EFFECT OF *ACACIA* SPECIES LEAF MEAL INCLUSION ON METHANE EMISSION AND PRODUCTIVITY OF YEARLING MALE BOER GOATS FED AN *AVENA SATIVA* HAY-BASED DIET

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DECLARATION

I declare that this mini-dissertation hereby submitted by me for the Degree of Master of Science in Agriculture (Animal Production) at the University of Limpopo is my original work conducted under supervision of Prof. J.W. Ng’ambi and Dr T Chitura has not been previously submitted by me at this or any other University. All material contained herein and all sources of information have been duly acknowledged by references.

Signature…………………………... Date………………………...

Rebecca Mmamakgone Mathobela

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DEDICATION

I dedicate this mini-dissertation to my late father, Motena Jan Mathobela (1965-2011), and may his soul rest in peace. I, also, dedicate this to my Mother, Morele Sarah Mathobela, my younger sister, Mmathabo Violet Mathobela and my nephew, Amohelang Motena Junior Mathobela. Their motivation, moral support, prayers and encouragement made me who I am today. Lastly, I dedicate this to my family, friends and relatives as a whole for being there for me.

ABSTRACT

A study was done to determine the effect of *Acacia (A.) karroo*, *A. tortilis* or *A. nilotica* leaf meal inclusion in a diet on methane emission and productivity of yearling male Boer goats fed a basal diet of *Avena sativa* hay. The first part of the study was conducted to determine and compare nutrient contents and tannin levels of *A. karroo, A. tortilis* and *A. nilotica* leaf meals and *Avena sativa* hay in a completely randomised design. The diets means were compared using Fisher's least significant difference at the 5 % level of probability. The three *Acacia* species had higher ($P<0.05$) crude protein contents compared to *Avena sativa* hay, ranging from 12.42 to 14.49 %. No tannins were detected in *Avena sativa* hay. Among *Acacia* species, *A. nilotica* leaves had higher ($P<0.05$) total phenolic and total tannin contents than *A. karroo* and *A. tortilis* leaves, the latter being similar ($P>0.05$). All three *Acacia* species had similar ($P>0.05$) contents of condensed tannins, ranging from 1.49 to 1.76 %. However, only *A. nilotica* leaves had hydrolysable tannins of 128 mg/g.

The second part of the study was conducted to determine the effect of *A*. *karroo*, *A*. *tortilis* or *A*. *nilotica* leaf meal inclusion level on diet intake and digestibility, methane emission, productivity and blood profiles of yearling male Boer goats. A total of three experiments were conducted and different goats were used in each experiment. A grand total of thirty six (twelve per experiment) yearling male Boer goats with initial mean live weights of 23 ± 2 kg (experiment 1), 23 ± 2 kg (experiment 2) and 23 ± 2 kg (experiment 3) were used in 21-day experiments. The goats were randomly assigned to four dietary treatments, each containing *A. karroo*, *A. tortilis* or *A. nilotica* leaf meal inclusion levels at 10, 15, 20 and 30 % with *Avena sativa* hay as a basal diet. Each goat was housed in well-ventilated individual metabolic pen. The diets were replicated three times. The data collected were subjected to analysis of covariance and analysis of variance in a completely randomized design using SAS. Differences were separated at 5 % level of probability. Additionally, regression equations were used to determine the relationships and responses in optimal diet intake and digestibility, methane emission, productivity and blood profiles of yearling male Boer goats to differing inclusion levels of *A*. *karroo*, *A*. *tortilis* and *A*. *nilotica* leaf meal.

Experiment 1 involved feeding different levels of *A. karroo* leaf meal inclusion to yearling male Boer goats fed *Avena sativa* hay as a basal diet. Results of methane emission before and during the experiment indicated that inclusion of *A. karroo* leaf meal in the diets of goats reduced ($P<0.05$) methane emission. Similarly, some of the blood parameters before and after experiment were affected ($P<0.05$) by inclusion of *A. karroo* leaf meal. However, *A. karroo* leaf meal inclusion level had no effect ($P>0.05$) on diet intake, methane emission, live weight changes and digestibility, except ($P<0.05$) for digestibility of crude fibre. Feed conversion ratio improved linearly with increased *A. karroo* leaf meal inclusion level.

In the case of experiment 2, results of methane emission before and during the experiment indicated that inclusion of *A. tortilis* leaf meal in the diets of goats reduced ($P<0.05$) methane emission. Similarly, some of the blood parameters before and after the experiment were affected ($P<0.05$) by inclusion of *A. tortilis* leaf meal. However, variation in *A. tortilis* leaf meal inclusion level had comparable effect ($P>0.05$) on methane emission, live weight changes and digestibility, except ($P<0.05$) for digestibility of crude protein and acid detergent fibre. Diet intake and feed conversion ratio were affected ($P<0.05$) by *A. tortilis* leaf meal inclusion level. A positive relationship was observed between *A. tortilis* leaf meal inclusion level and diet intake.

In experiment 3, results of methane emission before and during the experiment indicated that inclusion of *A. nilotica* leaf meal in the diets of goats reduced ($P<0.05$) methane emission. Similarly, some of the blood parameters before and the after experiment were affected ($P<0.05$) by inclusion of *A. nilotica* leaf meal. Apart from diet fat digestibility and feed conversion ratio, no statistical differences ($P>0.05$) were observed on diet intake, digestibility and live weight changes of goats fed *A. nilotica* leaf meal inclusion level. Positive relationships were observed between *A. nilotica* leaf meal inclusion level, diet fat digestibility and feed conversion ratio in male Boer goats.

The high crude protein and low tannin contents in *A. karroo, A. tortilis* and *A. nilotica* leaves indicate that these *Acacia* species can be safe to use as a source of protein in animal nutrition if used sparingly. It was noted that nutrient intake, digestibility, feed conversion ratio and blood profiles of Boer goats in the present study were optimised at different inclusion levels for all the three *Acacia* species. This may imply that inclusion levels of *A. karroo*, *A. tortilis* and *A. nilotica* leaf meals for optimal productivity will depend on the *Acacia* species used and, also, on particular productivity parameters in question. Although, *A. karroo*, *A. tortilis* and *A. nilotica* leaf meal reduced methane emission, optimal reduction in methane emission was not determined. Further validation is required to determine *Acacia* inclusion levels for optimal methane production and emission by goats.

Keywords: Yearling goats, feed intake, digestibility, growth performance and blood profiles.

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ABBREVIATIONS

A	Acacia
ADF	Acid detergent fibre
ALP	Alkaline phosphate
ALT	Alanine transaminase
AOAC	Association of Official Analytical Chemists
AST	Aspartate transaminase
CP	Crude protein
CT	Condensed tannin
dL	Decilitre
DM	Dry matter
FCR	Feed conversion ratio
GHG	Greenhouse gas
Hb	Haemoglobin
Hct	Haematocrit
HT	Hydrolysable tannin
IU	International unit
K/Ca + Mg	Ratio of potassium/Calcium plus Magnesium
mmol	Millimole
NDF	Neutral detergent fibre
nm	Nanometre
OM	Organic matter

P	Probability
pH	Potential hydrogen
ppm-m	Parts per million per metre
PVPP	Polyvinyl-polypirrolidone
r^2	Coefficient of determination
RBC	Red blood cells
rpm	Revolutions per minute
SAS	Statistical Analysis System
SPSS	Statistical Package for the Social Sciences
VFA	Volatile fatty acids
WAD	West African Dwarf
WBC	White blood cells
λ_{max}	Lambda maximum
µg	Microgram
µL	Microliter

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CHAPTER 1

INTRODUCTION

1.1 Background

Goat farming is practised throughout Southern Africa. The total national goat population in South Africa is approximately 7 million for both the commercial and communal meat, fibre and milk goat sectors (DAFF, 2011). Among the provinces in South Africa, Eastern Cape and Limpopo provinces are the largest goat-producing provinces, compromising 37 and 20 %, respectively (DAFF, 2011). Goats are economically, nutritionally and culturally very important to the people of Limpopo Province. However, they produce a lot of methane gas which is a loss of energy from the animal (Sallaku *et al*., 2011) and contributes to global warming (Kaufmann *et al*., 2006; Lassey, 2007).

Loss of energy from these goats limits their productivity. Again, their productivity is limited by scarcity of high quality and quantity of roughages, especially during the dry season (Hove *et al*., 2001). The roughages that are available during this time of the year are of poor quality and low feeding value. This is because they have low protein and high fibre contents which lead to poor growth of the goats (Tolera *et al*., 2000), thus, depressing productivity of the goats. As a result, scarcity of high quality roughages during the dry season leads to goats browsing on *Acacia* species. These species are well-adapted to drought and are identified as suitable protein supplements (Aganga & Tshwenyane, 2003). Inclusion of *Acacia* leaves in the diet improves intake, digestibility and animal performance (Abdulrazak *et al*., 2000, Mapiye *et al*., 2009).

Although *Acacia* species have a high protein content, they also contain tannins (Makkar, 2003). These tannins might limit intake and digestibility (Makkar, 2003; Waghorn, 2008), thus, depressing productivity of the goats. However, intake of small amounts of tannins tends to decrease methane production and emission in ruminant animals (Makkar *et al*., 2007). There is neither extensive nor conclusive data on tanniniferous *Acacia* leaf meal inclusion levels for optimal reduction in methane production and emission in the ruminant animals. Additionally, extensive knowledge on inclusion levels of *Acacia* leaf meal for optimal goat productivity is also minimal. This study, therefore, aimed at determining the effects of *Acacia (A.) karroo*, *A. tortilis* and *A. nilotica* leaf meal inclusion on methane emission and productivity of yearling male Boer goats.

1.2 Problem statement

High methane production and emission from livestock are major problems adversely affecting the environment and hence climate change (Kaufmann *et al*., 2006; Lassey, 2007). Methane emission is a loss of energy from the animal (Sallaku *et al*., 2011). There is evidence that tanniniferous feeds in the diets of ruminants can decrease methane production (Carulla *et al*., 2005; Puchala *et al*., 2005; Patra and Saxena, 2010), but this evidence is not extensive or conclusive (Makkar *et al*., 2007). It is, therefore, important to determine dietary *Acacia* species leaf meal inclusion levels for optimal methane reduction and productivity of growing Boer goats. *Acacia karroo, A*. *tortilis* and *A*. *nilotica* were selected because they are abundant and common throughout Limpopo province. Their leaves have condensed tannins which tend to bind with ammonia, protein and methane (Makkar, 2003), thus, reducing methane emission. Additionally, their leaves contain a high protein content which may enhance productivity of the goats (Makkar *et al*., 2007).

1.3 Motivation

Goat production plays important economic, nutritional and cultural roles in rural households of South Africa. Information on the effect of *A. karroo*, *A. tortilis* and *A. nilotica* leaf meal inclusion on methane emission, diet intake and digestibility, productivity and blood profiles of yearling male Boer goats generated in this study, may be useful to goat farmers. Such information may, also, be useful to organisations and governments aiming at reducing methane emission in ruminant animals. Reduction in methane production and emission from goats are of importance to farmers and policy makers. Use of *Acacia* leaf meal levels for optimal methane reduction may result in improved productivity of the goats and less greenhouse gas emissions (Carulla *et al*., 2005; Patra & Saxena, 2010). Thus, improved goat productivity may economically benefit goat farmers.

1.4 Objectives

The objectives of this study were to determine:

i. The nutrient and tannin contents of *A*. *karroo*, *A*. *tortilis* and *A*. *nilotica* leaf meals and *Avena sativa* hay.

ii. The effects of *A*. *karroo*, *A*. *tortilis* and *A*. *nilotica* leaf meal inclusion levels on methane emission, diet intake and digestibility, productivity and blood profiles of yearling male Boer goats.

iii. The relationships between *A*. *karroo*, *A*. *tortilis* and *A*. *nilotica* leaf meal inclusion levels on methane emission, diet intake and digestibility, productivity and blood profiles of yearling male Boer goats.

1.5 Hypotheses

i. *Acacia karroo, A. tortilis* and *A. nilotica* leaf meals has no different nutrient and tannin contents.
ii. *Acacia karroo, A. tortilis* and *A. nilotica* leaf meal inclusion levels has no effects on methane emission, diet intake and digestibility, productivity and blood profiles of yearling male Boer goats.
iii. There are no relationships between *A. karroo, A. tortilis* and *A. nilotica* leaf meal inclusion levels on methane emission, diet intake and digestibility, productivity and blood profiles of yearling male Boer goats.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Goats are very important to the people of Limpopo Province in South Africa. However, they produce a lot of methane gas which contributes to loss of dietary gross energy and global warming. Although there is some evidence that tannin-rich feeds in the diets of the ruminants decrease methane production (Patra and Saxena, 2010), not much has been done on *Acacia* leaf meal inclusion levels for optimal methane reduction in the rumen. Thus, it is important to determine dietary *Acacia* species leaf meal inclusion levels for optimal methane reduction and productivity of growing Boer goats.

Boer goats are a South African common goat breed and were developed in the early 1900s. The name “Boer” is derived from an Afrikaans word, which means ‘’farmer’’. Boer goats have gained worldwide recognition for fast growing rates, excellent body conformation and good carcass qualities. Boer goats are considered to be one of the most desirable goat breeds for meat production in the world (Barry and Godke, 1997). They are mostly found on commercial farms.

Goats (*Capra hircus*) are primarily browsers (Ngwa *et al*., 2000; Omphile *et al*., 2003), and about 60 to 80 % of their diets are made of browse materials (Kababya, 1995). This suggests that their main diets are tree leaves and twigs. Budisatria *et al*. (2010), also, reported that goats thrive better on tree leaves than on grazing diets. They prefer the leaves and twigs of trees containing condensed tannins and digest them better than other forage eating ruminants (Silanikove, 2000). Gilboa *et al*. (1995) and Silanikove *et al*. (1996) reported that under similar conditions, goats are able to consume larger amounts of tannin-rich browse than sheep. This may imply that they can tolerate browse materials rich in tannins more as compared to other ruminants. Moreover, they prefer leaves over stems, as leaves have much higher concentration of condensed tannins (Silanikove, 2000).

Productivity of goats is limited by high methane production from the rumen, poor quality and limited quantity of pastures (Middelaar *et al.*, 2013). Thus, low feed quality and inadequate amounts of pasture result in reduced goat productivity. However, goats thrive well under harsh conditions because they are able to feed on a variety of both browse and grass species. It could be said that goats survive well under unfavourable conditions due to their good behaviour of not being selective

(Silanikove *et al*., 1996). This suggests that they either graze or browse depending on which material is abundant and edible. Timberlake (1980) reported that nutrients for their maintenance and production in the dry season are met through browsing on different plant species, including *Acacia* species*.* Such animal performance on *Acacia* species shows the feeding value of these species to the ruminants. This could be attributed to the fact that *Acacia* species can easily meet nutrient requirements, mainly proteins and minerals (Mokoboki *et al.,* 2005) relative to other browse species without condensed tannins. Data on the use of *Acacia* species on methane emission and productivity of Boer goats is limited. Therefore, there was a need to determine nutrient and tannin contents of *Acacia (A.) karroo*, *A. tortilis* and *A. nilotica* leaf meal inclusion levels for optimal methane reduction and productivity of Boer goats.

***2.2 Avena sativa* hay as a goat feed**

Avena sativa hay is commonly known as oaten hay and is made from an oat plant. Oats is an annual cereal crop grown to provide hay or silage for livestock (Bargo *et al*., 2001; Arelovich *et al*., 2003; Suttie & Reynolds, 2004). It has long been used for livestock feeding (Schrickel *et al*., 1992). However, its nutritive value is similar to that of a low quality forage (Suttie & Reynolds, 2004). Improving its feeding value is essential for improved animal productivity and performance. Hamilton (2010) reported that *Avena sativa* straw can be offered as sole roughage during winter provided it is adequately supplemented.

