macro elements making it a better source of these mineral elements.

The high mineral content of Baobab seed cake was expected due to its leguminous nature as this group of plants is known to contain high mineral concentrations (McDonald *et al*., 2011).

The high effective degradability values of BSC and MOC in the present study is expected as it has been documented that oil seed cakes have higher rumen degradability of dry matter (Habib *et al*., 2013). The high ruminal degradability of dry matter, crude protein and subsequently their respective Amino acids of these cakes is an indication that they are best suited to be used or included in the diets of ruminant animals because they provide the microbial population with nutrients which will encourages the multiplication of the microbes which are beneficial to the animal. The microbes grow and eventually die and they are passed unto the small intestines where they are digested by the animals' enzymes and its proteins (Amino acids) absorbed by the animal for its own maintenance and production. The protein of rumen microbes is of high quality that's why ruminants seldom require addition of essential Amino acids in their diets. The increase in nutrients degradability after 16 hours of incubation of Baobab seed cake in the rumen is an indication that the longer this cake remains in the rumen the more its nutrients are going to be used up in the rumen thereby leaving very little for post ruminal digestion and utilization by the animal. The high fibre content of Macadamia oil cake negatively affects its degradability in the rumen as proved by its low degradability values (table 4.2) after 16 hours of incubation in the rumen.

Generally higher post-ruminal *in vitro* dry matter, crude protein and Amino acids digestibility of Macadamia oil cake and Baobab seed cake suggest that these two cakes' rumen undegradable nutrients are available to the animals for utilization. Baobab seed cake provides the most nutrients for utilization by the animal due to its high post-ruminal *in vitro* digestion values compared to those of Macadamia oil cake. The lower fiber content of Baobab seed cake is probably the reason why this cake exhibited higher digestion than Macadamia oil cake due to the fact that fibre negatively affects digestion.

The similar intake and faecal output of nutrients by lambs fed diets formulated to include 10 and 15% of Macadamia oil cake and Baobab seed cake suggest that the inclusion of these cakes in the diets of lambs have no negative effect on animal nutrient intake and nutrient output in the faeces. However, when the two cakes are compared without separating them by level of inclusion lambs on Baobab seed cake consumed more organic matter than those on Macadamia oil cake supporting the superior growth performance of lambs on Baobab diets. This is further supported by the high ADF faecal output observed in the current study which is probably the result of high ADF content of Macadamia oil cake reported in Chapter 3 on chemical composition of the two cakes. The lack of differences in the apparent digestibility of nutrients by lambs on diets constituted by two levels of Macadamia and Baobab cakes is an indictment of the close growth performance (15 – 17.25kg total weight gain) of these lambs observed in the growth trial. The least (15kg) total weight gain being recorded for lambs on 15% Macadamia cake diet which is supported by the least total organic matter consumption by lambs on Macadamia cake diet. Strangely, the lambs on 15% Macadamia cake diet retained more nitrogen than the rest of the other groups. Least performance by lambs on 15% Macadamia diet is further explained by the least daily feed consumption by these animals which fits perfectly with the general knowledge that feed intake is positively related with growth performance.

The differences in carcass characteristics especially the warm carcass and cold carcass masses with the 15% Macadamia cake lambs having the least values for these traits follows the same trend as for the growth performances of the lambs. Lambs which gained more weight ended up with heavier carcasses and vice versa. This is supported by the high nutrient and feed intake of these lambs. It therefore implies that the more feed an animal consume will translate into more weight gain and subsequent carcass yields.

The addition of Macadamia oil cake and Baobab seed cake in the diets of lambs in different quantities do not negatively affect most of the non-carcass components of the lambs. However, the heavier skins of lambs on Baobab seed cake suggest that the wool growth of these lambs may have been positively influenced by this cake compared to the lambs on Macadamia oil cake. South African Mutton Merinos are dual purpose breeds known for their meat and wool production. The differences in skin weights could possibly be attributed to the wool production of the lambs on the baobab based diets. It is not clear why lambs on Macadamia oil cake diets had heavier spleens, this anomaly warrants further investigation to establish what could be the cause of the increase in spleen weight in this treatment group.

6.2 General conclusion and recommendations

6.2.1 General conclusion

Macadamia oil cake and Baobab seed cake can be used in the diets of livestock as both intermediate protein and energy supplements. They are both highly degradable in the rumen and digestible post-ruminally making them perfect feed materials for ruminant animals. Their apparent digestibility values of diets made to incorporate Macadamia and Baobab cakes support a positive nitrogen balance of sheep which is an indication that they are good protein supplements. In the diets of growing (fattening) lambs Macadamia oil cake and Baobab seed cake can be included up to 15% of the total diet. This makes them potential vehicles for the reduction of feed costs for farmers situated in close vicinity to their areas of production. Their productions are confined to the Lowveld which also happen to be, areas which are frequently hardest hit by winter feed shortages. Production of these cakes from autumn, the beginning of summer makes these cakes the perfect winter feed supplement for animals. Generally, the inclusion of Macadamia oil cake and Baobab seed cake at 10% and 15% respectively to make up complete diets for lambs does not compromise the growth performance and carcass characteristics of the lambs.

6.2.2 Recommendations

The production of Macadamia oil cake in South Africa is carried out with and without the inclusion of soyabean hulls and this means that the production of this cake results in two different macadamia cake products which may potentially have different nutrient compositions. It is therefore recommended that the nutritive value of Macadamia oil cake produced without soybean hulls be evaluated for nutritive value using both ruminants and non-ruminants. It is also recommended that a similar study be conducted to determine the nutritive value of both BSC and MOC as protein supplement for goats and pigs. The inclusion of high fibre Macadamia oil cake evaluated in this study should be carefully done to avoid the negative effect which can be brought about by the fibre which could affect growth performance of the animals. When feeding non-ruminants the high unsaturated fatty acids composition of these cakes should be considered during formulation of the diets of the animals to avoid deposition of soft fat of the meat which could potentially reduce the price retailers will pay for the meat. There is therefore a need to conduct chemical composition analysis of MOC prior to ration formulation as it has been reported in this study that this cake contain different quantities of nutrients. The incorporation of MOC and BSC in diets for high producing animals might require the inclusion of a low rumen degradable protein source/supplement but highly digestible in the small intestines.

REFERENCE

Abdel-Hakim N.F.M, Lashin M.E, Al-Azab A.A, and Nazmi H.M. 2008. Effect of replacing soybean meal protein by other plant protein sources on growth performance and economic efficiency of monosex Nile, Tilapia (Oreachromis niloticus) cultured in tanks. Proceedings of the 8th International Symposium on Tilapia in Aquaculture, 739-755. Cairo, Egypt

Absalan M., Afzalzade M., Sharifi S.D., Khorvash M., and Kazemi-Benchenari M. 2011. Feeding of whole cottonseed on performance, carcass characteristics and intestinal morphology of Zandi lambs. South African Journal of Animal Science, 41(3): 309-317

Acheampong-Boateng O, Bakare A.G and Mbatha K.R. 2016. The potential of replacing soybean oilcake in Macadamia oil cake in broiler diets. Tropical Animal Health. 48:1283

Acheampong-Boateng O., Mikasi, M.S., Benyi, K. and Amey, A.K.A. 2008. Growth Performance and Carcass Characteristics of Feedlot Cattle Fed Different Levels of Macadamia Oil Cake. Tropical Animal Health and Production 40 (3): 175–79. doi:10.1007/s11250-007-9076-3.

Acheampong-Boateng O., Bakare A.G., Nkosi D.B., and Mbatha K.R. 2017. Effects of different dietary inclusion levels of Macadamia oil cake on growth performance and carcass characteristics in South African Mutton Merino lambs. Tropical Animal Health and Production 49: 733–738

Akinleye I, Roberts J.S, Charmaine D.M, Linnenbringer E. Obisesan T.O, Fesaye G.A and Green R.C. 2011. Differences between African American and white research volunteers in their attitudes, beliefs and knowledge regarding genetic testing fpor Alzheimeris Disease. Journal of Genetic Counseling. 20-650-659

Al Jassim R.A.M., Al-Ani A.N., Hassan S.A., Dana T.K. and Al-Jarian L.J. 1991. Effects of dietary supplementation with rumen undegradable protein on carcass characteristics of Iraqi Awassi lambs and desert goats. Small Ruminant Research, 4(3): 269-275

Alves F. J.L., Ferreira M.A., Urbano S.A., Andrade R.P.X., Silva A.E.M., Siquera M.C.B., Oliveira J.P.F., and Silva J.L. 2016. Performance of lambs fed alternative protein sources to Soyabean meal. R.Bras>Zootec, 45(4): 145-150

Association OF Official Analytical Chemists - AOAC. 2000. Official methods of analysis, 19.ed. Washington, D.C.

Aufrere J., Graviou D., Melcion J.P and Dermarquill (2001. Degradation in the rumen of lupin (lupinus albus) and pea (pisum sativum) seed proteins: effect of heat treatment. Animal. Feed Science and Technology. 92 (3-4) : 215-236

Ash A.J., and Norton B.W. 1987. Studies with the Australian cashmere goat. Ii. Grwoth and digestion in male and female goats given pelleted diets varying in protein content and energy level. Australian Journal of Agricultural Research, 38: 957-969

Babiker, M.S. 2012. Chemical Composition of Some Non-Conventional and Local Feed Resources for Poultry in Sudan. International Journal of Poultry Science, 11: 283-287.