INRA (2007) reported neutral detergent fibre and acid detergent fibre of 64 and 38 % at flowering stage, respectively. Despite its fibre content, *Avena sativa* hay has a low protein content of 6.3 % (INRA, 2007), which makes it a low quality roughage. Where roughage is of poor quality and does not meet nutrient requirements for optimal growth of livestock, it can be improved by adding a protein supplement (Arelovich *et al*., 2003). Supplementation with a high protein forage legume increased daily gain and milk production in crossbred cows grazing on oat (Mpairwe *et al*., 2003a; Mpairwe *et al*., 2003b). Thus, due to low protein content of *Avena sativa* hay, it is necessary to supplement the hay with protein sources such as *Acacia* species. Goats fed solely on *Avena sativa* hay may not respond well. This is because of inadequate protein supply (Suttie & Reynolds, 2004). Improved productivity or performance would come from a supplement of *Avena sativa* hay with good quality protein feeds.

2.3 *Acacia* species as a goat feed

Acacia trees are found in sub-Saharan Africa and extensively in South Africa. The majority of these species are unpleasant to livestock (Odenyo *et al.,* 1997), because they contain tannins. According to Jones *et al*. (1994), these tree species are, also, toxic to rumen microorganisms due to the same reason of containing anti-nutritional factors. This, therefore, limits the use of these feedstuffs for animal feeding. Fodder trees are not only considered as animal feed, but can also enhance utilisation of low quality roughages (Rubanza *et al*., 2005). However, level of inclusion should be taken into consideration in order to prevent harmful effects.

Acacia species are abundant in rural areas of Limpopo province and have been observed to be a good and cheap source of protein feed for communal goats (Mapiye *et al*., 2009). Yadav *et al*. (2013) indicated that *Acacia* is a genus name derived from the Greek word "*akis"*, meaning a barb. Bakshi & Wadhwa (2004) reported that *Acacia* species belong to the family Leguminosae and these species are rich in nutrients such as proteins and minerals. The nutrient composition of *A. karroo, A. tortilis* and *A. nilotica* tree leaves are shown in Table 2.01. Leaves, twigs and pods of *Acacia* species contain fairly high concentrations of protein and maintain higher protein and mineral contents during growth than grasses do (Aganga and Tshwenyane, 2003). However, due to the presence of high concentration of tannins in *Acacia* species, some animals limit their consumption. *Acacia* species are either beneficial or toxic depending on the amount or concentration of tannins present. The higher the amount of tannins the higher the toxicity and vice versa (Pathak *et al*., 2014; Dey & De, 2014). At the same time, these species can be used as supplements since they have the ability to retain their nutrients during their different stages of growth as compared to grasses (Aganga & Tshwenyane, 2003).

Table 2.01 Nutrient composition of *A. karroo, A. tortilis* and *A. nilotica* tree leaves

Nutritive value	*Acacia* species		
	A. karroo	*A. tortilis*	*A. nilotica*
Dry Matter (g/kg)	945.4	947.7	951.6
Organic Matter (g/kg DM)	897.0	864.6	882.6
Crude Protein (g/kg DM)	108.0	150.2	151.7
Neutral detergent fibre (g/kg DM)	504.6	621.7	572.0
Acid detergent fibre (g/kg DM)	406.9	544.9	472.2
Total phenolics (g/kg DM)	31.3	89.7	25.4
Simple phenolics (g/kg DM)	8.9	13.9	7.5
Extracted condensed tannins (g/kg DM)	80.7	5.0	44.3
Condensed tannins in neutral detergent fibre (g/kg DM)	38.9	19.8	25.9
Condensed tannins in acid detergent fibre (g/kg DM)	24.1	16.3	18.3

Source: Mokoboki *et al*. (2005)

2.3.1 Description of *Acacia karroo*

Acacia karroo is commonly known as a sweet thorn and soetdoring in afrikaans. In southern Africa, *Acacia karroo* is the most widespread *Acacia* species. It is very adaptable to various environmental conditions. According to Abdulrazak *et al*. (2001), *Acacia karroo* is abundant and able to grow in dry conditions as found in the RSA. The description of *A. karroo* is presented in Figure 2.01 and Table 2.02.

Figure 2.01 *Acacia karroo* tree

Table 2.02 Description of *Acacia karroo*

Size	Shrub to medium-sized tree and can grow up to 20 m high. The crown is rounded and dark green.
Bark	Blackish grey/brown to black, usually rough and longitudinally fissured.
Spine	Spines paired, long straight, white and usually more prominent on young plants.
Leaves and leaflet	Leaves are bipinnately compound.
Fruit	The pods are dark-brown, flat, sickle-shaped, slender and slightly constricted between the seeds.
Flowers	Globose heads, bright yellow and spherical.

Source: FAO (2002)

2.3.2 Description of *Acacia tortilis*

Acacia tortilis is one of the most important species of the genus *Acacia* belonging to family Leguminaceae. The name '*tortilis'* means twisted and refers to the twisted browny pod structure (Ecocrop, 2009; Ecoport, 2009). *Acacia tortilis* is, also, known as an umbrella thorn due to the fact that it is umbrella-shaped (Orwa *et al*., 2009). The description of *Acacia tortilis* is shown in Figure 2.02 and Table 2.03. *Acacia tortilis* is the most widespread and common throughout much of Africa. Goats browse heavily on this species and the tree can survive heavy browsing. It plays an important role in countries where it is found including South Africa. *Acacia tortilis* are drought resistant plants and these species are mainly found in arid and sub-arid area of Africa. The survival of this plant in severe drought is due to its deep taproot systems which gives it ability to tolerate harsh condition (FAO, 2009).

Figure 2.02 *Acacia tortilis* tree

Table 2.03 Description of *Acacia tortilis*

Size	Small to medium-sized evergreen tree that is usually about 4 - 8 m high but can grow up to 21 m tall. The crown is dense, umbrella-like and flat-topped, finely branched, spreading and rounded.
Bark	Grey to black or dark brown, rough and fissured.
Spine	Spines paired and white. 2 types: long straight spines mixed with short and hooked spines.
Leaves and leaflet	Leaves are compound and the leaflets (6 - 22 pairs) are very small (1-4 mm long x 0.6-1 mm broad), glabrous to pubescent.
Fruit	Tightly twisted browny pod.
Flowers	Globose clusters. White or pale cream in colour and highly aromatic.

Source: Orwa *et al*. (2009).

2.3.3 Description of *Acacia nilotica*

Acacia nilotica originated from the drier areas of Africa, Arabian Peninsula and Indian subcontinent (USDA, 2012). Its roots make it suitable for dry areas. The root system depends on the growing condition: A deep taproot in dry conditions and extensive lateral roots in flooded conditions. *Acacia nilotica* is a nearly evergreen multipurpose legume but may remain a shrub in poor growing conditions (Fagg *et al*., 2005; Ecocrop, 2009; Orwa *et al*., 2009). It is considered to be a weed in some areas (US Forest Service, 2012). In South Africa, there is some evidence that *Acacia nilotica* is a weed in its native habitat (Holm *et al*., 1979). The description of *A. nilotica* is presented in Figure 2.03 and Table 2.04.

Figure 2.03 *Acacia nilotica* tree

Table 2.04 Description of *Acacia nilotica*

Size	Medium-sized nearly evergreen tree that can reach a height of 20 - 25 m tall. The crown is flattened and rounded. The trunk is short, thick and cylindrical.
Bark	Dark grey with longitudinal fissures.
Spine	Spines paired, straight, white and usually pointing slightly backwards.
Leaves and leaflet	Leaves are compound and the leaflets (7 - 36 pairs) are very small (1.5 - 7 mm long x 0.5 - 2 mm broad), grey-green and hairy.
Fruit	The pods are dark-brown to grey in colour, flat, straight, deeply constricted between the seeds and contain flattened bean-shaped dark seeds.
Flowers	Globose heads. Bright to golden-yellow in colour and sweetly scented.

Sources: Fagg *et al*. (2005), Cook *et al*. (2005), Orwa *et al*. (2009) and Ecocrop (2012).

2.4 Tannins

Tannins are water-soluble polyphenolic substances with complex and different structures. They are traditionally classified into two classes: hydrolysable tannins (HT) and condensed tannins (CT). Their effects on animal's performance range from beneficial to toxicity and death, depending on their concentration and nature (Makkar, 2003). Some tannins are more toxic than others and the impacts of level of concentration range from low, medium to high. Tannins are, also, referred to as the anti-nutrient factors which can be present in different plant species (Makkar, 2003). Their chemical, physical and biological properties vary among trees (Zucker, 1983: Mangan, 1988). Levels of tannins in tree species vary within species, between species, stage of development, from season to season and location (Mehansho *et al*., 1987).

2.4.1 Condensed tannins

Condensed tannins (CT) are complex phenolic compounds which are found in a variety of browse species (Kumar & Vaithiyanathan, 1990). They are more often called proanthocyanidins. They comprise a group of polyhydroxyflavan-3-ol oligomers and polymers linked by carbon-carbon bonds between flavanol subunits (Figure 2.04). Condensed tannins are secondary plant compounds generally regarded as toxic to animals when consumed in large amounts (Carulla *et al.,* 2005). However, they are less toxic when compared to hydrolysable tannins (McSweeney *et al*., 2001). At low to moderate levels, CT are not toxic (Makkar, 2003). They are both beneficial and detrimental on animals depending on their levels. Barry & McNabb (1999) indicated that CT are found in a greater number of trees, legumes and shrubs around the world and are the most common type of tannins found in the browse species. They are more widely distributed in browse species than hydrolysable tannins and are considered to be more active in precipitating proteins. It has been reported that CT reduce methane emission in ruminant animals (Carulla *et al.,* 2005; Puchala *et al.,* 2005). They bind to proteins (Jones & Mangan, 1977) and lower enteric methane emission (Tedeschi *et al.,* 2011). Condenssed tannins inhibit ammonia and production of methane through their ability to form complexes with dietary protein and carbohydrates (Carulla *et al.,* 2005). Niezen *et al*. (1994) reported that levels of CT vary between different plant species. Thus, different *Acacia* species (e.g. *A. karroo, A. tortilis, A. nilotica*) have different levels of CT (see Table 2.01).

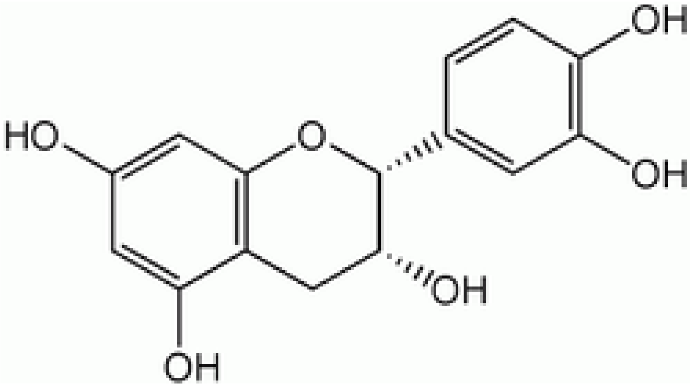

Figure 2.04 Base unit of Condensed tannin (Procyanidin)

2.4.2 Hydrolysable tannins

Structurally, Hydrolysable tannins (HT) contain Gallic acid which bonds to the hydroxyl group of glucose (Dalzell & Karven, 1998). The structure of HT is presented on Figure 2.05. Kumar & Vaithiyanathan (1990) reported that the bond can be broken down by hot water, tannase enzyme, mild acids and bases separating carbohydrate and phenolic acid. Hydrolysable tannins are known to be toxic to ruminant animals and are found in a variety of plants that are used as animal feeds (Shi, 1988). However, they are usually present in low amounts in plants. If large amounts are consumed within immature tree species, HT may result in poisoning animals (Garg *et al*., 1992). Apart from causing toxicity to animals, HT also have an adverse impact on a number of enzymes involved in the process of digestion (Yoshida *et al.,* 2000). They tend to reduce impotency of enzymes. The presence of CT in browse materials was commonly reported but not with hydrolysable tannin. Makkar (2003) reported that there is lack of information on the presence of hydrolysable tannins of browse materials. This is because HT are only present in few consumed feeds in low concentrations and, therefore, most of the focus has been on CT. Further studies on HT need to be conducted.

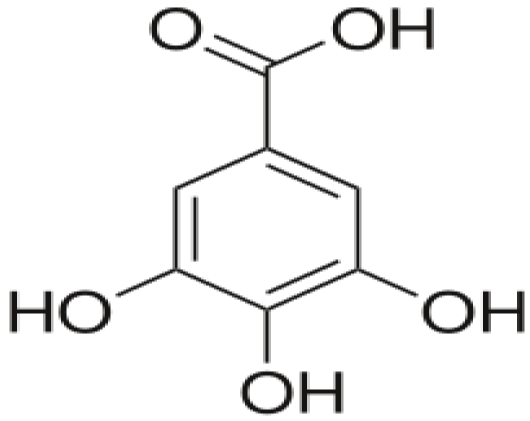

Figure 2.05 Base unit of Hydrolysable tannin (Gallic acid)

2.5 Effects of tannins on animal production

2.5.1 Effects of tannins on nutrient digestion

Tannins have the capacity to form reversible and irreversible complexes with proteins and carbohydrates due to their high molecular weight (Schofield *et al.,* 2001; Patra & Saxena, 2011; Smith *et al*., 2005). Their chemical structure determines and differentiates their binding ability. Tannins can not only form complexes with protein and carbohydrates but can also interact with minerals, polysaccharides, enzymes and bacterial cell membranes involved in protein and carbohydrate digestion (Horvath, 1981). This, further, affects nutritive value of feeds. Condensed tannins (CT) in plant tissues exist in three fractions: protein-bound CT, fibre-bound CT and extractable CT (Wolfe *et al*., 2008). According to Burritt *et al.* (1987), CT are polymers of condensed flavan and HT are esters of phenolics acids and glucose. This gives the two tannins the ability to bind with proteins from different origins (Horvath, 1981). Both the CT and HT form greater complexes with proteins even though they are structurally different (Hagerman & Klucher, 1986).

Biological activities of CT have been discussed and precipitation of proteins due to CT binding has been suggested to be the primary biological activity of CT (Mané *et al*., 2007). The binding ability of CT to nutrients is attributed to the basis for inhibition of microbial activity (Smith *et al*., 2005). According to Smith *et al*. (2005) and Patra & Saxena (2011), inhibition is due to interaction between CT and microbial cell wall constituents and nutrients, rendering nutrients unavailable to microorganisms. In other words, CT protect nutrients from ruminal microbes by binding to nutrients and dissociating them later in the small intestine for further digestion and absorption. The binding activity of CT to proteins starts in the mouth. In the mouth there is a formation of CT-salivary proteins which free CT to bind dietary proteins avoiding the subsequent negative effects on protein digestion and nutritional uptake (Horne *et al*., 2002). Apart from binding to protein, CT bind to minerals (Smith *et al*., 2005) and lipids (Delehanty *et al*. 2007). The ability of CT to bind minerals can bring about biological changes following iron deficiency (Smith *et al*., 2005). This may be due to the fact that iron dissociated in the small intestine may be efficiently absorbed by the lining of the small intestine and be efficiently transported throughout the body.

2.5.2 Effects of tannins on diet intake and digestibility

The presence of tannins at high levels can significantly restrict intake and the utilisation of nutrients, particularly nitrogen (McNeill *et al*., 1998; Barry *et al*., 2001). On the other hand, low levels of tannins in foliage can increase the utilisation of crude protein by protecting it from digestion in the rumen thereby increasing the flow of essential amino acids to the small intestine for absorption (Waghorn, 1990; Barry *et al.,* 2001). After rumen fermentation, protein that is bound by CT later dissociate in the small intestine. This may increase the rate of protein digestibility in the small intestine depending on the amount of tannin-rich feeds consumed.

Ng'ambi *et al.* (2009) and Mapiye *et al*. (2011) reported that the presence of thorns highly disturb voluntary intake and leaf selection of tannin-rich plants such as *Acacia* species, which further restrict the accessibility of the leaves and phenolic compounds (Teague, 1989). Phenol compounds present in tanniniferous plants are associated with reduced intake, degradability and nutrient availability (Mokoboki *et al*., 2005), and as well as reduced intestinal absorption of proteins and carbohydrates (Giner-Chavez, 1996). Makkar *et al*. (1995) reported that feed intake may be restricted due to the slow rate of degradation in tannin-rich feeds resulting in high rumen-fill. Robbins *et al.* (1987), Silanikove *et al*. (1994) and Silanikove *et al*. (1996), conducted experiments on the relationships between intake of tannin forage plants and palatability, digestibility and nitrogen retention in small ruminants. However, the results highlighted negative effects of tannins in ruminants as it resulted in reduced feed intake, palatability, low rate of evacuation of digesta out of the rumen and toxic effects (Provenza, 1995). These studies suggest that there is no positive relationship between feed intake and high level of tannins in the diet. Moreover, low feed intake results in overall low productivity.