Bale J.S, Mancha Y.P, Sanusi M, and Doma U.D. 2013. Effect of graded levels of Baobab (Adansonia digitata) seed meal on the growth performance and production economic analysis of Broiler chickens. International Journal of poultry science. 12 (5): 273-276

Bandyk C.A., Cochran R.C., Wickersham T.A., Titgemeyer E.C., Farmer C.G., and Higgins J.J. 2001. Effect of ruminal vs. postruminal administration of degradable protein on utilization of low-quality forage by beef steers. Journal of Animal Science, 79: 225-231

Barchiesi-Ferrari C., and Anrique R. 2011. Ruminal degradability of dry matter and crude protein from moist dehulled lupin and extruded rapeseed meal. Chilean Journal of Agricultural Research, 71(3): 430-436

Barry, T.N. and Manley, T.R. 1984. The role of condensed tannins in the nutritional value of Lotus pedunculatusfor sheep: II. Quantitative digestion of carbohydrates and protein. British Journal of Nutrition. 51:493–504.

Bateman H.G, Clark J.H and Murphy M.R (2005). Development of a system to predict feed protein flow to the small intestine of cattle. Journal of Dairy Science. 88, 282-295

Beken, Y. and Șahin, A. 2011. The effect of Prina (olive cake) feeding methods on growth performance and behaviour of awassi lambs. International Journal of Agriculture and Biology, 13: 423-426.

Belewu, M.A. and Ibikunle, M.A. 2009. Potential of lesser known seed meal in the diet of sheep. Green Farming Vol. 2 No. 10 pp. 694-695

Belewu, M.A., Fagbemi, T., Dosumu, O.O. and Adeniyi, M.O. 2008. Physico-chemical and anti-nutritional properties of some lesser known tree and leguminous seeds. International Journal of Agricultural Research, 3, 237–242.

Boateng M, Okai D.B, Baach J and Donkoh A. 2008. Palm kernel cake extraction and utilization in pig and poultry diets in Ghana. Livestock Research for Rural Development., 20(7): 99

Bolek Y., Tekerek H., Hayat K., and Bardak A. 2016. Screening of cotton genotypes for protein content, oil and fatty acid composition. Journal of Agricultural Science, 8(5):107-121

Bonsi, M.L.K., Tuah, A.K., Osuji, P.O., Nsahlai, V.I., and Umunna, N.N. The effect of protein supplement source or supply pattern on the intake, digestibility, rumen kinetics, nitrogen utilization and growth of Ethiopian Menz sheep fed tef straw. Animal Feed Science and Technology. 1996; 64: 11–25

Borja M.S., Oliveira R.L., Ribeiro C.V.D., Bagaldo A.R., Crvaldo G.G.P., Silva T.M., Lima L.S., and Barbosa L.P. 2010. Effects of feeding licury (Syagrus coronate) cake to growing goats. Asian-Australian Journal of Animal Science, 23(11): 1436-1444

Brand T.S, Van der Merwe G.D and Young D. 2001. Full-fat canola as protein source in diets for finishing lambs. Small Ruminants Research. 41 (3)

Brand T.S., van der Westhuizen E.J., van der Merwe D.A., and Hoffman L.C. 2017. Effect of days in feedlot on growth performance and carcass characteristics of Merino, South African Mutton Merino and Dorper lambs. South African Journal of Animal Science, 47(1): online version ISSN 2221-4062

Cabral, I.S., Azevêdo, J.A.G., Almeida, F.M., Pereira, L.G.R., Araújo, G.G.L., Cruz, C.L.S., Nogueira, A.S., Souza, L.L., and Oliveira, G.A., 2013. Performance and characteristics of carcass and non-carcass components of lambs fed peach-pa lm by-product. Tropical Animal Helath and Production, 45, 1737–1743.

Chkeredza S. 2003. Growth performance of weaner lambs offered maize stover supplemented with varying levels of maize and cotton seed meals. Livestock Production Science, 73: 35-44

Chipa M.J., Siebrits F.K., Ratsaka M.M., Leew K-J., and Nkosi B.D. 2010. Growth performance of feedlot weaners cattle fed diet containing different levels of cold press soyabean oilcake. South African Journal of Animal Science, 40(5 suppl.1): 499-501

Chanjula P., Siriwathananukul Y., and Lawpetchara A. 2011. Effect of feeding rubber seed kernel and palm kernel cake in combination on nutrient utilization, rumen fermentation characteristics, and microbial populations in goats fed on *Briachiaria humidicola* hay-based diet. Asian-Australian Journal of Animal Science. 24(1): 73-81

Chen X.B and Gomes M.J. 1992 Estimation of microbial protein supply to sheep and cattle based on urinary excretion of purine derivatives and overview of the technical details. Int. Feed resources Unit, Rowett Research Institute. Aberdeen. UK. 1-19

Chimvuramahwe, J., Musara, J.P. Mujuru, L., Gadzirayi, C.T. and Nyakudya. I.W. 2011. Effect of Feeding Graded Levels of Adansonia Digitata (Baobab) Seed Cake on the Performance of Broilers. Journal of Animal and Plant Science 11 (3): 1442–49.

Chisoro, P., Nkukwana, T.T., Mupangwa, J.F. and Mabusela, T.P. (2018). Feed intake, growth performance and carcass traits of broilers fed diets with various inclusion levels of baobab seed oilcake. South African Journal of Animal Science, 48(02): 284-294.

DAAF, 2012. A profile of South African macadamia nuts market value chain. National Department of Agriculture, Forestry and Fisheries, Pretoria, Republic of South Africa

Dabiri N., and Thonney M.L. 2004. Source and level of supplemental protein for growing lambs. Journal of Animal Science, 86: E287-E292

Da Silva Elias A.K., Alves K.S., Veras R. M.L., Oliveira L.R.S., Mezzomo R., Cutrim D.O., and Gomes D.I. 2015. Carcass and non-carcass characteristics of sheep fed with acai seed meal-based diet. African Journal of Agricultural Research, 10(49): 4395-4399

De—souza E.A, Pimentel F.S, Machado C.M, Martins L.S, da-Silva W.S. Montere-Lomeli M. and Masuda C.A. The unfolded protein response has a protective role in yeast models of classic galactosemia, Disease Models and Mechanisms. 7 (1): 55-61

Drackley J.K, Clark A.K and Sahly T. 1985. Ration Digestibilities and Ruminal characteristics in steers fed sunflower seeds with additional calcium. Journal of dairy science. 68 (2): 356-367

Economides, S. 1998. The Nutritive Value of Sunflower Meal and Its Effect on Replacing Cereal Straw in the Diets of Lactating Ewes and Goats. Livestock Production Science 55 (1): 89–97. doi:10.1016/S0301-6226(98)00118-3.

Egounlety, and Aworh, O.C. 2003. Effect of soaking, dehulling, cooking and fermentation with Rhizopus oligosporus on the oligosaccharides, trypsin inhibitor, phytic acid and tannins of soybean (Glycine max Merr.), cowpea (Vigna unguiculata L. Walp) and groundbean (Macrotyloma geocarpa Harms). Journal of Food Engineering, 56, 249–254.

Egounlety, M., and Aworh, O.C. 2003. Effect of soaking, dehulling, cooking and fermentation with Rhizopus oligosporus on the oligosaccharides, trypsin inhibitor, phytic acid and tannins of soybean (*Glycine max Merr*.), cowpea (*Vigna unguiculata L. Walp*) and groundbean (*Macrotyloma geocarpa Harms*). *Journal of Food Engineering, 56*, 249–254.10.1016/S0260-8774(02)00262-5.

El-Khidir, I.A, Babiker, S.A and Shafie, S.A. 1998. Comparative Feedlot Performance and Carcass Characteristics of Sudanese Desert Sheep and Goats. Small Ruminant Research 30: 147–51. doi:10.1016/S0921-4488(98)00097-2.

Ezeagu, I.E. 2005. “Baobab (Adansonia Digitata L.) Seed Protein Utilization in Young Albino Rats I: Biochemical Ingredients and Perfomance Characteristics.” *Animal Research International* 2 (1): 240–45.

Fadel J.G. 1999. Quantitative analyses of selected plant by-product feed stuffs, a global perspective. *Animal Feed Science and Technology*, 79: 255-268

Food and Agriculture Organization. 2002. Food insecurity in the words. United Nations Viale Delle Terme di Carcalla, Italy

Flakemore A.R., Otto J.R., Suybeng B., Balogun R.O., Malau-Aduli B.S., Nichols P.D., and Malau-Aduli A.E.O. 2015. Performance and carcass characteristics of Australian purebred and crossbred lambs supplemented with rice bran. Journal of Animal Science and Technology, 57:36. DOI 10.1186/s40781-015-0069

Frutos, P., Hervás, G., Giráldez, F.J. and Mantecón. A.R. 2004. Review Tannins and Ruminant Nutrition Tannins : Structure and Chemical. Spanish Journal of Agricultural Research 2: 191–202. doi:10.5424/73.

Furlan A.C., Mantovani C., Murakami A.E., Moreira I., Scapinello C., and Martins E.N. 2001. Use of sunflower meal in broiler chickens feeding. Revista Bras. Zootec, 30(1): 158-164

Gadanya, A.M., Atiku, M.K. and Otaigbe, B.O.L. (2014).Proximate and elemental analysis of baobab (Adansoniadigitata) Seed international.Journal of Analytical Biochemistry Resource. 1(1): 1- 4.

Gao W., Chen A., Zhang B., Kong P., Liu C., and Zhao J. 2015. Rumen degradability and post-ruminal digestion of dry matter, nitrogen and Amino acids of three protein supplements. Asian Australas Journal of Animal Science, 28(4): 485-493

Gargallo S., Calsamiglia S., and Ferret A. 2006. Technical note: A modified three-step *in vitro* procedure to determine intestinal digestion of proteins. Journal of Animal Science, 84: 2163-2167

Gionbelli M.P., de Campos Valadares Filho S., Detmann E., Paulino L.V.R., Valadares R.F.D., Santos T.R., Costa e Silva L.F., and Magalhaes F.A. 2012. Intake, performance, digestibility, microbial efficiency and carcass characteristiucs of growing Nellore heifers fed two concentrate levels. Revista Brasileira de Zootecnia, 41(5): 1243-1252

Goering H.K and van Soet P.J. 1970. Forage fibre analyses (apparatus, reagents, procedures and some applicantions). Agric. ARS-USDA, Washington, DC; (Handbook NO: 379)

Gleghorn J.F., Elam N.A, Galyean M.L, Duff G.C, Cole N.A and Rivera J.D. (2004). Effects of crude protein concentration and degradability on performance, carcass characteristics, and serum urea nitrogen concentrations in finishing beef steers. Journal of Animal Science. 82, 2705-2717.

Gonzalez J., Andres S., Rodriguez C., and Alvir M. 2002. In situ evaluation of the protein value of Soyabean meal and processed full fat soyabeans for ruminants. Animal Research, EDP sciences, 51(6): 455-464

Habib G, Saleem M, Hameed A. 2013. Mineral composition of local tree leaves for feeding sheep and goats in Kohat district of Khyber Pakhtunkhwa. Sarhad J. Agric. 29 (1): 97-103 Kendall E.M, Ingalis, J.R, and Boila R.J. 1991. Variability in the rumen degradability and postruminal digestion of the dry matter, nitrogen and Amino acids of Canola meal. Canadian Journal of Animal Science. 739-754.

Habib G., Ali M., Bezabih M., and Khan N.A. 2013. In situ assessment of ruminal dry matter degradation kinetics and effective rumen degradability of feedstuffs originated from agro-industrial by-products. Pakistan veterinary journal, 33(4): 466-470

Haddad S.G., and Goussous S.N. 2004. Effect of yeast culture supplementation on nutrient intake, digestibility and growth performance of Awassi lambs. Animal Feed Science and Technology, 118: 343-348

Hango A., Mtenga L.A., Kifaro G.C., Safari J., Mushli D.E., and Muhikambele V. R.M. 2007. A study on growth performance and carcass characteristics of small east African goats under different feeding regimes. Livestock Research for Rural Development, 19(9).

Hanning P.H. 1999. The feeding program. Feedlot management handbook, ANPI, ARC, South Africa, 96

Hayirli, A., Grummer, R.R., Nordheim, E.V. and Crump, P.M. 2002. Animal and dietary factors affecting feed intake during the prefresh transition period in Holsteins. Journal of Dairy Science. 85:3430-3443.

Hess B W, Moss G E, Rule D C. 2008. A decade of developments in the area of fat supplementation research with beef cattle and sheep. Journal of Animal Science. **86**: E188-E204

Hippenstiel F., Kivitz A., Benninghoff J., and Südekum K-H. 2015. Estimation of intestinal protein digestibility of protein supplements for ruminants using a three-step enzymatic *in vitro* procedure. Archives of Animal Nutrition, 69(4): 310-318

Hussein H.S and Jordan H.M. 1991. Fish meal as a protein supplement in ruminant diets: a review Journal of Animal Science. 69, 2147-2156

Hogg B.W., Mercer G.J., and Mortimer B.J. 1992. Carcass and meat quality attributes of commercial goats in New Zealand. Small Ruminants Research, 8: 243-256

Horwitz, W. 2000. Official Methods of Analysis of AOAC International. 17th ed. Vols. 1 and 2. AOAC International, Gaithersburg, MD.

Hutagulung R. I., and Mahyuddin M.D. 1985. Nutritive values and feeding systems on palm kernel cake and palm press fibre for ruminants. *Procedings 3rd AAAP Animal Production*, 2: 983-985

Ibrahim I.S.E., and Mukhtar M.A. 2016. Effect of Watermelon seed cake in broiler chickens performance. World Journal of pharmacy and pharmaceutical sciences, 5(4): 360-365

Ilori, H.B., Salami, S.A., Majoka, M.A. and Okunlola D.O. 2013. Acceptability and nutrient digestibility of West African Dwarf goat fed different dietary inclusion of Baobab (Adansonia digitata). ISOR Journal of Agriculture and Veterinary Science. 6 (3) 22 – 26.

Irshaid, R.H., Harp, M.Y. and Titi, H.H. 2003. Replacing soybean meal with sunflower seed meal in the ration of Awassi ewes and lambs. Small Rumin. Res., 50: 109–116.

Ivan M, Mir P.S, Mir Z, Entz T, He ML and McAllister T.A. 2004. Effects of dietary sunflower seeds on rumen protozoa and growth of lambs. British Journal of Nutrition. 92 (2): 303-10

Jelan Z.A., Ishak Y., and Yaakub T. 1991. Feedlotting of cattle on palm kernel cake in small holder farming system. *Procedings 14th Annual Conference Malaysian Society of Animal Production*: 99-102

Johnson C.M and Ulrich A. 1959. Analytical methods for use in plant analysis-II. California Agricultural Experiment Station. Bull., 766.

Kabir S.M.L, Rahman M.M, Rahman M.B, Rahman M.M. and Ahmed S.U. 2004. The dynamics of probiotics on growth performance and immune response in broilers. International Journal of Poultry Science. 3: 361-364

Kashani, S.M.M., and Bahari, M. 2017. The effect of sex and weaning age on growth performance of first generation lambs derived from crossing ½Romanov and Zel. Journal of Animal Research Nutrition, 2(24):1-5

Kendall E. M., Ingalls J.R., and Boila R.J. 1991. Variability in the rumen degradability and postruminal digestion of dry matter, nitrogen and Amino acids of canola meal. Canadian Journal of Animal Science, 71: 739-754

Kandylis K, Nikokyris P.N and Deligiannis K. 1999. Performance of fattening lambs fed diets containing different proportions of cotton seed meal. Journal of the Science of food and Agriculture 79(12): 1613-1619

Khandaker Z.H., Uddin M.M., MST, Sultana N., and Peters K.J. 2012. Effect of supplementation of mustard oil cake on intake, digestibility and microbial protein sysnthesis of cattle in a straw-based diet in Bangladesh. Tropical Animal Health and Production. 44: 791–800

Khalid M.F., Sarwar M., Rehman A.U., Shahzad M.A., and Mukhtar N. 2012. Effect of dietary protein sources on lamb's performance: A review. Iranian Journal of Applied Animal Science, 2(2): 111-120

Khan A.G. Azim A., Nadeem M.A., and Khan M.A. 1997. Effect of growing fattening diets on the growth performance of intensified Afghani lambs. Small Ruminant Research, 25(1): 39-42

Koyuncu, M. (2008). Growth performance and carcass quality of fattening lambs of Kivircik and Karacabey Merino breeds. Livestock Research for Rural Development. 20 (12).

Leao A.G and Bezema L.R. 2016. Carcass traits and meat quality of crossbred Boer goats fed peanut cake as a substitute for soybean meal. Journal of Animal Science. (4 (7): 2992-3000

Lee Y.H., Ahmadi F., Choi D.Y., and Kwak W.S. 2016. *In situ* ruminal degradation characteristics of dry matter and crude protein from dried corn, high-protein corn, and wheat distillers grains. Journal of Animal Science and Technology, 58: 33. https://doi.org/10.1186/s40781-016-0115-3

Lee C., Hristov A.N., Cassidy T.W., Heyler K.S., Lapierre H., Varga G.A. 2012. Rumen-protected lysine, methionine, and histidine increase milk protein yield in dairy cows fed a metabolizable protein-deficient diet. Journal of Dairy Science, 95: 6042-6056

Leupp J.L., Lardy G.P., Soto-Navarro S.A., Bauer M.L., and Caton J.S. 2006. Effects of canola seed supplementation on intake, digestion, duodenal protein supply, and microbial efficiency in steers fed forage-based diets. Journal of Animal Science, 84: 499-507

Lamayi D.W., Yirankinyuki F.F., Abubakar U., and Ayim P. 2014. Nutritional evaluation of baobab seed. International Journal of Research in Agriculture and Food Science, 2(2): 44-48

Luginhuhl J.M., Poore M.H., and Conrad A.P. 2000. Effect of level of whole cottonseed on intake, digestibility, and performance of growing male goats fed hay-based diets. Journal of Animal Science, 78(6): 677-683

Lupton C.J., Huston J.E., Hruska J.W., Craddock B.F., and Pfeiffer F.A. 2008. Comparison of three systems for concurrent production of high quality mahair and meat from Angora male kids. Small Ruminant Research 74: 64-71

Macome F., Lopes R., Regina A. B., Leal G.A., Pires L.B., and Costa M.A.S. 2011. Productive performance and carcass characteristics of lambs fed diets containing different levels of palm kernel cake. Revista MVZ Cordoba, 16(3): 2659-2667

Madzimure, J., Musimurimwa, C., Chivandi, E., Gwiriri, L. and Mamhare, E. (2011). Milk yield and quality in Guernsey cows fed cottonseed cake-based diets partially substituted with Baobab (Adansonia digitata L.) seed cake. Tropical Animal Health and Production., 43: 77–82.