Several studies have highlighted the relationship between tannins, palatability, intake and digestibility of the feed. According to Barry *et al*. (2001) and Mokoboki *et al*. (2005), CT reduces palatability of the feed and feed intake. However, one may argue that the effects of tannins on palatability depend on the amount and degree of tannins. Terrill *et al*. (1992) and Wang *et al*. (1996) reported that low inclusion of CT has no adverse effects on palatability. This may imply that a high level of CT affects the taste and it seems probable that it, also, has an effect on the voluntary feed intake. Barry & McNabb (1999) reported that tannins affect feed intake since they have the ability to affect nutrient composition of the feed. Voluntary feed intake is, also, associated with rate of digestion. Slow rate of digestion reduces flow of feed through the digestive tract. This results in a rumen fill and further reduces voluntary feed intake (Pathak, 2013a). Condensed tannins have also been found to reduce permeability of the digestive tract of ruminants (Kumar & Baithiyanathan, 1990). This suggests that CT restricts the smooth flow of degraded nutrients to pass through the intestinal membranes. Therefore, the likelihood of these nutrients being absorbed by the body is low and, thus, low digestibility.

2.5.3 Effects of tannins on animal productivity

Acacia species, as a protein source improves animal’s body weight and body condition scores. An improved body weight of the animal leads to improved meat grade and amount of meat produced as a result of heavier carcasses(Arsenos *et al*., 2009). Mapiye *et al. (*2009) reported that *A. karroo* leaf meal improves nutritional status, productivity performance and carcass characteristics of cattle because it is a source of protein. It could be said that feeds with high nutritive value promote high live weight gains.

On the contrary, *Acacia* species contain tannins and these tannins reduce the overall feeding value of tannin-rich feeds. This is supported by the study done by Abdulrazak *et al. (*2000), where it was observed that tannins negatively affect diet intake and digestibility. These tannins bind to proteins and reduce their optimal utilisation by the animal. As a result, weight gain and growth may be affected negatively (Kumar & Vaithiyanathan, 1990). During rumen fermentation, protein is bound by CT. But later it may dissociate in the small intestines and resulting in an increase in protein degradability in the small intestines. An increase in dietary protein in the small intestines increases overall growth and productivity in ruminants (Patra & Saxena, 2011). This is because absorption of nutrients takes place in the small intestine and the more the protein is absorbed, the better chance of it being utilised by the animal for body maintenance.

The quality and the quantity of the dietary protein source containing CT have diverse effects on the general performance of ruminants in relation to its essential amino acids. Condensed tannins have been reported to play a positive role by improving nutrient metabolism in the gut despite causing a reduction in feed intake when consumed in large quantities (Waghorn, 2008). West *et al. (*1993) and Al-Dobaib, (2009) reported that feeds containing tannins below toxic level improve live weight gain. This is attributed to the fact that low concentration of CT in the diet does not limit feed consumption. McMahon *et al.* (2000) indicated that the results are beneficial when ruminants consume a moderate level of CT. This is because a moderate level of CT makes proteins available for digestion in the small intestines and, also, facilitates absorption and utilisation of dietary essential amino acids, which further enhances productivity (Makkar, 2003). This mechanism occurs due to the fact that CT protects the proteins from degradation in the rumen and frees them on reaching the small intestines (McMahon *et al.,* 2000). This is where the absorption of proteins takes place which further aid in normal growth of the animals and, thus, increased productivity. In general, there is a link between an increase in dietary protein in the small intestine and overall improvements in animal performance.

2.5.4 Effects of tannins on animal blood profiles

Haematological studies are useful in the diagnosis of many diseases and are often used to determine the extent of damage to blood (Togun *et al*., 2007; Merck, 2012). According to Daramola *et al.,* 2005, haematological and biochemical values of blood can provide baseline information for comparison in conditions of nutrient deficiency, physiology and health status of animals. Thus, blood profiles serve as an important indicator of nutritional, physiological, pathological and health status of livestock (Etim *et al*., 2013). According to Olafedehan (2010), blood acts as a pathological reflector of the status of exposed animals to toxicants, conditions or agents. Under animal nutrition, blood is commonly used to detect nutritional problems (Etim *et al*., 2013). Thus, nutritional level is one of the factors which affect the physiology of animals (Ajao, 2013). Therefore, it is essential to analyse the nutrient composition of the feed through examination of an animal's blood. This is because blood contains relevant parameters (haematology, enzymes, proteins, metabolites and electrolytes) which serve as a reflection of an animal's condition and these parameters provide valuable information regarding the status of the animal (Otto *et al*., 1992). According to Ndlovu *et al. (*2009), protein, cholesterol and iron are examples of blood biochemistry parameters that are essential in analysing the nutrient profile of animals.

During microbial fermentation of tannin-rich feeds, hydrolysable tannins are broken down by the rumen microbes. Therefore, toxicity of these tannins depends on the amount of degraded tannins absorbed and may appear in the blood stream in the case when the liver is not able to detoxify those (McSweeney *et al*., 2001). This suggests that one can detect the effect of hydrolysable tannins on animals from analysing blood profiles. Studies from Terrill *et al*. (1994) and Abia & Fry (2001), show that the condensed tannins are not absorbed into the blood stream. This is due to the fact that they do not get degraded by rumen microbes (Makkar *et al*., 1995). As a result, these tannins are not likely to cause harmful effects on the liver, kidney and other organs. However, this is not the same for hydrolysable tannins (McSweeney *et al*., 1988; Garg *et al*., 1992).

Levels of inclusion play an important role in determining the welfare of animals. High levels of tannins can damage the intestinal membranes and this condition can allow the absorption of condensed tannins into the blood (Makkar, 2003). In the same way with the hydrolysable tannins, condensed tannins in this case can cause organ damages. When animals consume low levels of tannins, feed proteins escape the process of degradation in the rumen, leading to increased absorption of essential amino acids to the blood stream (Waghorn & Shelton, 1997). Increased absorption of amino acid is often associated with improved animal performance. According to Isaac *et al*. (2013), animals with good blood compositions are likely to show good performance. Knowledge and understanding of tannin application in the diet of animals is important. This is because tannins may pose negative effects on general health of the animals. As much as researchers want to improve productivity of animals through tannin-rich feeds, health status of the animals should not be compromised. Therefore, there was a need to determine the effect of *A. karroo, A. tortilis* and *A. nilotica* on blood profiles of Boer goats.

2.6 Methane production and emissions

According to Clayden *et al*. (2001), methane is a chemical compound with the chemical formula CH_4 (one atom of carbon and four atoms of hydrogen). The structure of methane (CH_4) is shown in Figure 2.06. Methane can be defined as loss of energy from an animal's body in the form of gas and it contributes to a loss of gross energy and global warming. Methane gas is colourless, odourless, tasteless and non-flammable. It is naturally present in the atmosphere and is mainly produced by the process of methanogenesis (Hook *et al*., 2010). Methanogenesis is a process whereby CH_4 is produced by microbes known as methanogens. This process occurs in the rumen during anaerobic conditions and without this process, ruminants such as goats would not be able to consume grass. Chagunda *et al.* (2009b) reported that CH_4 is released from the animals by exhaling the gas mainly through the mouth and nostrils into the atmosphere. Thus, CH_4 is released from the animal mainly by belching.

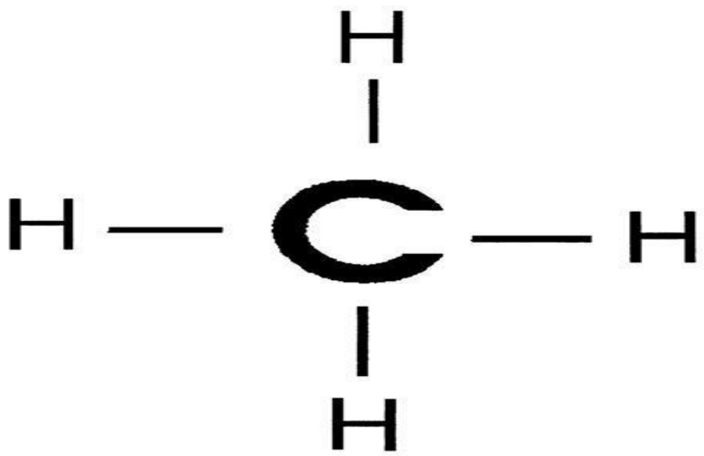

Figure 2.06 The structure of methane (Clayden *et al*., 2001)

From literature reviewed, it is noted that greenhouse gas (GHG) emissions are contributed through various processes of production within the agricultural sector (Alemu *et al*., 2011; Archibeque *et al*., 2012; Scholtz *et al*., 2012). These studies suggest that all farming activities such as production of animals, crops, pasture, flowers, fruit and vegetables account for GHG. Otter (2010) reported that from the agricultural sector, the largest contributor to CH_4 emissions are livestock emissions. Livestock emit CH_4 and nitrous oxide directly from manure (Sommer *et al*., 2004), directly from animals (Kebreab *et al*., 2008) and from agricultural products (Wang *et al*., 2009; Bauer *et al*., 2009). The combination of these emissions sum up to GHG emissions.

There are numerous factors that influence CH_4 production in livestock. These factors include the level of feed intake, digestibility of forage, type and quality of forage species, diet composition, energy consumption, animal size, level of production, growth rate, variation among animals in terms of genetics and environmental temperature (Shibata & Terada, 2010; Scholtz *et al*., 2012). According to Ramin and Huhtanen (2013), feed intake is the main nutritional factor influencing production of CH_4. Generally, CH_4 production increases with the increase in the daily feed intake (Shibata & Terada, 2010). However, it is not always the case. This is because CH_4 emission per dry matter intake decreases with an increase in comparative ratio of concentrates to roughages (Moss *et al*., 2000; Beauchemin *et al*., 2009). Increased concentrate supplementation has been shown to results in a greater proportion of propionate in rumen volatile fatty acids (VFA) and, therefore, less hydrogen gas (H_2) for CH_4 synthesis (Newbold *et al*., 2005).

The quality of forage species has an impact on both the activity of rumen microbes and CH_4 production in the rumen. This is because the activity of microorganisms requires energy, nitrogen and minerals for growth and survival (Moss *et al*., 2000; Shibata & Terada, 2010). An increase in the protein content of the feed decreases CH_4 production, and an increase in fibre content tends to increase CH_4 production (Johnson & Johnson, 1995; Shibata & Terada, 2010). Chianese *et al*. (2009) reported that consumption of dietary carbohydrate has been found to have minor impacts on CH_4 emissions. The type and amount of feed consumed by the animals is, also, directly linked to the amount of enteric CH_4 (Shibata & Terada, 2010; Ellis *et al*., 2007; Middelaar *et al.*, 2013). According to Waghorn & Hegarty (2011), animals grazing on high forage feeding systems resulted in the lowest CH_4 emissions.

The production of GHG occurs during rumen fermentation. Such gases include CH_4, carbon dioxide (CO_2) and nitrous oxide. Of the above mentioned gases, CH_4 is the most important gas contributing to global warming (Xiaoli *et al*., 2010). However, CO_2 comes first to CH_4 in terms of global warming contribution. According to Rawat *et al*. (2007), Lassey (2008) and Peterson *et al*. (2010), CH_4 is 15 to 20 % of all GHG emissions. These studies indicate that about 20 % of the gas is lost from the animal to the atmosphere. Sallaku *et al*. (2011) reported that CH_4 emissions by ruminants are produced in the rumen during microbial fermentation of feed, especially carbohydrates. During microbial fermentation, not all the digested carbohydrates are absorbed by the body. Some are lost in the form of gas during belching. Production of CH_4 from enteric fermentation by ruminants is not only an important GHG associated with environmental problems, but it is, also, associated with a loss of 2 to 14 % of dietary energy (Singh *et al*., 2005; Sallaku *et al*., 2011). It could be said that CH_4 production results in low productivity due to loss of gross energy to the animal and environmental crisis due to global warming. This is, also, supported by studies of Ramin and Huhtanen (2013) and Haarlem Van *et al.* (2008). These studies indicated a negative effect of CH_4 production on animal productivity, resulting in about 2 to 12 % lost energy of the animal's gross energy intake.

The flow and partitioning of dietary energy through the ruminant is presented in Figure 2.07 (Moran, 2005). All feeds contain gross energy. Only parts of the nutrients in feeds are available for the animal. Thus, not all the gross energy in consumed feed is available and useful to the animal. Some energy is lost from the animal through excretions (Singh *et al*., 2005; Sallaku *et al*., 2011). During rumen fermentation, nutrients are digested and not all the digested nutrients are absorbed by the body. Some are lost in the form of a gas (CH_4) through eructation. Loss of energy can result in serious nutritive consequences since animals would not have sufficient energy for useful purposes such as body maintenance and various forms of production.

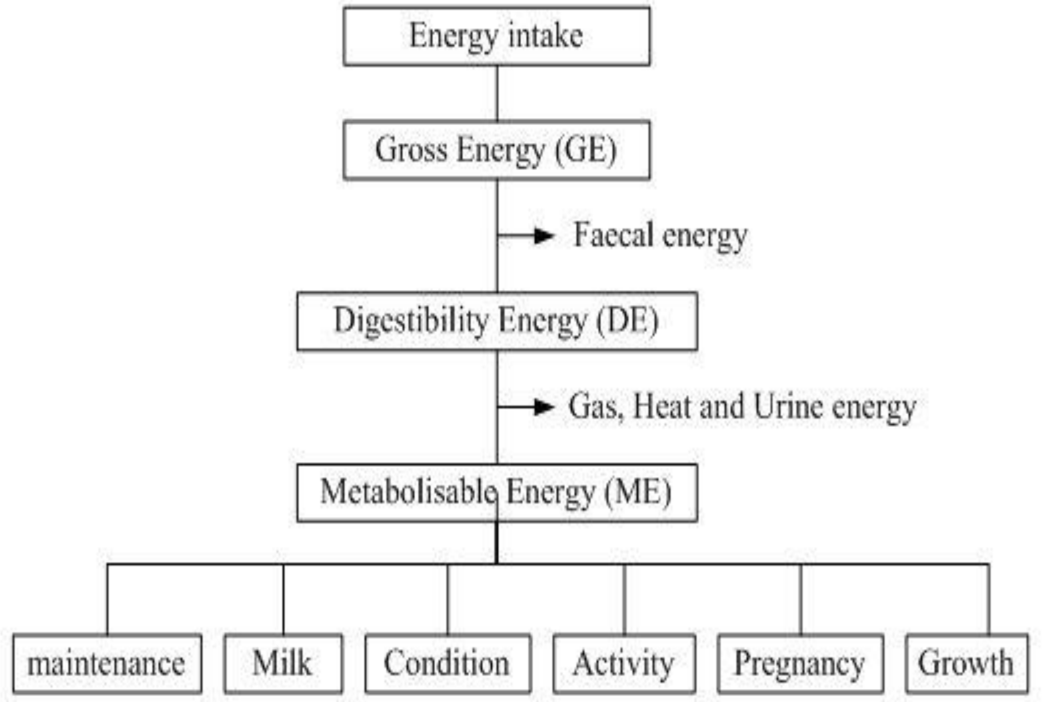

Figure 2.07 The flow and partitioning of dietary energy through the ruminant (Moran, 2005)

From literature reviewed, there are many ways of reducing CH_4 production and emission. DeRamus *et al*. (2003) reported that grazing management of livestock can be used as a CH_4 reduction strategy. The strategy is through implementing proper grazing management to improve the quality of pasture. Similarly, Lovett *et al*. (2008) indicated a 2 % reduction in on-farm GHG emissions due to an improvement of +0.05 UFL/kg in pasture. Improving pasture quality reduces enteric CH_4 production because of less fibrous forage resulting in a more propionate type rumen fermentation. Lovett *et al*. (2005) reported that nutrition serves as a CH_4 reduction strategy through increased fibre-based concentrates. Increased concentrate supplementation has been shown to result in a greater proportion of propionate in rumen VFA and, therefore, less hydrogen gas (H_2) for CH_4 synthesis (Newbold *et al*., 2005). Another possibility is that CT reduces the amount of H_2 available in the rumen to form CH_4. This, therefore, results in a decrease of CH_4 production. Beauchemin *et al*. (2008), Martin *et al*. (2009) and Shibata & Terada (2010) reported that modification of the dietary feed has been found to reduce CH_4 emission. According to Beauchemin *et al.* (2008) feeding 4 % oil in the diet will decrease enteric CH_4 emission per cow per day by 23 %. Effects may be due to a reduction in rumen protozoa, reduced fibre digestion, reduced intake, and H_2 use for saturation of unsaturated fatty acids. However, this approach is not profitable since it compromises the performance of the cow.