Mahgoub O., Khan A.J., Al-Maqbaly R.S., Al-Sabahi J.N., Annamali K., and Al-Sakry K. 1978. Fatty acid composition of muscle and fat issues on Omani Jebel Akhdar goats of different sexes and weights. Meat Science, 61: 381-387

Makker H.P.S., Blummel M. and Becker K. 1995. Formation of complexes between polyvinyl pyrrolidous or polyethylene glycols and tannins, and their implication in gas production and true digestibility in in-vitro techiniques. British Journal of Nutrition. 73(6): 897-913.

Mapiye C., Vahmani P., Aalhus J.L., Rolland D.C., Baron V.S., McAllister T.A., Block H.C., Uttaro B., and Dugan M.E.R. 2015. Fatty acid composition of beef steers as affected by diet and fat depot. South African Journal of Animal Science, 45(4): 386-3394

Marghazani I.B., Habib G., and Siddiqui M.M. 19999. Nitrogen retention and nutrients digestibility in sheep given a basal diet of sorghum hay supplemented with protein of varying degradabilities. Sarhad Journal of Agriculture, 15(5): 381-386

Maskal'ov'a I., Vajda V., Krempask'y M., and Bujnak L. 2014. Rumen degradability and ileal digestibility of proteins and Amino acids of feedstuffs for cows. Acta Vet.BRNO, 83: 225-231

Matiwos S., Melaku S. and Tolera, A. (2008). Supplementation of cottonseed meal on feed intake, digestibility, live weight and carcass parameters of Sidama goats. Livestock Science, 119: 137-144. 10.1016/j.livsci.2008.03.011.

McDonald, P., Edwards, R.A., Greenhalgh, J.F.D., Morgan, C.A., Sinclair, L.A., Wilkinson, R.G. 2011. Animal Nutrition (7th ed.), Prentice Hall/Pearson, Harlow, England

Mdziniso M.P., Dlamini A.M., Khumalo G.Z., and Mupangwa J.F. 2016. Effects of feeding Marula [Sclerocarya birrea (L.)] Seed cake on milk yield and composition for lactating dairy cows. British Journal of Applied Science and Technology, 18(1): 1-10.

Mekasha Y., Urge M., Kurtu M.Y., and Bayissa M. 2011. Effect of strategic supplementation with different proportion of agro-industrial by-products and grass hay on body weight change and carcass characteristics of tropical ogaden bulls (Bos indicus) grazing native pastures. African Journal of Agriculture Research, 6(4): 825-833

Merchen N.R, Darden D.E, Berger L.L, Fahey G.C, Jr, Titgemeyer E.C and Fernando R.L Effcets of dietary energy level and supplement protein source on performance of growing steers and nutrient digestibility and nitrogen balance in lambs. Journal of Animal Science. 65:658

Metcalfe L.D., Schmitz A.A and Pelka J.R. 1966. Rapid preparation of fatty acid esters from Gas Chromatographic Analisis. Analytical Chemistry, 38(3):514-515

Mhrez A.Z and Orskov E.R. 1977. A study of the artificial fibre determining the digestibility of feeds in the rumen. Journal of Agricultural Sciences Cambridge. 88 (1): 648-50

Mioc, B., Pavic, V. Vnuecec, I. Prpic, Z. Kostelik, A. and Subic, V. 2007. Effect of olive cake on daily gain, carcass characteristics and chemical composition of lamb meat. Czech Journal of Animal Science, 52: 31–36

Mishra S., and Rai S. N. 1996. Effects of different RDP and UDP ratios on voluntary intake, milk production and feed conversion efficiency in lactating goats. Small Ruminant Research, 20: 31-38

Mirza I.H., Anjum M.H., Khan A.G., and Azim A. 2004. Comparative evaluation of Cotton seed meal and Sunflower seed meal in urea molasses blocks versus commercial concentrate as supplement to basal ration of wheat straw with stall-fed buffalo calves. Asian-Australian Journal of Animal Science, 17(2): 193-198

Mjoun K, Kalscheur K.F, Hippen A.R. and Schingoethe D.J. 2010. Ruminal degradability and intestinal digestibility of the protein and Amino acids in soybean and corn distillers grain products. Journal of Dairy Science. 93(9) : 4144 – 4154

Mlambo V, Dlamini B J, Ngwenya M D, Mhazo N, Beyene S T and Sikosana J L N 2011: In sacco and *in vivo* evaluation of marula (Sclerocarya birrea) seed cake as a protein source in commercial cattle fattening diets. Livestock Research for Rural Development. Volume 23, Article #121. Retrieved December 8, 2016, from http://www.lrrd.org/lrrd23/5/mlam23121.htm

Mshigeni K.E and Haugula L. (2001). Africa's Baobab resources- unlocking their economic potential- University of Namibia

Mthiyane D.M., and Mhlanga B.S. 2017. The nutritive value of Marula (Sclerocarya birrea) seed cake for broiler chickens: nutritional composition, performance, carcass characteristics and oxidative and mycotoxin status. Tropical Animal Health and Production, 49: 835-842

Mustafa A.B and Alamin A.A.M. 2012. Chemical composition and protein degradability of watermelon (citrullus larcatus) seeds cake grown in Western Sudan. Asian Journal of Animal Sciences. 6(1): 33-37

Mwale, M., Mupangwa, J.F., Mapiye, C., Saina, H. and Chimvuramahwe, K. 2008. Growth Performance of Guinea Fowl Keets Fed Graded Levels of Baobab Seed Cake Diets. International Journal of Poultry Science 7 (5): 429–32. doi:10.3923/ijps.2008.429.432.

Nagalakshmi D, Sastry V.R.B., Kesava Rao V. 2002. Influence of feeding processed cotton seed meal on meat and wool production of lambs. Asian-Australian Journal of Animal Science. 15(1): 26-33

Nagalakshmi, D, Dhanalakshmi, K. and Himabindu, D. 2011. Replacement of groundnut cake with sunflower and karanj seed cakes on performance, nutrient utilization, immune response and carcass characteristics in Nellore lambs. Small Ruminant Research, 97: 12-20.

Nang THU T.T., Bondin N., De Saegar S. Laroundelle Y and Rollin X. Substituion of fish meal by sesame oilcake (sesamum ludicum L.) in the diet of rainbow trout (onchorychus mykiss W.). Aquaculture Nutrition research. 17: 80-89

National Research Council. 2001. Nutrient Requirements of Dairy cattle. 7th Ed. National Research Council National Academy Press. Washington, DC., USA

NRC. Nutrient Requirements of Swine. 11th rev ed. Natl Acad. Press; Washington, DC, USA: 2012.

Narahari D., and Kothandaraman P. 1984. Chemical composition and nutritional value of para-rubber seed and its products for chickens. Animal Feed Science and Technology, 10:257

Ndemanisho E E, Kimoro B N, Mtengeti E J and Muhikambele V R M 2007**:** *In vivo* digestibility and performance of growing goats fed maize stover supplemented with browse leaf meals and cotton seed cake based concentrates. Livestock Research for Rural Development. Volume 19, Article #105. Retrieved October 20, 2017, from http://www.lrrd.org/lrrd19/8/ndem19105.htm

Nelson A.B and Watkins W.E. 1967. Influence of internal of feeding cotton seed meal to sheep on ration digestibility, nitrogen balance and blood constituents. Journal of Animal Nutrition. 26, 1175-1178

Nia Moshtaghi S.A and Ingalls J.R. 1995. Evaluation of moist heat treatment of canola meal and digestion in the rumen, small intestine, large intestine and total digestive tract of steers. Canadian Journal of Animal Science 279-280

Ngongoni N.T., Mapiye C., Mwale M., Mupeta B., and Chimonyo M. 2007. Potential of farm-produced crop residues as protein sources for small-medium yielding dairy cows. African Journal of Agricultural Research, 2(7): 309-317

Nkafamiya, I.I., Aliyu, B.A., Manji, A.J., Modibbo, U.U. 2007c. Degradation properties of wild Adansonia digitata and Prosopsis africana oils on storage. African Journal of Biotechnology, 6(6): 751-755.

Nkafamiya, I.I., Aliyu, B.A., Manji, A.J., Modibbo, U.U. 2007d. Evaluation of deterioration of traditionally produced groundnut oil on storage. J. Chem. Soc. Nigeria, 32(1): 137-142.

Nkafamiya, II, Osemeahon, SA, Dahiru, D, Umaru, HA. 2007. Studies on the chemical composition and physicochemical properties of the seeds of Baobab (Adasonia digitata) African Journal of Biotechnology. 6 (6):756–759.