According to Christopherson *et al*. (2008) and Iqbal *et al*. (2008), another option is the alteration of the rumen fermentation process. Altering the rumen fermentation through improved nutrition reduces the volume of CH_4 produced (Iqbal *et al*., 2008). In vitro CH_4 emission is reduced when the rumen wall is artificially stimulated with increased grain diets in sheep (Christopherson *et al*., 2008). There are, also, other ways of reducing CH_4 production in the rumen, for instance by adding substances such as halogen analogues of CH_4 to the feed to reduce CH_4 production (McDonald *et al*., 2011). However, their effects tend to decrease over time as ruminal microbes adapt to their presence. Antibiotic growth promoters such as lasalocid and monensin, also, reduce the production of CH_4 (McDonald *et al*., 2011), but their uses have been banned in Europe since 2006 because of their harmful effects on the environment (Makkar *et al*., 2007). There is evidence that large quantities of starchy feeds and low inclusion of fibrous feeds favour the channelling of carbon and hydrogen into propionate and a reduction of CH_4 production as a result of less favourable ruminal environment for the CH_4 producing bacteria (Yoshida *et al*., 2010). There are drawbacks of this approach in that the animal is more susceptible to acidosis (McDonald *et al*., 2011).

Another option to consider is the selection of forage legumes with tannins and grasses with high concentrations of water-soluble carbohydrates (Lascano & Cardenes, 2010). Legume-based forages compared to grasses reduce enteric CH_4 production per unit of dry matter intake possibly because of lower fibre and faster rate of passage. In general legumes containing high concentrations of condensed tannins have been shown to reduce enteric CH_4 emission (Lascano & Cardenes, 2010). However, the exact proportion of the forage mixture for effective results is not known. It has been reported that CT reduces CH_4 emission by ruminant animals (Carulla *et al.,* 2005; Puchala *et al.,* 2005). Carulla *et al*. (2005) reported that tannins inhibit ammonia and CH_4 productions through their ability to form complexes with dietary proteins and carbohydrates. Their effects on performance of the animal range from beneficial to toxicity, depending on tannin concentration and nature (Makkar, 2003). Makkar (2003), also, reported that the slow rate of degradation of tannin-rich feeds may result in high rumen fill and hence restrict feed intake. However, the intake of small amounts of tannins tends to decrease CH_4 production and emission in ruminant animals (Makkar *et al*., 2007). Patra & Saxena (2010) compared the effects of CT on CH_4 production and rumen fermentation in livestock. Their review provided extensive information on which forage types are likely to reduce methane emission. Condensed tannins from different plant sources may have different effects on CH_4 production. Similarly, different inclusion level of CT may also affect the amount of CH_4 produced in different ways. It seems probable that all the above mentioned strategies may reduce CH_4 production and emission from livestock. However, their effectiveness may differ from one another ranging from low to medium or high. No study was found on the use of *Acacia* leaf meals on methane emission and productivity of Boer goats. Therefore, there was a need to determine the effect of *A. karroo*, *A. tortilis* and *A. nilotica* leaf meal inclusion levels for optimal productivity and reduction in methane production and emission in goats.

2.7 Conclusion

Goats are economically, nutritionally and culturally very important to the people of Limpopo Province, South Africa. For the goats to survive and be productive they have to browse or graze on high or adequate quality feed materials. During the dry season, feed materials are scarce and available ones are of low quality to meet the nutrient requirements of the goats. On the contrary, browse material such as *Acacia* species are abundantly available during the dry season and have high crude protein. Such protein can be used to offset dietary protein limitation and, therefore, enhance productivity of the goats. However, *Acacia* species contain tannins which are considered to have both adverse and beneficial effects depending on their concentration and nature. Tannins are divided into two major structural classes: condensed and hydrolysable tannins. If large quantities are consumed, condensed tannins reduce forage quality and hydrolysable tannins cause poisoning in animals. Inclusion of *Acacia* species in the diet may also reduce methane produced from the goats since they contain tannins which tend to bind with nutrients. However, there is no conclusive data on the effects of *Acacia* species inclusion on methane production and emission. Additionally, inclusion levels of *Acacia* leaf meals for optimal goat productivity are also not available.

CHAPTER 3

METHODOLOGY AND ANALYTICAL PROCEDURES

3.1 Study site

The experiment was conducted during spring (from August to October, 2016), at the University of Limpopo Experimental farm (Syferkuil), Limpopo province, South Africa. The farm is situated 10 km north-west of the Turfloop campus of the University of Limpopo. The University of Limpopo lies at latitude 27.55 ºS and longitude 24.77 ºE. The ambient temperatures around this area are above 32 °C during summer and between 5 and 25 °C during winter seasons. The mean annual rainfall ranges between 446.8 and 468.4 mm. The dry season occurs between April and October and the rainy season occurs between November and March (Kutu & Asiwe, 2010). Vegetation structure is a Savanna type (bushveld) that is characterised by trees, shrubs and grass undercover. Browsing animals, traditionally, keep a balance between trees and grass. The plant species that are common around the area are *Acacia (A.)* species*, Eragrostis spp.* and *Panicum maximum* (Mucina & Rutherford, 2006).

3.2 Collection and storage of the feeds

The experimental diets consisted of *Avena sativa* hay as a basal diet mixed with *A*. *karroo*, *A*. *tortilis* or *A*. *nilotica* leaf meals. *Acacia* leaves were hand-harvested for a period of a month in June, 2016 at the University of Limpopo Experimental farm. The small branches were cut using a pair of scissors. The leaves from the branches were then shade-dried and stored indoor for 14 days prior to chopping. The samples were chopped, using a 2 mm screen, and then stored in air-tight bags until needed for analysis and feeding. *Avena sativa* hay was bought from a local farmer by the name of Fourie Boerdery in Ladanna, Polokwane. The hay was harvested before summer rains while still green, soft and less stalky. It was shade-dried. It was then chopped and stored in bags under a shade until needed for analysis and feeding.

3.3 Experimental procedures, dietary treatments and designs

The first part of this study was to determine and compare nutrient contents and tannin levels of the three *Acacia* species (*A. karroo, A. tortilis* and *A. nilotica* leaf meals) and *Avena sativa* hay. A completely randomised design was used (SAS, 2008). The three species of *Acacia* leaves and *Avena sativa* hay were the treatments and were replicated three times.

The second part of the study involved feeding different levels of the three *Acacia* species to healthy yearling male Boer goats fed a basal diet of *Avena sativa* hay. The study was divided into a series of experiments due to a lack of equipment to conduct the whole experiment in one session. Inclusion levels were 10, 15, 20 or 30 % for each *Acacia* species. A total of three experiments were conducted and different goats were used in each experiment. A grand total of thirty six (twelve per experiment) yearling male Boer goats with an initial mean live weight of 23 ± 2 kg were ear-tagged and used in a 21-day experiment. The experimental diets were as indicated in Table 3.01, 3.02 and 3.03 for *A. karroo, A. tortilis* and *A. nilotica,* respectively. These inclusions include high and low levels as indicated in the literature (Makkar, 2003). Before the experiment, the goats were dipped and dosed for external and internal parasites with Clout Pour-On and Ecomectin 1 % subcutaneous injection, respectively (manufactured by Afrivet). The goats were, also, intramuscularly injected with oxytetracycline LA-200 antibiotic manufactured by Pfizer. The goats were randomly assigned to four dietary treatments, each having three replications. A completely randomised design (SAS, 2008) was used. The goats were housed in well-ventilated individual metabolic pens. The pens and surrounding environment were cleaned thoroughly and disinfected with Jeyes Fluid manufactured by Tiger Brands.

Table 3.01 Dietary treatments for Experiment 1: *Acacia karroo*

Diet code	Diet description
$H_{As90}AK_{10}$	Yearling male Boer goats fed a mixed diet of 90 % *Avena sativa* hay and 10 % *A. karroo*
$H_{As85}AK_{15}$	Yearling male Boer goats fed a mixed diet of 85 % *Avena sativa* hay and 15 % *A. karroo*
$H_{As80}AK_{20}$	Yearling male Boer goats fed a mixed diet of 80 % *Avena sativa* hay and 20 % *A. karroo*
$H_{As70}AK_{30}$	Yearling male Boer goats fed a mixed diet of 70 % *Avena sativa* hay and 30 % *A. karroo*

Water and mineral lick were offered *ad libitum*. The nutritional composition of the mineral lick is presented in Table 3.04. Diet intake and digestibility, methane emission, productivity and blood profiles of the goats were determined. There were 14 days of adaptation, followed by 7 days of data collection.

Table 3.02 Dietary treatments for Experiment 2: *Acacia tortilis*

Diet code	Diet description
$H_{As90}AT_{10}$	Yearling male Boer goats fed a mixed diet of 90 % *Avena sativa* hay and 10 % *A. tortilis*
$H_{As85}AT_{15}$	Yearling male Boer goats fed a mixed diet of 85 % *Avena sativa* hay and 15 % *A. tortilis*
$H_{As80}AT_{20}$	Yearling male Boer goats fed a mixed diet of 80 % *Avena sativa* hay and 20 % *A. tortilis*
$H_{As70}AT_{30}$	Yearling male Boer goats fed a mixed diet of 70 % *Avena sativa* hay and 30 % *A. tortilis*

Table 3.03 Dietary treatments for Experiment 3: *Acacia nilotica*

Diet code	Diet description
$H_{As90}AN_{10}$	Yearling male Boer goats fed a mixed diet of 90 % *Avena sativa* hay and 10 % *A. nilotica*
$H_{As85}AN_{15}$	Yearling male Boer goats fed a mixed diet of 85 % *Avena sativa* hay and 15 % *A. nilotica*
$H_{As80}AN_{20}$	Yearling male Boer goats fed a mixed diet of 80 % *Avena sativa* hay and 20 % *A. nilotica*
$H_{As70}AN_{30}$	Yearling male Boer goats fed a mixed diet of 70 % *Avena sativa* hay and 30 % of *A. nilotica* per goat per day

Table 3.04 Nutritional composition of the mineral block offered to the experimental goats

Nutrients	Quantity	Units
Protein	280	g/kg
Protein from urea	61.5	%
Protein from other NPN	2.85	%
Urea	60	g/kg
NPN	6	g/kg
Crude fibre	120	g/kg
Moisture	120	g/kg
Calcium	10 / 45	g/kg
Phosphorus	6	g/kg
Magnesium	4	g/kg
Sulphur	8	g/kg
Potassium	12	g/kg
Copper	40	mg/kg
Manganese	600	mg/kg
Zinc	600	mg/kg
Cobalt	1	mg/kg
Iodine	8	mg/kg
Iron	500	mg/kg
Selenium	4	mg/kg
Vitamin A	12 000	IE/kg

Source: Molatek Animal feeds (Multi block 28), South Africa

3.4 Data collection

The live weight of goats was measured using an electronic weighing scale when the experiment commenced. Thereafter, live weight was measured weekly. The live weights were used to calculate growth rates of the goats.

Feed intake and feed conversion ratio were measured throughout the study period. Intake was measured daily by subtracting the weight of the feed leftovers from the feed offered. Feed conversion ratio was calculated as the total amount of feed consumed divided by the weight gain of live goats.

Methane emissions were measured using a hand-held methane detector according to Chagunda *et al*. (2009a). The laser beam of the methane detector was pointed at a distance of 1 m away from the goat and onto the nasal area of the goat to detect the methane gas. Measurements were taken on individual goats with a minimum radius of 6 m away from any other animal. The laser beam is not easily seen under direct sunlight. However, in the current study, it was easy to see the laser beam since the goats were kept in a roofed house. The measurements were taken at 10:00 hours (2 hours after feeding) when the goats were ruminating. All measurements were taken at the same time of the day (10:00 hours). The measurements for each goat were taken within a period of 60 seconds daily and repeated for five consecutive days. Methane produced was then read as parts per million-metre (ppm-m) and reported in ppm-m.

Digestibility measurements were carried out in specially designed metabolic cages fitted with faeces collection trays, separate watering and feeding troughs. The goats were placed in metabolic cages throughout the experiment. Three goats from each dietary treatment were allowed to adapt for a period of 14 days in their cages prior to collection of feed offered, feed leftover and excreta. Faecal bags were used to collect faeces. The data was collected from each replicate for 5 days, weighed, dried, weighed again and then kept for chemical analysis. Water and mineral lick were provided *ad libitum*. Apparent digestibility (AD) of nutrients was calculated according to Khan *et al*. (2003) with the following formula:

$$\text{AD (decimal)} = \frac{\text{(Amount of nutrient ingested - amount of nutrient excreted)}}{\text{(Amount of nutrient ingested)}}$$

Blood was collected before commencement of the experiment and, also, at the end of the experiment. Twelve millilitres of blood samples were collected from each animal *via* the jugular vein puncture. Five and 2 mL of blood samples were released into labelled sample bottle containing ethylene diamine tetra acetic acid (EDTA) and sodium oxalate fluoride for haematological and glucose parameters, respectively. The remaining 5 mL was collected into anticoagulant-free plastic tubes and allowed to clot at room temperature and then centrifuged at 1500 x g for 10 minutes. The supernatant sera were collected and stored at a temperature of -20 ^{o}C for biochemical analysis.

3.5 Chemical composition

All the diets and faeces were analysed for dry matter, organic matter, ash, crude protein, fat, energy and minerals according to AOAC (2002). Neutral and acid detergent fibre contents of feeds and faeces were determined according to Van Soest *et al*. (1991). Tannin contents were determined using the methods of Waterman & Mole (1994).

3.5.1Total phenolics and total tannin determination (Makkar *et al*., 1993, Makkar, 2000)

The total phenolic and tannin contents were measured using Folin-ciocalteu method according to Makkar *et al*. (1993) and Makkar (2000).

Preparation of plant extract

Ten grams of 3 finely ground *Acacia* leaves (*A. karroo, A. tortilis* or *A. nilotica*) were mixed with 100 % (100 mL) methanol separately in clean glass beakers. The 3 samples were placed in a shaker for 1 hour at 200 rpm at room temperature. After 1 hour, they were then removed from the shaker, filtered and placed under a fan to dry. Extracted weights for each sample were calculated after drying.

Preparation of the solutions for standard calibration curve

Folin reagent, distilled water, tannic acid solution and sodium carbonate solution were prepared for tannic acid standard calibration curve. Tannic acid solution (0.1 mg/mL) was prepared by dissolving 0.01 g of tannic acid in 10 mL of distilled water. Methanol was then added to the solution to fill the volume to 100 mL. Sodium carbonate solution was prepared by dissolving 10 g of sodium carbonate in 50 mL of distilled water. Different standard concentrations (0, 0.02, 0.04, 0.06, 0.08, 0.01 mL) ere prepared from a stock solution of tannic acid. The solutions were collected in micro tubes and were mixed well. All the tubes were then placed in the dark for 40 minutes at room temperature. The absorbance of each solution was then measured using Ultra-violet visible (UV-vis) spectrophotometer at a wavelength of 725 nm.

Analysis of total phenolic contents in the extracts

Stock solution of 1 mg/mL of extract with 1000 µL of tannic acid solution was prepared for each sample. Therefore, 400 µL of distilled water, 250 µL of folin reagent and 1250 µL of sodium carbonate solution were added to each sample. The blank was prepared the same way except for the inclusion of the extract. The tubes were mixed well and placed in the dark for 40 minutes at room temperature. The samples were then transferred to spectrophotometer to measure the absorbance rate at a wavelength of 725 nm. The amounts of total phenols were then calculated as tannic acid equivalent from the calibration curve and expressed on a dry matter basis.