Nkosi, B.D., Kanengoni A.T. and Thomas, R. 2011. Effects of Ensiling Total Mixed Potato Hash Ration with or without Bacterial Inoculation on Silage Fermentation and Nutritive Value for Growing Pigs. Journal of Animal and Veterinary Advances Volume: 10 (13): 1667-1672

Noula F.S. 2004. The comparison of plant cell wall degrading in the rumen. Unpublished P.H.D Thesis, University of Hohoheim Institute, 480

Nsahlai I.V., Green H., Bradford M., and Bonsai M.L. 2002. The influence of source and levels of protein, and implantation with zeranol on sheep growth. Livestock Production Science, 7(1): 103-112

NRC. 2001. Nutrient requirements of dairy cattle. 17th revised edition. National Research Council National Academy Press, Washington, DC., USA

NRC, 1985. Nutrient requirements of sheep. 6th revised Edn. National Academy press; Washington, DC., USA

Ørskov E.R. 1987. Feeding of ruminants. Principles and practice, p92.Chalcombe publishers, Marlow, Uk: ISBN:0948617098

Orskov E.R., and McDonald I. 1979. The estimation of protein degradability in the rumen from incubation measurements weighted according to rate of passage. Journal of Agriculture Science, 92: 499-503

Obeidat, B.S., Abdullah, A.Y., Mahmoud, K.Z., Awawdeh, M., Al-beitawi, N., Al-Lataifeh, F. 2009. Effects of feeding sesame meal on growth performance, nutrient digestibility and carcass characteristics of Awassi lambs. Small Ruminant Research, 82:13-17.

Okonkwo S.I., and Okafor, E.C. 2016. Determination of the proximate composition, physicochemical analysis and characterization of fatty acid on the seed and oil of *Gossypium hirsutum.* International Journal of Chemistry, 8(3): 57-61

Omar J.M.A. 2002. Effect of feeding different levels of sesame oil cake on performance and digestibility of Awassi lamb. Small Ruminant Research, 46: 187-190

Oladunjoye, I.O., Akinlade, M. and Lawal, M. 2014. Perfomance, Digestibility, Carcass and Blood Profile of Grower Rabbits Fed Baobab (Adansonia Digitata) Pulp and Seed Meal. Indian Journal of Fundamental and Applied Life Sciences, 4 (2): 234–40.

Oliveira RL, Leão AG, Ribeiro OL, Borja MS, Pinheiro AA, Oliveira RL, Santana MCA. 2012. Biodiesel by-products used for ruminant feed. *Revista Colombiana de Ciencias Pecuarias* 25: 627–640.

Orsavova J., Misurcova L., Ambrozova J.V., Vicha R., and Mlcek J. 2015. Fatty Acids Composition of Vegetable Oils and Its Contribution to Dietary Energy Intake and Dependence of Cardiovascular Mortality on Dietary Intake of Fatty Acids. International Journal of Molecular Sciences, 16:12871-12890

Osman M. 2004. Chemical and Nutrient analysis of Baobab (Adansonia digitata) fruit and seed protein solubility. Plant Foods for Human Nutrition. 59: 29-33

Oyewusi P. A., Akintayo E. T., and Olaofe O. 2007.The proximate and Amino acid composition of defatted rubber seed meal. Journal of Food, Agriculture and envoronment. 5, 115–118.

Palmquist, D.L., and Jenkins, T.C. 1980. Fat in lactation rations: review. Journal of Dairy Science, 63:1-14

Phosa, M.A. 2009. The nutritive value of Macadamia oil cake meal and wood ash as alternative feed ingredients for chickens in rural areas. M.Inst. Agrar. thesis, University of Pretoria, South Africa.

Ponnampalam E.N, Egan A.R, Sinclair A.J and Leury B.J. 2005. Feed intake, growth, plasma glucose and urea, nitrogen concentration, and carcass traits of lambs fed isoenergetic amounts of canola meal, soybean meal and fish meal with forage based diet. Small Ruminants Research. 58, 245-252

Promkot C., and Wanapat M. 2003. Ruminal degradation and intestinal digestion of crude protein of tropical protein resources using nylon bag technique and three-step *in vitro* procedure in dairy cattle. *Livestock Research for Rural Development.* 15, #81. Retrieved October 20, 2017, from http://www.lrrd.org/lrrd15/11/prom1511.htm

Plaisance R., Petit H.V., Seoane J.R., and Rioux R. 1997. The nutritive value of canola, heat-treated canola and fish meals as protein supplements for lambs fed grass silage. Animal Feed Science and Technology, 68: 139-152

Rajan A., Sreekumaran T., Mammel J.A., and Vijayakumar V. 1990. An assessment of the goitrogenic effect of rubber seed cake. Indian Journal of Animal Science, 60: 995-997

Ravindran, V., Abdollahi, M.R., and Bootwalla, S.M. (2014). Nutrient analysis, metabolizable energy, and digestible Amino acids of soyabean meals of different origins for broilers. Poultry Science, 93:2567 - 2577

Richardson C.R, Beville R.N, Ratcliff R.K. and Albin R.C. 1981. Sunflower meal as a protein supplement for growing ruminants. Journal of Animal Science. 53: 557-563.

Rizzi L., Held E.V., Bertelli G, Nasi E., Saviance F., and Valenari A. 2002. In Lejeune T., Fermandes J., eds, ASP Conf. Ser. 274: Observed Hr Digrams and Stellar Evolution. 490

Rizzi, L., Simioli, M., Sardi, L. and Monetti, P.G. 2001. Carcass quality, meat chemical and fatty acid composition of lambs fed diets containing extruded soybeans and sunflower seeds. Animal Feed Science and Tecnology, 97:103-114.

Rosa P.M., Antoniassi R., Freitas S.C., Bizzo H.R., Zanotto D.L., Oliveira M.F., and Castiglioni V. B. R. 2009. Chemical composition of Brazilian sunflower varieties. *Helia,* 32 (50): 145-156

Robertson J.B and Van Saest P.J. 1981. The detergent system of analysis and its application to human foods. In: W.P.T. James. O. Theander (Eds). The analysis of dietary fiber in foods. Marcel Dekker, New York, NY. 123

Sapa. 2016. Feed ingredient report. Feed ingredient report using December 2016 as base with an outlook to July 2017 – executive summary. South African poultry association. https://www.sapoultry.co.za/pdf-statistics/feed-ingredient-report.pdf

Santos-Silva, J. Bessa, R.J.B. and Mendes, I.A. 2003. The effect of supplementation with expanded sunflower seed on carcass and meat quality of lambs raised on pasture. Meat Science, 65, pp. 1301–1308

Saulawa, L.A., Yaradua, A.I. and Shuabu, L. 2014. Effect of Different Processing Methods on Proximate, Mineral and Anti nutritional factors content of Boabab (Adansonia Digitata) seed. Pakistan Journal of Nutrition, 13: 314-318.

Satwar, M.M., Khan A. and Zafar I. 2002. Feed resources for livestock in Pakistan. International Journal of Agriculture and Biology. 1:186-194

Schwab C.J., Huhtanen P., Huht C.W., and Hvelplund T. 2005. Nitrogen requirements of cattle. 13-70. In Pfeffer, E., and A.N. Hristov (eds.) Nitrogen and phosphorus nutrition of cattle. CAB international, Wallingford, UK

Sen, U., Sirin, E., Ulutas, Z., Kuran, M. 2011. Fattening performance, slaughter, carcass and meat quality traits of Karayaka lambs. Tropical Animal Health and Production, 43(2):409-416.

Sherrod, L.B. and Ishizaki, S.M. 1966. Effect of supplemental protein levels upon the utilization of Kikuyu and Pangola grass nutrients. Proceedings of Western Section of American Society of Animal Science. 18:273.

Sherrod, L.B. and Ishizaki, S.M. 1967. Further studies on levels of feed-grain macadamia nuts in concentrate rations for sheep. Journal of Animal Science, 26:862-866

Shirima, E.J.M, Louis, A.M., Kimambo, A.E. Laswai, G.H., Mgheni, D.M., Mushi, D.E., Shija, D.S. and Safari, J.G. 2014. Influence of Age at Entry and Level of Concentrate Feeding on Growth and Carcass Characteristics of Feedlot-Finished Tanzanian Long-Fat-Tailed Sheep. Tropical Animal Health and Production 46 (5): 815–22. doi:10.1007/s11250-014-0570-0.

Sindhu A.A., Khan M.A., Mahr-Un-Nisa and Sarwar M. 2002. Agro-Industrial by-products as a potential source of livestock feed: a Review. International Journal of Agriculture and Biology, 4(2): 307-310

Sidibe M., and Williams J.T. 2002. Baobab (Adansonia digitata). International centre for underutilized crops, Southhampton, UK

Silva T.M., Medeiros A.N. de., Oliveira R.L., Gonzaga Neto S., Ribeiro M.D., Bagaldo A.R., Ribeiro O.L. 2015. Peanut cake as a substitute for soybean in the diet of goats. Journal of Animal Science 93(6): 2998-3005

Skenjana, A. 2011. The potential nutritive value of waste products from the sub-tropical fruit processing industry as livestock feed. MSc Agric. Thesis, University of Pretoria, South Africa.

Skenjana A., van Ryssen J.B.J., Acheampong-Boateng O., Roets M., Dombo A., and Nkosi D.B. 2002. Nutrient composistion of waste products from the tropical fruit industry. (GSSA/SASAS joint congress, 13-16 May 2002, Christiana Aventura), 165

Skenjana, A., Van Ryssen, J.B.J. and Van Niekerk, W.A. 2006. *In vitro* digestibility and in situ degradability of avocado meal and Macadamia waste products in sheep. South African Journal of Animal Science. 36 (Suppl.1), 78-81.

Sola-Ojo, F.E., Adeyemi, K.D., Toye, A.A., Bolu, S.A., Fayeye, T.R., Annongu, A.A. Garba, S.O. and Karim, R.O. 2013. "Performance, Carcass Profile and Oxidative Stability of Broiler Chickens Fed Processed Baobab Seed Meal." *Bulletin of Environment, Pharmacology and Life Sciences* 2 (10): 94–99.

Sola-Ojo, F.E., Bolu, S.A.O. and Usman, T.O. 2011. Performance evaluation of layers fed Baobab (Adansonia digitata) seed meal based diet. Journal of Applied Agricultural Research, 3: 113-122.

Sola-Ojo, F.E., Toye, A.A., Bolu, S.A.O., V.Ojo, Okukpe, K.M., Alli, I.O., Adeyemi, K.D. and Garba, S.O. 2013. Effect of Baobab (Adansonia digitata) seed meal on growth and Morphometric Traits in Broiler Chickens. Nigerian Society for Experimental Biology Journal, 13 (1and2), 29-32.

Solomon M, Melaku S, Tolera A. 2008. Supplementation of cottonseed meal on feed intake, digestibility, live weight and carcass parameters of Sidama goats. Livestock Science. 119 (1-3): 137-144

Spackman D.H., Stan W.H and Moore S. 1993. Automatic recording apparatus for use in the Chromatography of Amino Acids. Analyt. Chem. 30:1190

Stein H.H., Casas G.A., Abelilla J.J., Liu Y., and Sulabo R.C. 2015. Nutritional value of high fibre co-products from the copra, palm kernel, and rice industries in diets fed to pigs. Journal of Animal Science and Biotechnology, 6(56): 1-9

Stringhini J.H., Café M.B., Fernandes C.M., Andrade M.L., Rocha P.T., and Leandro N.S.M. 2000. Evaluation of the nutritional value of sunflower meal for poultry. Ciencia Animal Brasileira, 1(2): 123-126

Stroebel A., Swanepoel F.J.C and Pell A.N. 2011. Sustainable smallholder livestock systems: A case study of Limpopo Province, South Africa. Livestock Science. 139: 186-190

Stroebel, A. 2004. Socio-economic complexities of small-holder resource-poor ruminant livestock production systems in sub-Saharan Africa. Unpublished PhD Thesis. University of the Free State, Bloemfontein, South Africa.

Suliman G.M and Babiker. 2007. Effect of diet protein source on lamb fattening. Research Journal of Agriculture and Biological Sciences 3: 403-408

Swansen K.C., Caton J.S., Redmer D.A., Burke V.I., and Reynolds L.P. 2000. Influence of undegraded intake protein on intake, digestion, serum hormones and metabolites and nitrogen lalance in sheep. Small Ruminants Research, 35(3): 225-233

Thirumalaisamy G., Purushothaman M.R., Kumar P.V. and Selvaraj P. 2016. Effect of feeding Cotton seed meal on some hematological and serum biochemical parameters in broiler birds. Veterinary world, 9(7): 723-727

Titi H.H., 2003. Replacing soybean meal with sunflower meal with or without fibrolytic enzymes in fattening diets of goat kids. Small Ruminant research. 48 (1): 45-50

Tiwari U.P., and Jha R. 2017. Nutrient, Amino acids, fatty acid and non-starch polysaccharide profile and *in vitro* digestibility of macadamia nut cake in swine. Animal Science Journal, 88: 1093-1099

Todare M, Comao A, Carmela M.A Barone and Giaccone P. 2006. Use of weaning concentrate inn the feeding of suckling kids: Effects on meat quality. Small Ruminant Research. 66 (1-3) : 44-50.

Turki I.Y., Elkadier O.A., Amin M., Zuber D., and Hassabo A.A. 2011. Effect of guar meal and oil cakes on carcass characteristics and meat quality attributes of beef cattle. Biological Research Communication, 1: 66-75

Tripathi M.K., Raghuvansi S.K.S., Mondal D., and Karim S.A. 2014. Effect of Bt-cotton seed meal feeding on performance, fermentation, ciliates population and microbial hydrolytic enzymes in lamb. African Journal Biotechnology, 13(3): 509-522

Udo I.U and Umoren. 2011. Nutritional evaluation of some locally available ingredients use for least cost Ration formulation for African Catfish (Clarias gariepinus) in Nigeria. Asian Journal of Agricultural Research. 5(3): 164-175

Udo M.D., Ekpo U., and Ahamefule F.O. 2016. Effects of processing on the nutrient composition of Rubber seed meal. Journal of the Saudi society of Agricultural sciences, http://dx.doi.org/10.1016/j.jssas.2016.06.001

Ustuner H., Dikmen S., and Turkmen I.I. 2012. Effect of feed processing on the fattening performance and carcass traits of Awassi ram lambs. Asian Journal of Animal and Veterinary Advances. DOI:10.3923/ajava.2012

van der Walt K.E., Einkamer O.B., van der Merwe H.J, Hugo A., Slippers S.C and Fair M.B. 2014. The effect of dietary saturation and antioxidant type on the performance of finishing lambs. South African Journal of Animal Science, 44(5): 536-540

Vahmani P., Mayiye C., Prieto N., Rolland D.C., McAllister T.A., Aalhus J.L., and Dugan M.E.R 2015. The scope for manipulating the polyunsaturated fatty acid content of beef: A review. Journal of Animal Science and Biotechnology, 6:29

Van der Westhuizen E.J., Brand T.S., Hoffman L.C., and Aucamp B.B. 2010. The effect of age and gender on the fat distribution in Merino lambs. South African Journal of Animal Science, 40 (5;1): 459-461

van Ryssen J.B.J., Phosa, M.A. and van Rensburg, C.J. 2014. Different Levels of Macadamia Oil Cake Meal, and Wood Ash vs. Feed Lime as Dietary Sources of Calcium on Bone Characteristics of Slow-Growing Chickens. South African Journal of Animal Science 44 (1): 71-79

Venter, S.M., Witkowski, Ed T.F. 2013. Fruits of our labour: Contribution of commercial Baobab (Adansonia digitata L.) fruit harvesting to the livelihoods of marginalized people in northern Venda, South Africa. Agroforestry Systems, 87, pp.159–172.

Villamide M.J., and San Juan L.D. 1998. Effect of chemical composition of sunflower seed meal on its true metabolizable energy and Amino acids digestibility. Poultry Science, 77: 1884-1892

Waghorn, G. 2008. Beneficial and detrimental effects of dietary condensed tannins for sustainable sheep and goat production-Progress and challenges. Animal Feed Science and Technology, 147: 116–139.

Waller J, Klopfestein T and Poos M. 1980. Distillers feeds as protein sources for growing ruminants. Journal of Animal Science, 51, 1134-1167

Walz L.s., White T.W., Fernandez J.M., Gentry L.R., Blouin D.C., Freotschel M.A., Brown T.F., Lupton C.J., and Chapa A.M. 1998. Effect of fish meal and sodium bentonite on daily gain, wool growth, carcass characteristics and ruminal and blood characteristics of lamb fed concentrate diets. Journal of Animal Science, 76: 2025-2031

Wright C., von Keyserlingk M., Swift M., Fisher L., Shelford J., and Dinn N. 2005. Heat and lignosulfonate-treated canola meal as a source of ruminal undegradable protein for lactating dairy cows. Journal of Dairy Science, 88:238-243

Yagoub M.Y and Talha E.E.A, 2009. Effect of replacement of groundnut cake with decorticated sunflower cake on the performance of Sudanese Desert Lambs. Pakistan Journal of Nutrition. 8(1): 46-48

APPENDICES

Appendix 1: Two-sample T-Test for chemical composition (g kg^{-1} DM) of BSC and MOC

Source	df	Moisture	Ash	Fat	GE	CP	CF	NDF	ADF	ADL	C	HC	NFE
T-Value	10	-0.83	13.83**	0.08	-1.86	2.51	-9.83**	-5.54**	-4.96**	21.87**	1503.5**	0.46	215.22**
P-value	10	0.43	0.00	0.93	0.14	0.03	0.00	0.00	0.00	0.00	25.0	10.56	1.85

**: *P* <0.01; *: *P* <0.05. df: Degree of Freedom, CP: Crude Protein, NPN: Non Protein Nitrogen,NDF: Neutral Detergent Fibre, ADF: Acid Detergent Fibre, ADL: Acid Detergent Lignin, C: Cellulose, HC: Hemicellulose and NFE: Nitrogen Free Extracts

Appendix 2: Two-sample T-Test for macro- (g kg^{-1}) and micro- (mg kg^{-1}) minerals of BSC and MOC

Source	Df	Ca	Mg	K	Na	P	Zn	Cu	Mn	Fe
T-value	10	5.24**	7.97**	10.90**	0.37	4.51**	2.76*	8.37**	-5.12**	-2.71*
P-value	10	0.00	0.00	0.00	0.72	0.00	0.02	0.00	0.00	0.02

**: *P* <0.01; *: *P* <0.05. df: Degree of Freedom, Ca: Calcium, Mg: Magnesium, K: Potassium, Na: Sodium, P: Phosphorus, Zn: Zinc, Cu: Copper, Mn: Manganese and Fe: Iron.