Analysis of total tannin contents in the extracts

Polyvinyl-polypirrolidone (PVPP) which binds tannins was used to determine tannin content in the extracts. From the above mentioned stock solution, 1 mL of extract was mixed with 100 mg of PVPP. The sample was then vortexed, kept at 4 °C for 15 minutes and centrifuged at 3 000 rpm for 15 minutes. The non-tannin phenolics were determined the same way as the total phenolics in the clear supernatant according to Velioglu *et al*. (1998). The difference between the total phenolics and non-tannin phenolics was calculated to get the amount of tannins in the extract. The amounts of tannins were then calculated as tannic acid equivalent from the calibration curve and expressed on a dry matter basis.

3.5.2 Condensed tannin determination (Porter *et al.,* 1986: Waterman & Mole, 1994)

A 37 % Butanol-HCL reagent and ferric reagent (2 % ferric ammonium sulphate in 2N HCL) were prepared according to Porter *et al.* (1986) and Waterman and Mole (1994). Three finely ground *Acacia* samples of 2 g were mixed with 10 mL of 100 % acetone and left to dissolve overnight. From the samples, 0.5 mL of tannin extract diluted with 0.3 mL of 100 % acetone was pipetted into a 100 x 12 mm test tube. Thereafter, 3.0 mL of Butanol-HCL reagent and 0.1 mL of the ferric acid were added. The tubes were vortexed and then the mouths of the tubes were covered with parafilm and put in a boiling water bath for 60 minutes. The tubes were allowed to cool and absorbance was recorded at 550 nm. To get the condensed tannin absorbance, the absorbance of unheated mixture (suitable blank) was subtracted from heated mixture. Condensed tannins (% in dry matter) were then calculated as leucocyanidin equivalent using the formula:

$$\frac{(\text{absorbance 550 nm} \times 78.26 \times \text{dilution factor})}{(\%\text{ in dry matter})}$$

3.5.3 Test for tannins (Ayoola *et al*., 2008)

Avena sativa hay was tested for the presence of tannins. A sample of 0.5 g of the extract was boiled in 10 mL of water in a test tube and then filtered. A few drops of 0.1 % ferric chloride was added and observed for brownish green or a blue-black colouration.

3.5.4 Hydrolysable tannin determination (Hartzfeld *et al*., 2002)

Hydrolysable tannins were measured using a modified method of Hartzfeld *et al*. (2002). A widely used method for analysing hydrolysable tannins after reaction with potassium iodate (KIO_3) has been modified to include a methanolysis step followed by oxidation with KIO_3. In the new method, hydrolysable tannins (gallotannins and ellagitannins) were reacted at 85 °C for 20 hours in methanol to quantitatively release methyl gallate. *Acacia* leaf samples were methanolyzed under the same conditions to convert hydrolysable tannins to methyl gallate. Oxidation of the methyl gallate by KIO_3 at pH 5.5, 30 °C, formed a chromophore with λ_{max} 525 nm, which were determined spectrophotometrically. The detection limit of the method was 1.5 µg of methyl gallate, and with the samples, relative standard deviations of less than 3 % were obtained.

3.5.6 Blood profile determination

Haematocrit and haemoglobin concentration determinations followed the procedures outlined by Dacie & Lewis (2001). Red blood cells (RBC) and white blood cells (WBC) were determined using the Neubauer haemocytometer after appropriate dilution. Serum urea was measured by modified method of Valley *et al*. (1980). Sodium oxalate fluoride was used for glucose preservation while the blood glucose was determined by enzymatic colorimetric test (Quimica Clinica Applicada, S.A Kit). Cholesterol was determined using the method of Pires *et al.* (2003). Serum total protein and albumin were determined by the biuret method (Peters *et al*., 1982). The activities of the enzymes alkaline phosphate (ALP), alanine transaminase (ALT) and aspartate transaminase (AST) were measured using the method of Roy (1970). Electrolytes and mineral elements were estimated with an atomic absorption spectrophotometer, Model 490 (Gallenkamp and Co. Ltd., London).

3.6 Statistical analysis

The nutrient and tannin contents of *A*. *karroo* leaves, *A*. *tortilis* leaves, *A*. *nilotica* leaves and *Avena sativa* hay were subjected to analysis of variance (ANOVA) using SAS (2008). All the treatment effects of *A. karroo, A. tortilis* and *A. nilotica* leaf meal inclusion levels on diet intake and digestibility, methane emission, productivity and blood profiles of yearling male Boer goats were subjected to analysis of covariance (ANCOVA) using SAS (2008).

Intake, digestibility, live weight, weight gain and feed conversion ratio (FCR) were adjusted for final weight, FCR, dry matter intake, FCR and weight gain, respectively, by covariance analysis and were presented as adjusted least-square means. Where the covariates showed no significant effect, the data were analysed with ANOVA in a completely randomized design at 5 % ($P<0.05$) level of probability with diet as a fixed factor (SAS, 2008). Where significant treatment effects were detected, means were separated by Fisher's least significant difference (LSD) using SAS (2008).

In the case of methane and blood, data were scrutinised by ANCOVA using methane and blood baseline values, respectively, as the covariates to control statistically for differences in baseline values. Where the covariates showed no significant effect, the data were analysed with ANOVA in a completely randomized design with diet as a fixed factor. Additionally, methane and blood data obtained before and during the experiment were compared using ANOVA in a completely randomized design to monitor the changes in methane and blood of yearling Boer goat on *A. karroo*, *A. tortilis* and *A. nilotica* leaf meals. Where significant treatment effects were detected, treatment means were compared using LSD at the 5 % level of probability.

Regression equations were used to determine the relationships and responses in optimal diet intake and digestibility, methane emission, productivity and blood profiles of yearling male Boer goats to differing inclusion levels of *A*. *karroo*, *A*. *tortilis* and *A*. *nilotica* leaf meal (SPSS, 2009). The levels for optimal responses were modelled using the following quadratic equation (SPSS, 2009):

$Y = a + b_1x + b_2x^2$

Where y = diet intake or digestibility, methane emission, productivity or blood profiles; a = intercept; b_1 and b_2 = coefficients of the quadratic equations, x = inclusion level of *A. karroo, A. tortilis* or *A. nilotica* leaf meal and $-b_1/2b_2$ = x value for optimal response. The quadratic model was used because it gave the best fit.

Where applicable, the relationship between optimal responses in diet intake and digestibility, methane emission, productivity or blood profiles across different inclusion levels of *A. karroo, A. tortilis* and *A. nilotica* leaf meal were modelled using the following linear regression equation (SPSS, 2009):

$Y = a + bx$

Where y = optimal diet intake or digestibility, methane emission, productivity or blood profiles; a = intercept; b = coefficient of the linear equation, x = inclusion level of *A. karroo, A. tortilis* or *A. nilotica* leaf meal.

CHAPTER 4

RESULTS

4.1 The nutrient and tannin composition of *Acacia karroo*, *Acacia tortilis* and *Acacia nilotica* leaf meals and *Avena sativa* hay

The nutrient and tannin contents of *Acacia* (*A.*) *karroo*, *A. tortilis* and *A. nilotica* leaf meals and *Avena sativa* hay are presented in Table 4.01. All the three *Acacia* species and *Avena sativa* hay had similar (P>0.05) dry matter, potassium, zinc and phosphorus contents. *Avena sativa* hay and *A. tortilis* leaves had higher (P<0.05) organic matter (OM) contents than *A. karroo* and *A. nilotica* leaves. However, *Avena sativa* hay and *A. tortilis* leaves had similar (P>0.05) OM contents. Similarly, *A. karroo* and *A. nilotica* leaves had same (P>0.05) OM contents. All the three *Acacia* species had higher (P<0.05) ash contents compared to *Avena sativa* hay. *Acacia karroo* leaves had higher (P<0.05) ash content than *A. tortilis* leaves. However, *A. karroo* and *A. nilotica* leaves had similar (P>0.05) ash contents. Similarly, *A. tortilis* and *A. nilotica* leaves had same (P>0.05) ash contents.

All the three *Acacia* species had higher (P<0.05) crude protein (CP) contents compared to *Avena sativa* hay (Table 4.01). *Acacia tortilis* leaves had higher (P<0.05) CP content than *A. karroo* and *A. nilotica* leaves. However, *A. karroo* and *A. nilotica* leaves had similar (P>0.05) CP contents. *Avena sativa* hay and *A. tortilis* leaves had higher (P<0.05) neutral detergent fibre contents than *A. karroo* and *A. nilotica* leaves*,* followed by *A. karroo* leaves*. Acacia tortilis* leaves had higher (P<0.05) acid detergent fibre content, followed by *Avena sativa* hay, *A. karroo* and *A. nilotica* leaves, respectively. *Acacia* species had higher (P<0.05) fat contents than *Avena sativa* hay. Among *Acacia* species, *A. tortilis* leaves had higher (P<0.05) fat content than *A. karroo* and *A. nilotica* leaves. However, *A. karroo* and *A. nilotica* leaves had similar (P>0.05) fat contents. *Acacia* species had higher (P<0.05) energy contents than *Avena sativa* hay. Among *Acacia* species, *A. tortilis* and *A. nilotica* leaves had higher (P<0.05) energy contents than *A. karroo* leaves. However, no differences (P>0.05) in energy contents were observed between *A. tortilis* and *A. nilotica* leaves.

No tannins were detected in *Avena sativa* hay (Table 4.01). Among *Acacia* species, *A. nilotica* leaves had higher (P<0.05) total phenolic and total tannin contents than *A. karroo* and *A. tortilis* leaves*.* However, similar (P>0.05) total phenolic and total tannin contents were observed in *A. karroo* and *A. tortilis* leaves. All the three *Acacia*

Table 4.01 Nutrient composition of the *Acacia* leaves and *Avena sativa* hay

Nutrient	*Acacia* species			*Avena sativa* hay
	A. karroo	*A. tortilis*	*A. nilotica*	
Dry matter (%)	94.55 ±0.318	95.35 ±0.202	94.44 ±0.254	94.29 ±0.167
Organic matter (%)	84.74^{b} ±0.427	87.11^{a} ±0.064	85.76^{b} ±0.439	87.77^{a} ±0.445
Ash (%)	9.81^{a} ±0.467	8.24^{b} ±0.139	8.76^{ab} ±0.439	6.52^{c} ±0.300
Crude protein (%)	13.08^{b} ±0.046	14.49^{a} ±0.283	12.42^{b} ±0.243	6.93^{c} ±0.537
Neutral detergent fibre (%)	43.50^{b} ±0.289	62.04^{a} ±0.023	32.37^{c} ±0.214	62.36^{a} ±0.208
Acid detergent fibre (%)	37.31^{c} ±0.179	47.30^{a} ±0.173	19.54^{d} ±0.312	40.22^{b} ±0.127
Fat (%)	2.49^{b} ±0.283	3.08^{a} ±0.046	2.21^{b} ±0.121	1.10^{c} ±0.058
Energy (MJ/kg)	18.42^{b} ±0.050	19.67^{a} ±0.186	19.35^{a} ±0.009	17.57^{c} ±0.119
Total phenolics*	2.76^{b} ±0.438	2.59^{b} ±0.342	4.07^{a} ±0.038	0.00^{c} ±0.000
Total tannins*	2.14^{b} ±0.079	1.96^{b} ±0.266	3.73^{a} ±0.422	0.00^{c} ±0.000
Condensed tannins**	1.61^{a} ±0.352	1.76^{a} ±0.437	1.49^{a} ±0.281	0.00^{b} ±0.000
Hydrolysable tannins (mg/g)	0.00^{b} ±0.000	0.00^{b} ±0.000	128^{a} ±7.390	0.00^{b} ±0.000
Calcium (%)	2.12^{a} ±0.069	1.74^{a} ±0.427	1.73^{a} ±0.422	0.28^{b} ±0.046
Magnesium (%)	0.33^{a} ±0.017	0.20^{b} ±0.029	0.16^{b} ±0.035	0.12^{b} ±0.012
Potassium (%)	1.09 ±0.052	1.04 ±0.023	1.00 ±0.289	1.85 ±0.491
Sodium (%)	1.23^{a} ±0.133	0.03^{b} ±0.006	0.02^{b} ±0.006	0.04^{b} ±0.006
K/Ca + Mg (%)	0.21^{b} ±0.064	0.26^{b} ±0.035	0.26^{b} ±0.092	2.03^{a} ±0.306
Phosphorus (%)	0.10 ±0.029	0.11 ±0.017	0.09 ±0.023	0.16 ±0.035
Zinc (mg/kg or ppm)	17.00 ±1.155	15.00 ±1.732	19.00 ±1.155	15.00 ±1.155
Copper (mg/kg or ppm)	3.00^{b} ±0.577	2.00^{b} ±0.289	10.00^{a} ±2.887	3.00^{b} ±0.289
Molybdenum (mg/kg)	31.00^{d} ±1.155	54.00^{b} ±1.732	60.00^{a} ±1.155	44.00^{c} ±2.309
Iron (mg/kg or ppm)	337^{c} ±4.042	653^{a} ±3.464	513^{b} ±4.042	235^{d} ±2.887

$^{a, b, c, d}$:	Means in the same row not sharing a common superscript are significantly different (P<0.05)
*:	Percentage DM tannic acid equivalent
**:	Percentage DM leucocyanidin equivalent
K/Ca + Mg:	Potassium/Calcium plus Magnesium

species had similar (P>0.05) contents of condensed tannins. *Acacia nilotica* leaves had higher hydrolysable tannins than *A. karroo* and *A. tortilis* leaves and *Avena sativa* hay. However, *A. karroo* and *A. tortilis* leaves and *Avena sativa* hay had similar (P>0.05) hydrolysable tannin contents.

Acacia species had higher ($P<0.05$) calcium contents than *Avena sativa* hay (Table 4.01). However, *A. karroo, A. tortilis* and *A. nilotica* leaves had similar ($P>0.05$) calcium content levels. *Acacia karroo* leaves contained higher ($P<0.05$) magnesium and sodium contents than did *A. tortilis* and *A. nilotica* leaves and *Avena sativa* hay. *Acacia tortilis* leaves, *A. nilotica* leaves and *Avena sativa* hay contained similar ($P>0.05$) magnesium and sodium contents. *Avena sativa* hay had higher ($P<0.05$) ratio of potassium/calcium plus magnesium than *Acacia* species. However, no differences ($P>0.05$) in ratio of potassium/calcium plus magnesium were observed between *Acacia* species. *Acacia nilotica* leaves had higher ($P<0.05$) copper content than *A. karroo* and *A. tortilis* leaves and *Avena sativa* hay, which were observed to be similar ($P>0.05$). *Acacia nilotica* leaves had higher ($P<0.05$) molybdenum content, followed by *A. tortilis* and *A. karroo* leaves and *Avena sativa* hay, respectively. *Acacia tortilis* leaves had higher ($P<0.05$) iron content, followed by *A. nilotica* and *A. karroo* leaves and *Avena sativa* hay, respectively.

4.2 Effect of *Acacia karroo* leaf meal inclusion level on diet intake, digestibility, methane emission, live weight, feed conversion ratio, haematological indices and blood biochemical components of yearling male Boer goats fed an *Avena sativa* hay-based diet

The nutrient composition of mixtures of *A. karroo* and *Avena sativa* hay are presented in Table 4.02. *Acacia karroo* leaf meal inclusion level had no effect ($P>0.05$) on diet dry matter (DM), organic matter (OM), acid detergent fibre (ADF) and energy contents. However, *A. karroo* leaf meal inclusion level affected ($P<0.05$) diet ash, crude protein (CP), neutral detergent fibre (NDF) and fat contents. Diet ash, CP and fat contents increased ($P<0.05$) with increased *A. karroo* leaf meal inclusion levels. A diet having a 10 % *A. karroo* leaf meal inclusion level had a higher ($P<0.05$) NDF content than those having 20 or 30 % *A. karroo* leaf meal inclusion levels. Similarly, a diet having a 20 % *A. karroo* leaf meal inclusion level had a higher ($P<0.05$) NDF content than a diet having a 30 % *A. karroo* leaf meal inclusion level. However, diets having 15 or 20 % *A. karroo* leaf meal inclusion levels had similar ($P>0.05$) NDF contents.