Appendix 3: Two-sample T-Test for essential Amino acids of BSC and MOC

Source	df	Trp	Arg	Thr	Met	Val	Phe	IsoL	Leu	His	Lys
T-value	4	30.74**	7.89**	2.21	0.00**	12.01**	11.02**	5.88**	5.44**	0.77	2.29
P-value	4	0.00	0.00	0.09	1.00	0.00	0.00	0.00	0.01	0.48	0.08

**: P<0.01; *: P<0.05. df: Degree of Freedom, (Trp) Tryptophan (Arg) Arginine, (Thr) Threonine, (Met) Methionine, (Val) Valine, (Phe) Phenylalanine, (IsoL) Isoleucine, (Leu) Leucine, (His) Histidine and (Lys) Lysine

Appendix 4: Two-sample T-Test for non-essential Amino acids of BSC and MOC

Source	Df	Cys	Ser	Asp	Glu	Gly	Ala	Tyr	Pro
T-value	4	15.24**	1.17	3.10*	8.81**	-1.47	2.05	-1.55	1.22
P-value	4	0.00	0.30	0.04	0.00	0.22	0.11	0.20	0.29

**: P<0.01; *: P<0.05. df: Degree of Freedom, (Cys) Cysteine, (Ser) Serine, (Asp) Aspartic Acid, (Glu) Glutamic Acid, (Gly) Glycine, (Ala) Alanine, (Tyr) Tyrosine, (Pro) Proline, (HOP) HO Proline and (Met) Methionine.

Appendix 5: Two-sample T-Test for fatty acids profile of BSC and MOC

Sample	df	C12:0	C14:0	C15:0	C16:0	C16:1	C18:0	C18:1n9t	C18:1n9c	C18:2n6t	C18:2n6c	C18:3n6	C18:3n3
T-value	4	0.0000735**	0.0079935**	0.63	19.83**	-441.4**	-61.75**	0.0001215**	-2236.95**	0.0000000	917.12**	0.0000135**	1-13.93**
P-value	4	0.0000020	0.0000080	0.56	0.00	0.0000	0.000	0.0000020	0.000	0.00000	0.0000	0.0000005	0.0000065

**: P<0.01; *: P<0.05. df: Degree of Freedom

Appendix 6: Two-sample T-Test for fatty acids profile of BSC and MOC for fatty acids profile of BSC and MOC

Sample	df	C20:0	C20:1	C20:2	C21:0	C22:0	C22:1n9	C24:0	C17:0	C17:1	C20:4n6	C23:0
T-value	4	14.37**	15.80**	0.0000002	1.22	-14.60**	0.0013500**	17.98**	0.34	9.30**	0.71	0.0000000
P-value	4	0.000	0.000	0.0000002	0.29	0.0000	0.0000020	0.000	0.751	0.001	0.52	1.00000

**: P<0.01; *: P<0.05. df: Degree of Freedom

Appendix 7: Two-sample T-Test for fatty acids of BSC and MOC

Sample	df	SFA	MONO-UFA	POLY-UFA	TRANS FA	CIS FA
T-value	4	-20.64*	-21.37**	17.26**	-13.00**	-14.02**
P-value	4	0.000	0.000	0.000	0.000000	0.000

**: P<0.01; *: P<0.05. df: Degree of Freedom, (FA) Fatty Acid, (SFA) Saturated Fatty Acid (MONO-UFA) MONO-Unsaturated Fatty Acid and (POLY_UFA) POLY-Unsaturated Fatty Acid.

Appendix 8: Analysis of variance for growth performance (g kg^{-1} DM) of SA Mutton Merino sheep

Source	df	IBW	FBW	WG	ADG	FC	FCR
Diet (D)	1	0.0616	7.724	9.165	0.0015458	0.01600	1.2370
Level (L)	1	0.0099	5.914	5.441	0.0009177	0.01223	0.4866
D x L	3	0.7579	30.897*	21.303	0.0035930	0.15684*	0.2750
Error	16	0.7579	6.509	5.601	0.0009446	0.02523	0.6170

**: *P* <0.01; *: *P* <0.05. df: Degree of Freedom, IBW: initial body weight, FBW: final body weights, WG: weight gain, ADG: average daily gain, FC: feed consumed and FCR: feed conversion ratio.

Appendix 9: Analysis of variance for carcass characteristics (g kg^{-1} DM) of SA Mutton Merino sheep

Source	Df	DP	WC	CC	CL	NW	REA
Diet (D)	1	17.094*	0.295	0.090	23.414	0.04030	0.278
Level (L)	1	0.365	0.776	0.550	5.699	0.00063	0.714
D x L	3	3.023	11.983*	11.983*	1.863	0.03622	1.713
Error	16	2.714	1.653	1.681	6.411	0.01992	1.718

**: *P* <0.01; *: *P* <0.05. df: Degree of Freedom, DP: Dressing Percentage, WC: Warm Carcass, CC: Chilled Carcass, NW: Neck Weight and REA: Rib-Eye Area.

Appendix 10: Analysis of variance for carcass characteristics (g kg^{-1} DM) of SA Mutton Merino sheep

Source	df	S	R+I	Li	Sp	Lu	Tr	H	He	T	FT	BWT
Diet (D)	1	0.7414	0.2716	0.008567	0.026016**	0.000551	0.005286*	0.010554	0.0025375	0.0001139	0.214	5.94
Level (L)	1	0.8938	0.0035	0.000346	0.000252	0.001726	0.000045	0.003314	0.0005099	0.0000001	5.309*	3.51
D x L	3	1.4128*	0.8540	0.020643	0.000025	0.002731	0.001479	0.001313	0.0000272	0.0003104	0.216	8.73
Error	16	0.2473	0.4002	0.005426	0.001974	0.001946	0.001136	0.004282	0.0006292	0.0005527	1.108	14.79

**: *P* <0.01; *: *P* <0.05. df: Degree of Freedom, S: Skin, R+I: Rumen + Intestine, Li: Liver, Sp: Spleen, Lu: Lungs, Tr: Troters, H: Head, He: Heart, T: Trachea, FT: Fat Thickness and BWT: Body Weight Thickness.

Appendix 11: Analysis of variance for DM and CP ruminal degradability of BSC and MOC

Component	Source	df	0	2	4	8	12	16	24	36	48	72
DM	Animal	2	1.416	23.45	1.736	42.233	27.023	61.180	67.591	79.91	41.27	32.069
	Sample	1	53.789	37.88	14.12	0.878	5.780	5.073	15.402	52.87	11.68	6.390
	Error	2	3.642	23.73	4.190	3.605	8.968	5.757	3.188	62.29	31.89	0.413
CP	Animal	2	0.008267	0.3314	0.2437	0.1850	0.1094	0.07167	0.0104	0.1153	0.1811	0.0083
	Sample	1	0.086400**	13.1424**	17.8538**	16.5336**	11.2614**	0.40560*	3.0246**	7.1941**	7.6614**	8.4966**
	Error	2	0.004133	0.166	0.122	0.093	0.055	0.03583	0.0052	0.0576	0.0905	0.0041

Appendix 12: Analysis of variance for DM and CP ruminal degradability of BSC and MOC

Component	Source	df	a	b	c	a+b	0.02	0.05	0.08
DM	Animal	2	1.447	36.67	0.0001024	29.715	17.206	8.650	5.275
	Sample	1	54.000	17.00	0.0001623	10.402	54.120	61.825	65.935
	Error	2	3.660	11.43	0.0000311	4.702	5.351	5.882	6.108
CP	Animal	2	0.27*	3.155	0.0000002	5.23	0.85*	0.64*	0.54*
	Sample	1	878.46**	0.427	0.0000001	840.17	2764.91**	2088.80**	1763.36**
	Error	2	0.01	4.952	0.0000002	5.23	0.02	0.02	0.01

Appendix 13: Analysis of variance for ruminal degradability of essential Amino acids of BSC and MOC

Amino acids	Source	df	Incubation hours				
			0	12	16	24	48
Arginine	Animal	2	2.57	1.09	2.02	7.50	2.11
	Sample	1	852.40*	2019.75**	803.49	587.55*	681.58**
	Error	2	16.26	9.50	8.80	18.58	5.37
Threonine	Animal	2	40.95	10.237	8.292	255.93	10.24
	Sample	1	295.14**	191.949**	18.052**	459.18	1231.89
	Error	2	0.73	0.364	0.147	4.55	0.18
Methionine	Animal	2	71.55	24.2	13.1	1714.2	246.91
	Sample	1	12.99	2.1	229.6	371.7	0.0
	Error	2	55.57	116.8	111.0	510.5	123.5
Valine	Animal	2	30.008	7.502	6.08	187.55	7.50
	Sample	1	34.268*	137.072**	514.18**	1085.51**	1834.14**
	Error	2	1.579	0.395	0.32	9.87	0.39
Phenylalanine	Animal	2	18.752	9.36	7.58	233.95	9.36
	Sample	1	106.070	338.91	382.45**	1045.84*	959.37
	Error	2	9.871	0.44	0.36	10.97	0.44
Isoleucine	Animal	2	54.253*	13.5634*	10.986	339.08*	13.56*
	Sample	1	14.648	1.6276	104.167	937.50*	937.50**
	Error	2	2.170	0.5425	0.439	13.56	0.54
Histidine	Animal	2	7.411	9.062	7.656	236.29	9.452
	Sample	1	0.195	30.678**	63.800	28.36	63.800
	Error	2	6.884	0.004	3.828	118.1	4.726
Leucine	Animal	2	17.344	4.336	3.51	108.40	4.34
	Sample	1	18.467*	40.568**	4.88.44**	999.59	961.14**
	Error	2	0.636	0.159	0.13	3.97	0.16
Lysine	Animal	2	17.344	4.336	3.51	108.40	4.34
	Sample	1	18.467	40.568	488.44	999.59	961.14
	Error	2	0.636	0.159	0.13	3.97	0.16