Table 4.02 Nutrient composition of the experimental *Acacia karroo* diets

Nutrient	Diet$^{\#}$			
	$H_{As90}AK_{10}$	$H_{As85}AK_{15}$	$H_{As80}AK_{20}$	$H_{As70}AK_{30}$
Dry matter (%)	94.32 ±0.545	94.33 ±0.545	94.34 ±0.545	94.37 ±0.545
Organic matter (%)	87.47 ±0.505	87.32 ±0.504	87.16 ±0.503	86.86 ±0.502
Ash (%)	6.85^{d} ±0.040	7.01^{c} ±0.041	7.18^{b} ±0.042	7.51^{a} ±0.043
Crude protein (%)	7.55^{d} ±0.044	7.85^{c} ±0.045	8.16^{b} ±0.047	8.78^{a} ±0.051
Neutral detergent fibre (%)	60.47^{a} ±0.349	59.53^{ab} ±0.344	58.59^{b} ±0.338	56.70^{c} ±0.327
Acid detergent fibre (%)	39.93 ±0.231	39.78 ±0.229	39.64 ±0.228	39.35 ±0.227
Fat (%)	1.24^{d} ±0.007	1.31^{c} ±0.008	1.38^{b} ±0.008	1.52^{a} ±0.009
Energy (MJ/kg)	17.66 ±0.103	17.70 ±0.094	17.74 ±0.086	17.83 ±0.070
Total phenolics*	0.28^{d} ±0.002	0.41^{c} ±0.002	0.55^{b} ±0.003	0.83^{a} ±0.005
Total tannins*	0.21^{d} ±0.001	0.32^{c} ±0.002	0.43^{b} ±0.003	0.64^{a} ±0.004
Condensed tannins**	0.16^{d} ±0.001	0.24^{c} ±0.001	0.32^{b} ±0.002	0.48^{a} ±0.003
Hydrolysable tannins (mg/g)	0.00 ±0.000	0.00 ±0.000	0.00 ±0.000	0.00 ±0.000
Calcium (%)	0.46^{d} ±0.003	0.56^{c} ±0.003	0.65^{b} ±0.004	0.83^{a} ±0.005
Magnesium (%)	0.14^{d} ±0.001	0.15^{c} ±0.001	0.16^{b} ±0.001	0.18^{a} ±0.001
Potassium (%)	1.77^{a} ±0.010	1.74^{b} ±0.010	1.70^{c} ±0.009	1.62^{d} ±0.009
Sodium (%)	0.16^{d} ±0.001	0.22^{c} ±0.001	0.28^{b} ±0.002	0.40^{a} ±0.002
K/Ca + Mg (%)	1.85^{a} ±0.011	1.76^{b} ±0.010	1.67^{c} ±0.009	1.48^{d} ±0.009
Phosphorus (%)	0.15^{a} ±0.001	0.15^{a} ±0.001	0.15^{a} ±0.001	0.14^{b} ±0.001
Zinc (mg/kg or ppm)	15.20^{b} ±0.088	15.30^{b} ±0.088	15.40^{ab} ±0.089	15.60^{a} ±0.090
Copper (mg/kg or ppm)	3.00 ±0.017	3.00 ±0.017	3.00 ±0.017	3.00 ±0.017
Molybdenum (mg/kg)	42.70^{a} ±0.247	42.05^{ab} ±0.243	41.40^{b} ±0.239	40.10^{c} ±0.234
Iron (mg/kg or ppm)	245^{d} ±1.426	250^{c} ±1.445	255^{b} ±1.475	265^{a} ±1.533

$^{a, b, c, d}$: Means in the same row not sharing a common superscript are significantly different (P<0.05)

*: Percentage DM tannic acid equivalent

**: Percentage DM leucocyanidin equivalent

K/Ca + Mg: Potassium/Calcium plus Magnesium

$^{\#}$: Diet codes are explained in Table 3.01, Chapter 3

No hydrolysable tannins were detected in the *A. karroo* and *Avena sativa* mixed diets (Table 4.02). Increasing *A. karroo* leaf meal inclusion level in the diet increased (P<0.05) total phenolics, total tannins and condensed tannins (CT). Similarly, increased levels of *A. karroo* leaf meal resulted in increased (P<0.05) diet levels of calcium, magnesium and sodium. However, increasing *A. karroo* leaf meal inclusion level in the diet decreased (P<0.05) levels of potassium and the ratio of potassium/calcium plus magnesium. A diet having a 30 % *A. karroo* leaf meal inclusion level had a lower (P<0.05) phosphorus (P) content than diets having 10, 15 or 20 % *A. karroo* leaf meal inclusion levels. However, diets having 10, 15 or 20 % *A. karroo* leaf meal inclusion levels had similar (P>0.05) P contents.

Acacia karroo leaf meal inclusion level in the diets based on *Avena sativa* hay had no effect (P>0.05) on diet copper content (Table 4.02). A diet having a 30 % *A. karroo* leaf meal inclusion level had a higher (P<0.05) zinc (Zn) content than those having *A. karroo* leaf meal inclusion levels of 10 or 15 %. However, diets having 10, 15 or 20 % *A. karroo* leaf meal inclusion levels had similar (P>0.05) Zn contents. Similarly, diets having 20 or 30 % *A. karroo* leaf meal inclusion levels had same (P>0.05) Zn contents. A diet with a 10 % *A. karroo* leaf meal inclusion level had a higher (P<0.05) molybdenum (Mo) content than those having 20 or 30 % *A. karroo* leaf meal inclusion levels. Similarly, a diet having a 20 % *A. karroo* leaf meal inclusion level had a higher (P<0.05) Mo content than that having a 30 % *A. karroo* leaf meal inclusion level. However, diets having 10 or 15 % *A. karroo* leaf meal inclusion levels had similar (P>0.05) Mo contents. Similarly, diets having 15 or 20 % *A. karroo* leaf meal inclusion levels had same (P>0.05) Mo contents. Increasing *A. karroo* leaf meal inclusion level increased (P<0.05) diet iron content.

The results of the effect of *A. karroo* leaf meal inclusion level on intake, digestibility, methane emission, live weight, weight gain and feed conversion ratio (FCR) of yearling male Boer goats fed *Avena sativa* hay-based diets are presented in Table 4.03. *Acacia karroo* leaf meal inclusion level had no effect (P>0.05) on diet intake, methane emission, live weight and weight gain of goats. Similarly, *A. karroo* leaf meal inclusion level had no effect (P>0.05) on diet DM, OM, ash, CP, fat and energy digestibilities by goats. However, diet NDF and acid detergent fibre (ADF) digestibilities were affected (P<0.05) by *A. karroo* leaf meal inclusion level. Male Boer goats on a diet having a 20 % *A. karroo* leaf meal inclusion level had higher (P<0.05) NDF and ADF digestibilities than those on a diet having a 30 % *A. karroo* leaf meal inclusion level. However, goats on diets containing 10, 15 or 20 % *A. karroo* leaf meal inclusion levels had similar (P>0.05) diet NDF and ADF digestibility values. Similarly, goats on diets having 10, 15 or 30 % *A. karroo* leaf meal inclusion levels had same (P>0.05) diet NDF and ADF digestibilities.

Table 4.03 Effect of *Acacia karroo* leaf meal inclusion level on diet intake, digestibility, methane emission, live weight change and feed conversion ratio of yearling male Boer goats fed an *Avena sativa* hay-based diet

Variable	Diet[#]			
	$H_{As90}AK_{10}$	$H_{As85}AK_{15}$	$H_{As80}AK_{20}$	$H_{As70}AK_{30}$
Intake (g/goat/day)				
DM	264 ±40.223	337 ±40.451	370 ±40.602	288 ±40.247
OM	231 ±35.047	295 ±35.246	322 ±35.377	250 ±35.068
Ash	18.09 ±2.901	23.65 ±2.918	26.54 ±2.929	21.60 ±2.903
CP	19.94 ±3.309	26.49 ±3.328	30.16 ±3.340	25.26 ±3.311
NDF	160 ±23.493	201 ±23.627	217 ±23.715	163 ±23.507
ADF	106 ±15.932	134 ±16.023	147 ±16.083	113 ±15.942
Fat	3.28 ±0.561	4.42 ±0.564	5.10 ±0.566	4.37 ±0.562
Energy intake (MJ/day)	4.67 ±0.688	5.97 ±0.691	6.56 ±0.694	5.13 ±0.688
Intake (g/kg $W^{0.75}$)				
DM	25.29 ±3.415	31.79 ±3.435	34.19 ±3.447	26.99 ±3.417
OM	22.12 ±2.976	27.76 ±2.993	29.80 ±3.004	23.44 ±2.978
Ash	1.73 ±0.246	2.23 ±0.248	2.45 ±0.248	2.03 ±0.246
CP	1.91 ±0.280	2.50 ±0.282	2.79 ±0.283	2.37 ±0.281
NDF	15.29 ±1.996	18.92 ±2.007	20.03 ±2.015	15.30 ±1.997
ADF	10.10 ±1.353	12.65 ±1.361	13.55 ±1.366	10.62 ±1.354
Fat	0.31 ±0.048	0.42 ±0.048	0.47 ±0.048	0.41 ±0.048
Energy intake (MJ/kg $W^{0.75}$)	0.45 ±0.058	0.56 ±0.059	0.61 ±0.059	0.48 ±0.058
Digestibility (decimal)				
DM	0.55 ±0.147	0.55 ±0.063	0.63 ±0.078	0.42 ±0.277
OM	0.55 ±0.148	0.54 ±0.063	0.62 ±0.079	0.40 ±0.279
Ash	0.44 ±0.221	0.55 ±0.095	0.51 ±0.118	0.39 ±0.418
CP	0.31 ±0.268	0.48 ±0.115	0.44 ±0.143	0.20 ±0.507
NDF	0.44^{ab} ±0.198	0.38^{ab} ±0.085	0.52^{a} ±0.105	0.16^{b} ±0.374
ADF	0.29^{ab} ±0.278	0.27^{ab} ±0.119	0.41^{a} ±0.148	0.04^{b} ±0.526
Fat	0.61 ±0.466	0.48 ±0.201	0.42 ±0.248	0.42 ±0.882
Energy	0.50 ±0.174	0.50 ±0.075	0.59 ±0.092	0.34 ±0.328
Methane emission (ppm-m)	13.80 ±1.668	13.07 ±0.668	13.33 ±0.668	12.40 ±0.698
Live weight (g/goat/day)				
Initial (kg)	23.15 ±3.715	22.52 ±2.639	23.97 ±2.965	22.85 ±2.707
Final (kg)	23.38 ±3.534	22.88 ±2.511	24.33 ±2.821	23.27 ±2.576
Weight gain (g/goat/day)	46.00 ±200.621	73.33 ±86.252	73.33 ±106.608	83.33 ±379.350
Feed conversion ratio	5.74^{a} ±0.241	4.60^{b} ±0.238	5.04^{ab} ±0.238	3.45^{c} ±0.242

[a, b, c]: Means in the same row not sharing a common superscript are significantly different (P<0.05)

[#]: Diet codes are explained in Table 3.01, Chapter 3

Boer goats on a diet containing a 30 % *A. karroo* leaf meal inclusion level had a better (P<0.05) FCR value than those on diets having 10, 15 or 20 % *A. karroo* leaf meal inclusion levels. Similarly, goats on a diet with a 15 % *A. karroo* leaf meal inclusion level had a better (P<0.05) FCR value than goats on a diet having a 10 % *A. karroo* leaf meal inclusion level. However, goats on diets having 10 or 20 % *A. karroo* leaf meal inclusion levels had similar (P>0.05) FCR values. Similarly, goats on diets containing 15 or 20 % *A. karroo* leaf meal inclusion levels had similar (P>0.05) FCR values.

Diet NDF and ADF digestibilities by goats were optimised at *A. karroo* leaf meal inclusion levels of 13.50 (r^2 = 0.805) and 16.75 (r^2 = 0.838), respectively (Figures 4.01 and 4.02, respectively, and Table 4.04). A negative relationship was observed between *A. karroo* leaf meal inclusion level and FCR (r^2 = 0.825) in male Boer goats (Figure 4.03).

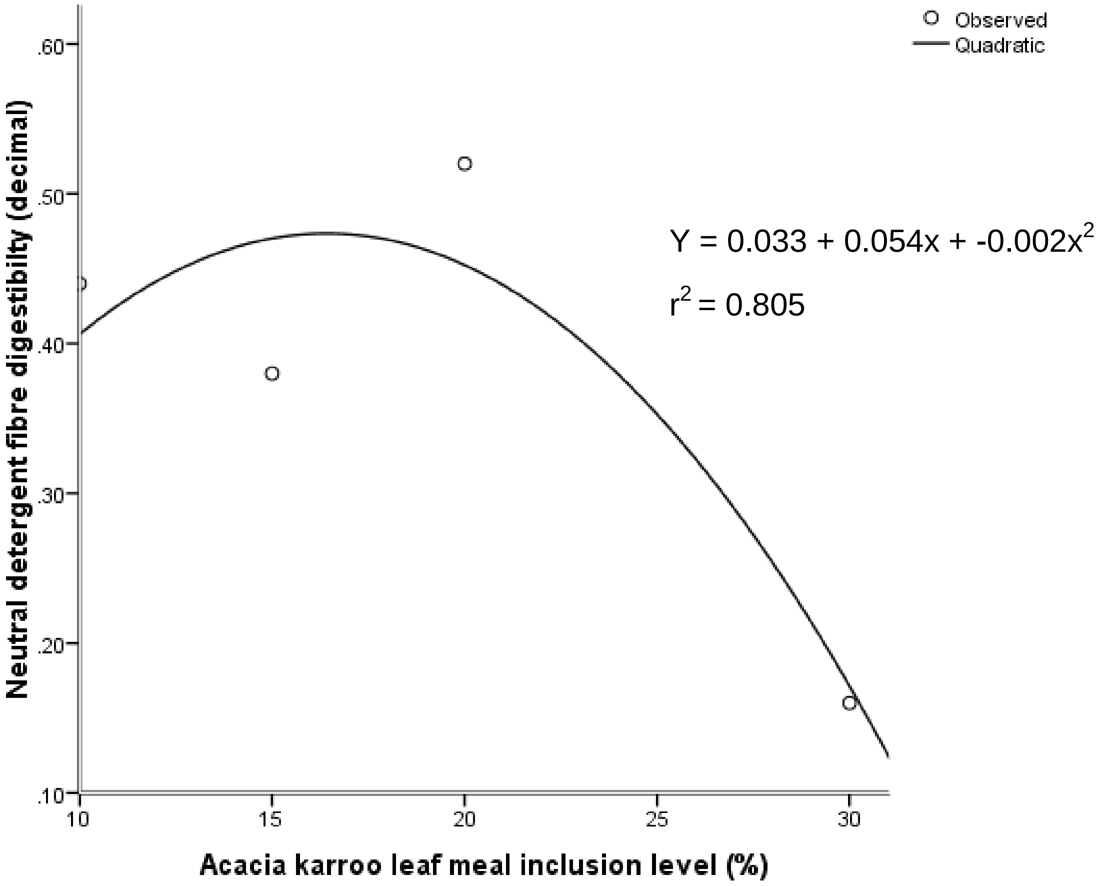

Figure 4.01 Effect of *Acacia karroo* leaf meal inclusion level on diet neutral detergent fibre digestibility in yearling male Boer goats fed an *Avena sativa* hay-based diet