Appendix 14: Analysis of variance for ruminal degradability of non-essential Amino acids of BSC and MOC

Amino acids	Source	df	Incubation hours				
			0	12	16	24	48
Serine	Animal	2	37.36	24.394	86.77	72.66	62.71
	Sample	1	154.59	53.761	352.51*	502.37^	650.88**
	Error	2	15.22	5.734	4.97	16.79	6.84
Aspartic acid	Animal	2	15.71	11.40	5.24	29.71	10.6
	Sample	1	403.71*	465.98**	524.00**	1277.73**	4494.3**
	Error	2	4.44	1.92	1.38	0.56	1.1
Glutamic acid	Animal	2	0.24	0.061	0.05	1.53	0.06
	Sample	1	921.97**	290.185**	1516.38**	1023.48**	1528.08**
	Error	2	2.29	0.571	0.46	14.28	0.57
Glycine	Animal	2	10.757	2.714	2.198	67.840	2.71
	Sample	1	12.404*	188.823	33.505**	91.705*	1408.83*
	Error	2	0.155	0.036	0.029	0.896	0.04
Alanine	Animal	2	31.038	7.7594	7.259	224.03	8.96
	Sample	1	18.216*	9.9518*	210.770**	199.82**	624.85**
	Error	2	0.735	0.1837	0.039	1.22	0.05
Tyrosine	Animal	2	40.500	10.125	8.20	253.13	10.13
	Sample	1	73.500**	18.375**	294.00**	253.50*	337.50**
	Error	2	0.500	0.125	0.10	3.12	0.13
Proline	Animal	2	13.951	2.372	1.881	143.79	3.92
	Sample	1	160.563*	77.965*	186.247*	735.19	2076.50**
	Error	2	6.538	3.190	2.673	9.73	1.27
HO Proline	Animal	2	61.169	28.125	42.07	168.17	17.691
	Sample	1	1.687	9.375	0.22	14.00	38.804*
	Error	2	0.562	3.125	10392	22.34	0.450

Appendix 15: Analysis of variance for nutrients intake, nutrient faecal-out, nitrogen in the urine and urinary allantoins

		Nutrients intake				feaces			Urine	
Source	df	CP	OM	NDF	ADF	NDF	ADF	OM	Urinary N	Allantoin
Diet (D)	1	5.29	50.4	4553.0*	3434	365	0.7	9948	0.07712	8.435
Level (L)	3	1.04	22.1	138.7	1126	2188*	2937.9	266	0.16787	0.108
D x L	3	0.55	44.9	105.1	3228	5437	178.4	3169	0.07918*	0.973
Error	16	60.67	216.7	671.8	3747	2180	347.3	4559	0.04335	43.454

Appendix 16: Analysis of variance for nutrients digestibility

		Nutrients digestibility			
Source	df	OM	NDF	ADF	N Retention
Diet (D)	1	9628	33948	401	0.00001
Level (L)	3	36	9798	61724	0.02012
D x L	3	3131	2547	24511	0.20215*
Error	16	4804	26228	17849	0.04020

Appendix 17: Analysis of variance for 16 hours ruminal degradability and *in vitro* digestibility of dry matter and crude protein (g/kg**)**

Source	Df	RDMD	IVDMD	RCPD	IVCPD
Sample	1	30	58724**	176	64600**
Error	16	3162	3620	3418	455

**: P<0.01; *: *P* <0.05. df: Degree of Freedom, RDMD: Ruminal dry matter degradability, IVDMD: *In vitro* dry matter digestibility, RCPD: Ruminal crude protein degradability, IVCPD: *In vitro* crude protein digestibility.

Appendix 18: Analysis of variance for 16 hours ruminal degradability and *in vitro* digestibility of dry matter for four diets of the growth trial (g/kg)

Source	Df	RDMD	IVDMD
Diet (D)	1	3810.5*	1714
Level (L)	1	17232.2**	1124
D x L	1	1.1	423
Error	32	701.4	2687

**: P<0.01; *: *P* <0.05. df: Degree of Freedom, RDMD: Ruminal dry matter degradability and IVDMD: *z* dry matter degradability.

Appendix 19: Analysis of variance for Ruminal Degradability and *In Vitro* Digestibility of essential Amino acids of BSC and MOC

Component	Source	df	Arg	Thr	Met	Val	Phe	IsoL	Leu	His	Lys
DR	Sample	1	28739	5274	41667	18716	8605	25	1357	3144	4112.1
	Error	10	5145	10621	25849	7441	7871	6495	7336	31615	141.1
IVD	Sample	1	651.0	11087**	6552	77518	49960**	31731*	34969**	6893	16681
	Error	10	774.3	391	47194	1560	1497	3831	842	78230	15914

**: P<0.01; *: P<0.05. df: Degree of Freedom, (Trp) Tryptophan (Arg) Arginine, (Thr) Threonine, (Met) Methionine, (Val) Valine, (Phe) Phenylalanine, (IsoL) Isoleucine, (Leu) Leucine, (His) Histidine and (Lys) Lysine

Appendix 20: Analysis of variance for Ruminal Degradability and *In Vitro* Digestibility of non-essential Amino acids of BSC and MOC

Components	Source	df	Ser	Asp	Glu	Gly	Ala	Tyr	Pro	HOP
RD	Sample	1	6807	9540	11914	44491	13941	2501	13666	203
	Error	10	12535	6219	17292	6628	49168	2545	4091	4915
IVD	Sample	1	16681	15275**	25760*	64348*	36548*	273969**	30565	26188
	Error	10	15914	480	2469	4421	3019	395	4129	3260

**: P<0.01; *: P<0.05. df: Degree of Freedom, (Cys) Cysteine, (Ser) Serine, (Asp) Aspartic Acid, (Glu) Glutamic Acid, (Gly) Glycine, (Ala) Alanine, (Tyr) Tyrosine, (Pro) Proline, (HOP) HO Proline and (Met) Methionine.

Appendix 21a: Analysis of variance for Ruminal Degradability and 3-step *In Vitro* Digestibility of nutrients of Macadamia oil cake or Baobab seed cake based diets

Component	Source	df	CP	Arg	Thr	Met	Val	Phe	Isol	Leu	His
RD	Diet (D)	1	19199	1537	327	9204	3254	1190	2421	114	14427
	Level (L)	1	16542	118	4881	127	561	631	5553	1241	14427
	D x L	1	24156	0	5002	2759	1278	1779	15235	6224	22993
	Error	10	1698	1536	1811	2138	2111	1818	3132	1461	35733
IVD	Diet (D)	1	12	118	25055	11179	874	3991	409	736	119010
	Level (L)	1	2616	17313	30145	18117	39	370	3779	1620	12884
	D x L	1	46	55708	9644	5677	5147	20331	14	1005	685
	Error	10	1931	909	1777	1967	2071	1972	2355	1849	2583

**: P<0.01; *: P<0.05. df: Degree of Freedom, (Cys) Cysteine; (Thr) Threonine; (Met) Methionine; (Val) Valine; (Phe) Phenylalanine; (IsoL) Isoleucine; (Leu) Leucine; (His) Histidine; (Lys) Lysine; (Ser) Serine; (Asp) Aspartic Acid; (Glu) Glutamic Acid; (Gly) Glycine; (Ala) Alanine; (Trp) Tryptophan; (Pro) Proline; (BSC) Baobab seed cake; (MOC) Macadamia oil cake.

Appendix 21b: Analysis of variance for Ruminal Degradability and 3-step *In Vitro* Digestibility of nutrients of Macadamia oil cake or Baobab seed cake based diets

Component	Source	df	Lys	Ser	Asp	Glu	Gly	Ala	Try	Pro
RD	Diet (D)	1	5285	156	14871.3	476.0	990	3035	141	1485
	Level (L)	1	487	557	2806.8	3378.4	3	1188	1786	19
	D x L	1	545	156	1280.9	666.9	20	2544	38	134
	Error	10	1658	2552	905.6	956.3	1636	1882	1647	1672
IVD	Diet (D)	1	270	1204	20483	3406	1010	86303	20397	2162
	Level (L)	1	1696	1019	106787	33523	1549	24253	84213	467
	D x L	1	46780	2	76164	47710	125913	67246	121055	5166
	Error	10	2878	2824	1662	33567	1155	1873	1225	1427

**: P<0.01; *: P<0.05. df: Degree of Freedom, (Cys) Cysteine; (Thr) Threonine; (Met) Methionine; (Val) Valine; (Phe) Phenylalanine; (IsoL) Isoleucine; (Leu) Leucine; (His) Histidine; (Lys) Lysine; (Ser) Serine; (Asp) Aspartic Acid; (Glu) Glutamic Acid; (Gly) Glycine; (Ala) Alanine; (Trp) Tryptophan; (Pro) Proline; (BSC) Baobab seed cake; (MOC) Macadamia oil cake.