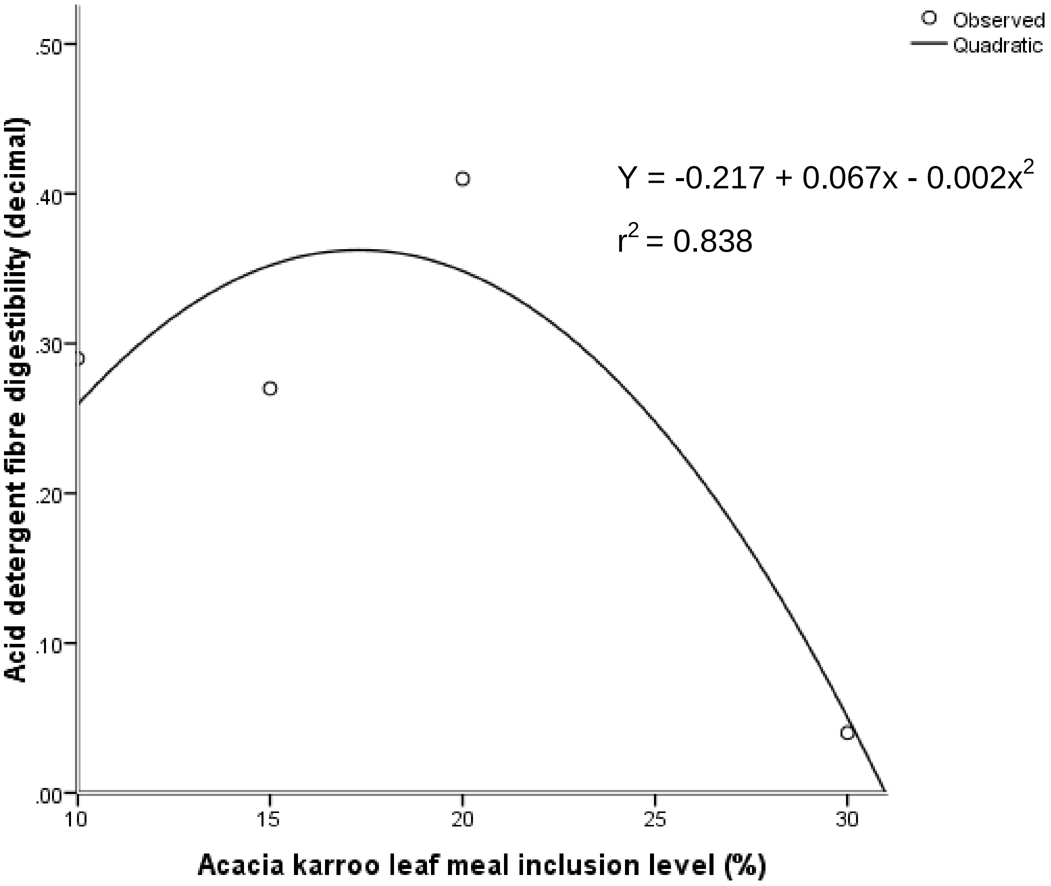

Figure 4.02 Effect of *Acacia karroo* leaf meal inclusion level on diet acid detergent fibre digestibility in yearling male Boer goats fed an *Avena sativa* hay-based diet

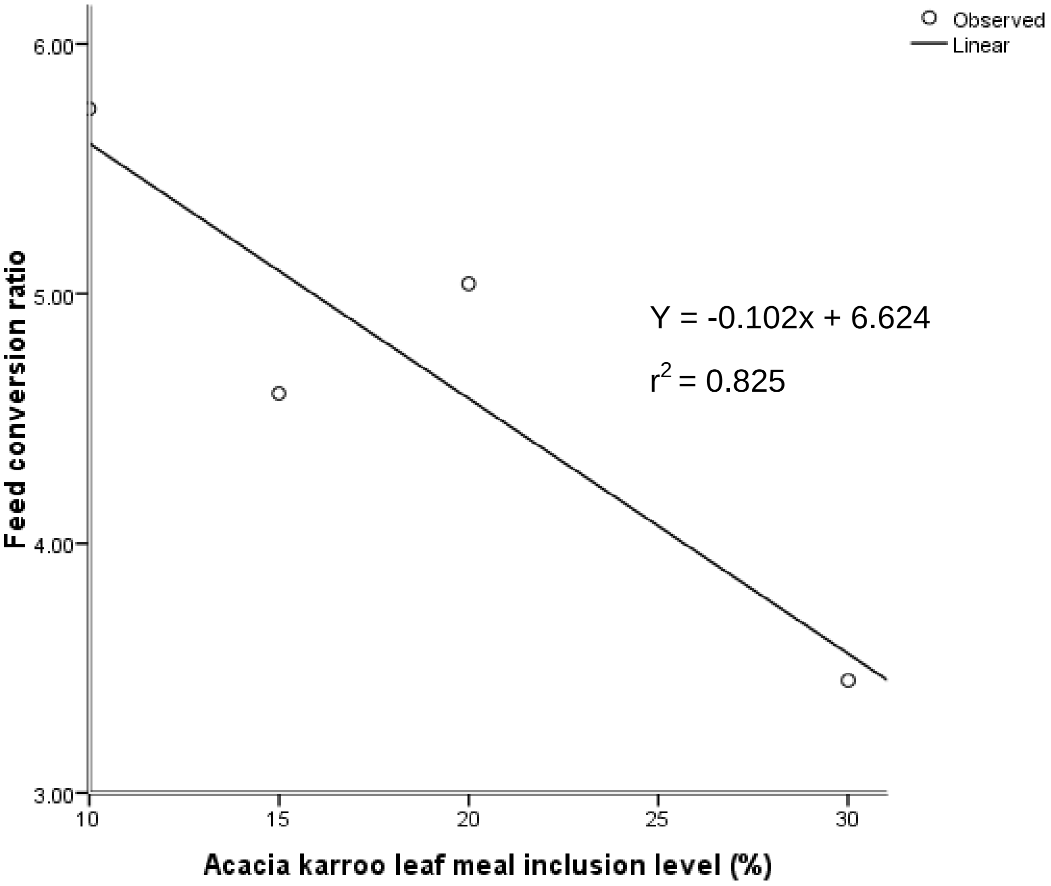

Figure 4.03 Relationship between *Acacia karroo* leaf meal inclusion level and feed conversion ratio in yearling male Boer goats fed an *Avena sativa* hay-based diet

Table 4.04 *Acacia karroo* leaf meal inclusion levels for optimal diet intake and digestibility in yearling male Boer goats fed an *Avena sativa* hay-based diet

Factor	Formula	X	Y	r^2	P
Digestibility (decimal)					
NDF	$Y = 0.033 + 0.054x + -0.002x^2$	13.50	0.40	0.805	0.442
ADF	$Y = -0.217 + 0.067x -0.002x^2$	16.75	0.78	0.838	0.402

X: Inclusion level for optimal value

Y: Optimal Y-level

r^2: Coefficient of determination

P: Probability

Methane emission values of yearling Boer goats before the start of the experiment and during the experiment involving *A. karroo* leaf meal inclusion level are presented in Table 4.05. Inclusion of *A. karroo* leaf meal in the diets of male Boer goats reduced ($P<0.05$) methane emission.

Table 4.05 Effect of *Acacia karroo* leaf meal inclusion on methane emission of yearling male Boer goats fed an *Avena sativa* hay-based diet

Diet[#]	Methane emission (ppm-m)	
	Before experiment	After experiment
$H_{As90}AK_{10}$	$22.00^a \pm 5.686$	$13.80^b \pm 1.963$
$H_{As85}AK_{15}$	$23.00^a \pm 5.686$	$13.07^b \pm 1.009$
$H_{As80}AK_{20}$	$21.67^a \pm 4.163$	$13.33^b \pm 0.982$
$H_{As70}AK_{30}$	$23.00^a \pm 2.603$	$12.40^b \pm 0.757$

$^{a,\ b}$: Means in the same row not sharing a common superscript are significantly different ($P<0.05$)

[#]: Diet codes are explained in Table 3.01, Chapter 3

The haematological indices and blood biochemical components of yearling Boer goats before the start of the experiment are presented in Table 4.06. All the goats had similar ($P>0.05$) haematological indices and blood biochemical values. The haematological indices and blood biochemical components of yearling Boer goats fed diets having different mixture levels of *A. karroo* leaf meal and *Avena sativa* hay are presented in Table 4.07. *Acacia karroo* leaf meal inclusion level had no effect ($P>0.05$) on the haematological indices, blood proteins and enzymes of Boer goats.

Similarly, *A. karroo* leaf meal inclusion level did not affect (P>0.05) blood urea of the goats. However, goats on diets having 15, 20 or 30 % *A. karroo* leaf meal inclusion levels had higher (P<0.05) blood glucose levels than those on a diet having a 10 % *A. karroo* leaf meal inclusion level. Goats on diets having 15, 20 or 30 % *A. karroo* leaf meal inclusion levels had similar (P>0.05) blood glucose levels. Goats fed a diet having a 10 % *A. karroo* leaf meal inclusion level had a higher (P<0.05) blood cholesterol level than those on diets having 15, 20 or 30 % *A. karroo* leaf meal inclusion levels. However, goats on diets having 15, 20 or 30 % *A. karroo* leaf meal inclusion levels had similar (P>0.05) blood cholesterol levels.

Acacia karroo leaf meal inclusion level had no effect (P>0.05) on blood electrolytes of Boer goats except for inorganic phosphate (Table 4.07). Goats on a diet having a 30 % *A. karroo* leaf meal inclusion level had a higher (P<0.05) blood inorganic phosphate than those on diets having 10, 15 or 20 % *A. karroo* leaf meal inclusion levels. However, goats on diets having 10, 15 or 20 % *A. karroo* leaf meal inclusion levels had similar (P>0.05) blood inorganic phosphate values.

Blood glucose and cholesterol contents in Boer goats were optimised at *A. karroo* leaf meal inclusion levels of 23.50 (r^2 = 0.912) and 20.83 (r^2 = 0.978), respectively (Figures 4.04 and 4.05, respectively, and Table 4.08). A positive relationship was observed between *A. karroo* leaf meal inclusion level and blood inorganic phosphate (r^2 = 0.959) in male Boer goats (Figure 4.06).

Table 4.06 Haematological indices and blood biochemical components of yearling Boer goats before the start of the experiment on *Acacia karroo* leaf meal

Variable	Diet[#]			
	$H_{As90}AK_{10}$	$H_{As85}AK_{15}$	$H_{As80}AK_{20}$	$H_{As70}AK_{30}$
Haematology				
Red blood cell ($x10^{12}$/L)	1.51 ±0.044	1.88 ±0.187	2.08 ±0.159	5.43 ±3.854
Haemoglobin (g/dL)	8.90 ±0.751	8.90 ±0.555	9.40 ±0.610	9.25 ±0.618
Haematocrit (L/L)	0.62 ±0.062	0.65 ±0.050	0.69 ±0.085	0.65 ±0.027
White blood cell ($x10^{9}$/L)	22.66 ±1.726	29.66 ±2.326	28.14 ±3.432	28.95 ±3.280
Metabolites (mmol/L)				
Urea	5.25 ±0.479	5.00 ±0.408	4.25 ±0.629	5.25 ±0.479
Glucose	3.40 ±0.108	3.23 ±0.132	3.85 ±0.427	3.58 ±0.243
Cholesterol	1.57 ±0.201	2.06 ±0.155	1.71 ±0.151	1.76 ±0.218
Proteins (g/L)				
Total Protein	72.00 ±2.701	77.00 ±7.106	73.50 ±6.198	75.50 ±5.575
Albumin	16.00 ±0.707	16.00 ±0.707	16.50 ±1.190	15.75 ±0.947
Enzymes (IU/L)				
ALP	166 ±71.968	155 ±84.645	245 ±83.577	292 ±134.617
ALT	23.25 ±1.377	23.75 ±3.119	25.00 ±2.739	30.00 ±5.339
AST	60.00 ±5.492	68.25 ±5.558	76.00 ±5.212	75.00 ±5.874
Electrolytes (mmol/L)				
Sodium	143 ±1.205	143 ±0.348	144 ±0.746	143 ±0.875
Potassium	4.76 ±0.122	5.07 ±0.024	5.09 ±0.316	4.81 ±0.203
Chloride	110 ±0.696	109 ±0.505	110 ±0.590	110 ±0.885
Total Calcium	2.21 ±0.049	2.20 ±0.066	2.25 ±0.081	2.26 ±0.071
Corrected Calcium	2.19 ±0.041	2.20 ±0.057	2.16 ±0.073	2.18 ±0.025
Inorganic Phosphate	2.28 ±0.151	2.32 ±0.162	2.46 ±0.192	2.24 ±0.100
Magnesium	0.94 ±0.046	0.98 ±0.060	0.99 ±0.072	0.94 ±0.025

ALP: Alkaline phosphate; ALT: Alanine transaminase; AST: Aspartate transaminase

[#]: Diet codes are explained in Table 3.01, Chapter 3

Table 4.07 Effect of *Acacia karroo* leaf meal inclusion level on haematological indices and blood biochemical components of yearling male Boer goats fed an *Avena sativa* hay-based diet

Variable	Diet[#]			
	$H_{As90}AK_{10}$	$H_{As85}AK_{15}$	$H_{As80}AK_{20}$	$H_{As70}AK_{30}$
Haematology				
Red blood cell ($x10^{12}$/L)	1.67 ±4.912	2.35 ±0.859	1.97 ±0.784	1.99 ±0.332
Haemoglobin (g/dL)	9.35 ±0.924	9.87 ±0.934	9.67 ±0.945	8.37 ±0.919
Haematocrit (L/L)	0.12 ±0.027	0.08 ±0.026	0.07 ±0.027	0.07 ±0.026
White blood cell ($x10^{9}$/L)	18.47 ±10.564	19.75 ±6.541	29.61 ±5.723	17.45 ±5.894
Metabolites (mmol/L)				
Urea	3.30 ±0.619	3.37 ±0.582	4.03 ±0.685	2.53 ±0.619
Glucose	1.71^{b} ±0.219	2.84^{a} ±0.303	2.89^{a} ±0.207	3.02^{a} ±0.190
Cholesterol	3.25^{a} ±0.141	2.80^{b} ±0.176	2.42^{b} ±0.125	2.83^{b} ±0.121
Proteins (g/L)				
Total Protein	75.00 ±2.818	71.33 ±2.537	68.67 ±2.497	70.00 ±2.500
Albumin	24.50 ±1.968	26.00 ±1.968	25.00 ±2.009	28.00 ±2.001
Enzymes (IU/L)				
ALP	63.00 ±30.979	85.00 ±31.197	108 ±29.517	84.00 ±30.447
ALT	16.50 ±2.393	18.67 ±1.830	17.00 ±1.751	19.67 ±1.936
AST	65.00 ±7.462	69.00 ±5.262	69.33 ±6.297	73.33 ±5.830
Electrolytes (mmol/L)				
Sodium	143 ±1.315	145 ±1.416	143 ±1.556	146 ±1.329
Potassium	7.60 ±0.606	6.67 ±1.606	7.63 ±0.485	7.13 ±0.493
Chloride	110 ±1.316	111 ±1.524	114 ±1.406	112 ±1.322
Total Calcium	2.18 ±0.063	2.21 ±0.064	2.20 ±0.062	2.17 ±0.063
Corrected Calcium	2.49 ±0.036	2.44 ±0.036	2.45 ±0.036	2.45 ±0.035
Inorganic Phosphate	1.75^{b} ±0.145	1.84^{b} ±0.143	2.05^{b}±0.154	2.65^{a} ±0.159
Magnesium	1.04 ±0.063	1.02 ±0.061	1.02 ±0.062	1.07 ±0.070

[a, b]: Means in the same row not sharing a common superscript are significantly different ($P<0.05$)

ALP: Alkaline phosphate; ALT: Alanine transaminase; AST: Aspartate transaminase

[#]: Diet codes are explained in Table 3.01, Chapter 3

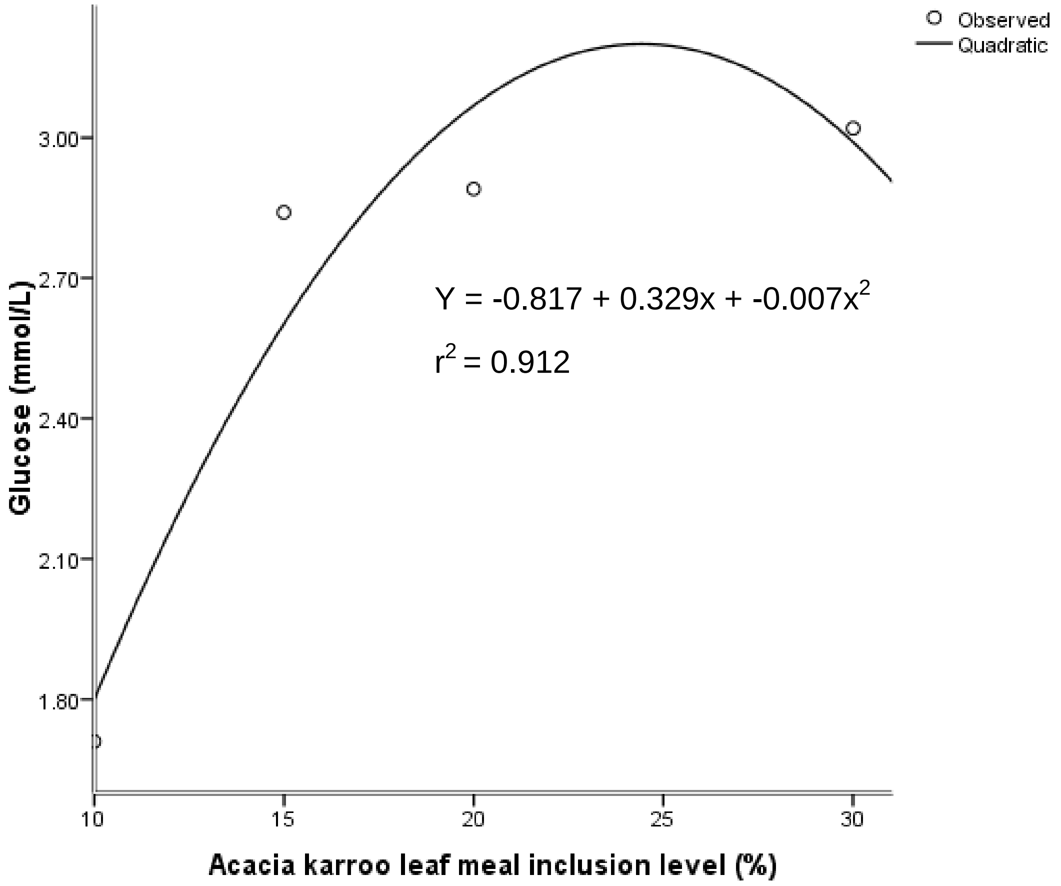

Figure 4.04 Effect of *Acacia karroo* leaf meal inclusion level on blood glucose of yearling male Boer goats fed an *Avena sativa* hay-based diet

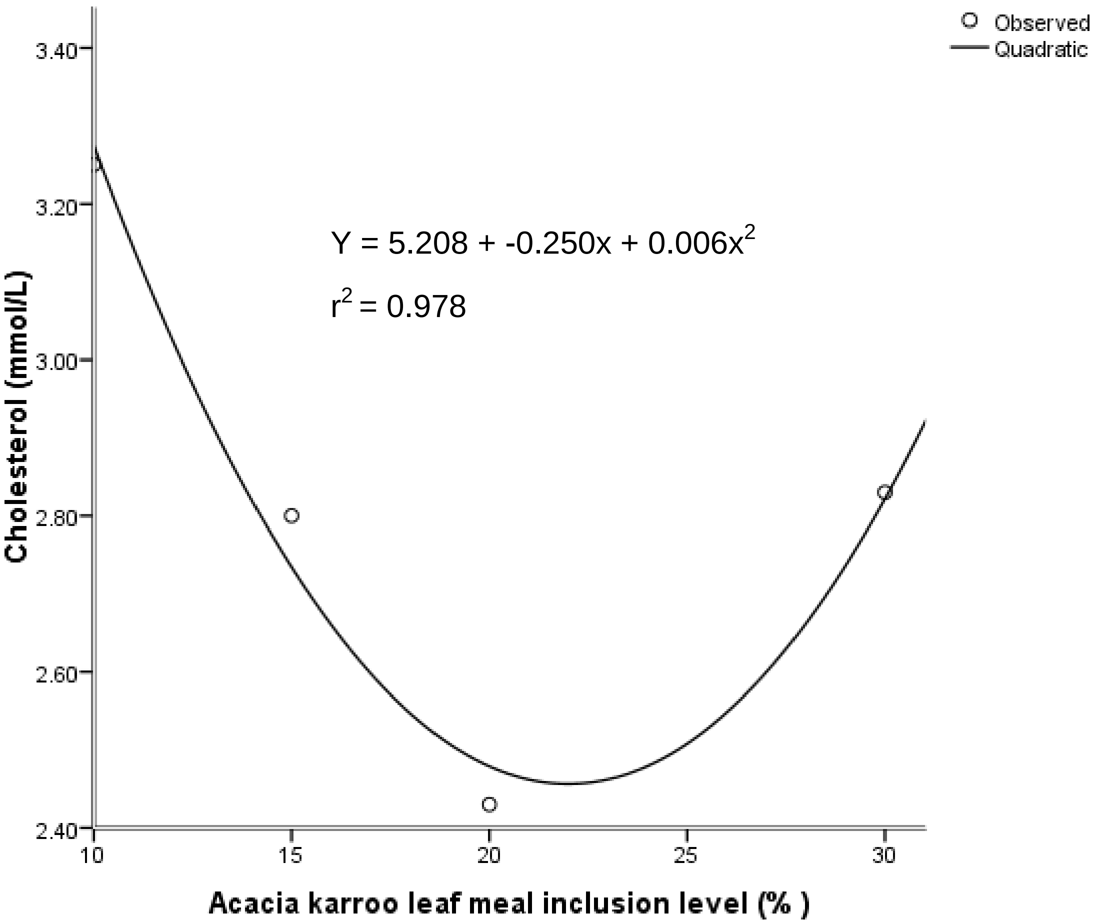

Figure 4.05 Effect of *Acacia karroo* leaf meal inclusion level on blood cholesterol of yearling male Boer goats fed an *Avena sativa* hay-based diet

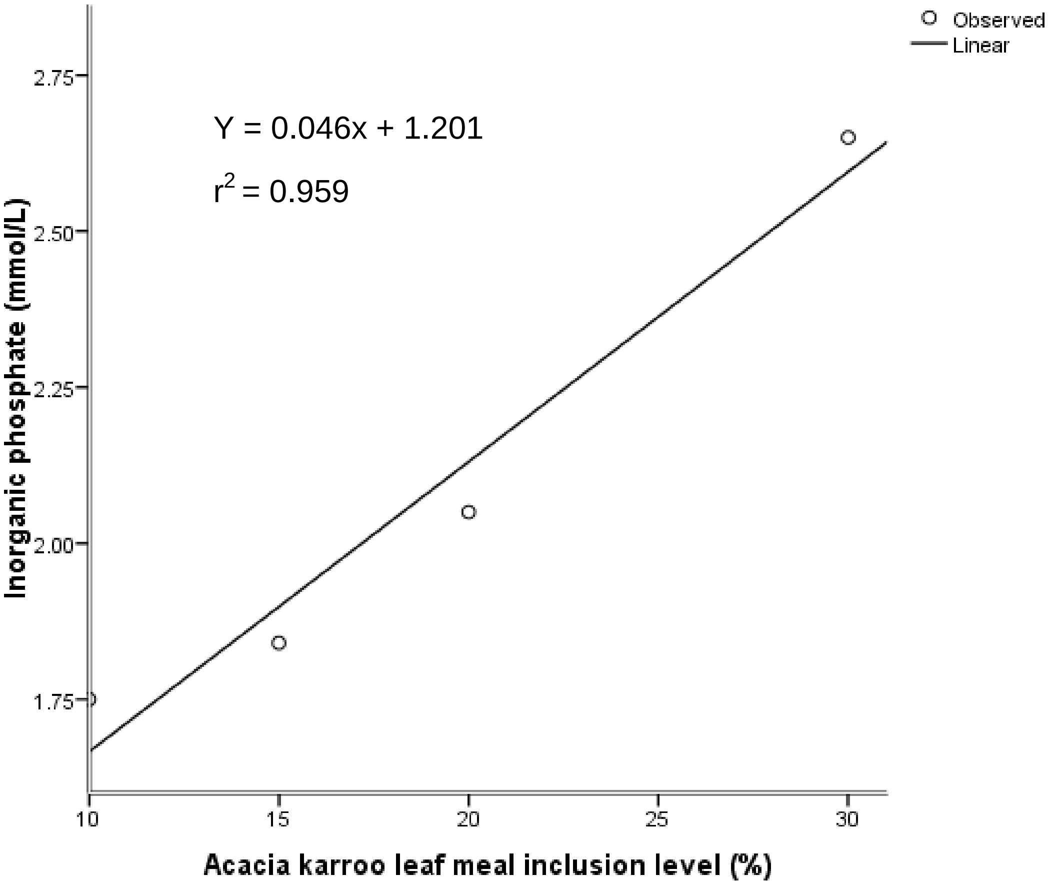

Figure 4.06 Relationship between *Acacia karroo* leaf meal inclusion level and blood inorganic phosphate in yearling male Boer goats fed an *Avena sativa* hay-based diet

Table 4.08 *Acacia karroo* leaf meal inclusion levels for optimal blood metabolites of yearling male Boer goats fed an *Avena sativa* hay-based diet

Factor	Formula	X	Y	r^2	P
Blood metabolites (mmol/L)					
Glucose	$Y = -0.817 + 0.329x + -0.007x^2$	23.50	3.05	0.912	0.296
Cholesterol	$Y = 5.208 + -0.250x + 0.006x^2$	20.83	2.60	0.978	0.148

X: Inclusion level for optimal value

Y: Optimal Y-level

r^2: Coefficient of determination

P: Probability

Major haematological indices and blood biochemical component values of yearling Boer goats before the start of the experiment and during the experiment involving *A. karroo* leaf meal inclusion level are presented in Table 4.09. Inclusion of *A. karroo* leaf meal in the diets of male Boer goats had no effect ($P>0.05$) on red blood cell counts and total serum proteins. However, reduction ($P<0.05$) in haematocrit levels of goats was observed when *A. karroo* leaf meal was included in the diets. In the case of white blood cell (WBC) counts, a diet having a 15 % *A. karroo* leaf meal inclusion level reduced ($P<0.05$) WBC counts. However, Boer goats on diets having 10, 20 or 30 % *A. karroo* leaf meal inclusion levels had similar ($P>0.05$) WBC counts as those on diets without *A. karroo* leaf meals. Reductions ($P<0.05$) in urea levels of goats fed diets having 10, 15 or 30 % *A. karroo* leaf meal inclusion levels were observed. However, level of urea in goats fed a diet having a 15 % *A. karroo* leaf meal inclusion level remained similar ($P>0.05$) to those on a diet without *A. karroo* leaf meal. Inclusion levels of 15, 20 or 30 % *A. karroo* leaf meals in the diets of male Boer goats had no effect ($P>0.05$) on glucose levels. However, goats fed a diet having a 10 % *A. karroo* leaf meal inclusion level had a lower ($P<0.05$) glucose level than those on a diet without *A. karroo* leaf meal.

Table 4.09 Effect of *Acacia karroo* leaf meal inclusion level on major haematological indices and blood biochemical components of yearling male Boer goats fed an *Avena sativa* hay-based diet

Variable[#]	Before experiment	After experiment
Red blood cell (x10^{12}/L)		
$H_{As90}AK_{10}$	1.51 ±0.044	1.67 ±0.231
$H_{As85}AK_{15}$	1.88 ±0.187	2.35 ±0.101
$H_{As80}AK_{20}$	2.08 ±0.159	1.97 ±0.440
$H_{As70}AK_{30}$	5.43 ±3.854	1.99 ±0.259
Haematocrit (L/L)		
$H_{As90}AK_{10}$	0.62^{a} ±0.062	0.12^{b} ±0.069
$H_{As85}AK_{15}$	0.65^{a} ±0.050	0.08^{b} ±0.005
$H_{As80}AK_{20}$	0.69^{a} ±0.085	0.07^{b} ±0.017
$H_{As70}AK_{30}$	0.65^{a} ±0.027	0.07^{b} ±0.011
White blood cell (x10^{9}/L)		
$H_{As90}AK_{10}$	22.66 ±1.726	18.47 ±2.982
$H_{As85}AK_{15}$	29.66^{a} ±2.356	19.75^{b} ±0.637
$H_{As80}AK_{20}$	28.14 ±3.432	29.61 ±7.707
$H_{As70}AK_{30}$	28.95 ±3.280	17.45 ±4.345
Urea (mmol/L)		
$H_{As90}AK_{10}$	5.25^{a} ±0.479	3.30^{b} ±0.041
$H_{As85}AK_{15}$	5.00^{a} ±0.408	3.37^{b} ±0.517
$H_{As80}AK_{20}$	4.25 ±0.629	4.03 ±0.671
$H_{As70}AK_{30}$	5.25^{a} ±0.489	2.53^{b} ±0.731
Glucose (mmol/L)		
$H_{As90}AK_{10}$	3.40^{a} ±0.108	1.71^{b} ±0.318
$H_{As85}AK_{15}$	3.23 ±0.132	2.84 ±0.199
$H_{As80}AK_{20}$	3.85 ±0.427	2.89 ±0.106
$H_{As70}AK_{30}$	3.58 ±0.243	3.02 ±0.124
Total protein (g/L)		
$H_{As90}AK_{10}$	72.00 ±2.708	75.00 ±2.450
$H_{As85}AK_{15}$	77.00 ±7.106	71.33 ±1.650
$H_{As80}AK_{20}$	73.50 ±6.198	68.67 ±3.682
$H_{As70}AK_{30}$	75.50 ±5.575	70.00 ±1.633

[a, b]: Means in the same row not sharing a common superscript are significantly different (P<0.05)

[#]: Diet codes are explained in Table 3.01, Chapter 3

4.3 Effect of *Acacia tortilis* leaf meal inclusion level on diet intake, digestibility, methane emission, live weight, feed conversion ratio, haematological indices and blood biochemical components of yearling male Boer goats fed an *Avena sativa* hay-based diet

The nutrient composition of mixtures of *A. tortilis* and *Avena sativa* hay are presented in Table 4.10. *Acacia tortilis* leaf meal inclusion level had no effect (P>0.05) on diet dry matter (DM), organic matter (OM) and neutral detergent fibre (NDF) contents. However, *A. tortilis* leaf meal inclusion level affected (P<0.05) diet ash, crude protein (CP), acid detergent fibre (ADF), fat and energy contents. Diet CP and fat contents increased (P<0.05) with increased *A. tortilis* leaf meal inclusion levels. A diet having a 30 % *A. tortilis* leaf meal inclusion level had a higher (P<0.05) ash content than those having 10, 15 or 20 % *A. tortilis* leaf meal inclusion levels. Similarly, a diet with a 20 % *A. tortilis* leaf meal inclusion level had a higher (P<0.05) ash content than that with a 10 % *A. tortilis* leaf meal inclusion level. However, diets having 15 or 20 % *A. tortilis* leaf meal inclusion levels had similar (P>0.05) ash contents. Similarly, diets having 10 or 15 % *A. tortilis* leaf meal inclusion levels had same (P>0.05) ash contents.

A diet having a 30 % *A. tortilis* leaf meal inclusion level had a higher (P<0.05) ADF content than those having 10 or 15 % *A. tortilis* leaf meal inclusion levels (Table 4.10). However, diets with 10, 15 or 20 % *A. tortilis* leaf meal inclusion levels had similar (P>0.05) ADF contents. Similarly, diets having 20 or 30 % *A. tortilis* leaf meal inclusion levels had same (P>0.05) ADF contents. A diet with a 30 % *A. tortilis* leaf meal inclusion level had a higher (P<0.05) energy content than that with a 10 % *A. tortilis* leaf meal inclusion level. However, diets having 10, 15 or 20 % *A. tortilis* leaf meal inclusion levels had similar (P>0.05) energy contents. Similarly, diets having 20 or 30 % *A. tortilis* leaf meal inclusion levels had same (P>0.05) energy contents.

No hydrolysable tannins were detected in the *A. tortilis* and *Avena sativa* mixed diets (Table 4.10). Increasing *A. tortilis* leaf meal inclusion level in the diet increased (P<0.05) total phenolics, total tannins and condensed tannins (CT). Similarly, increased inclusion levels of *A. tortilis* leaf meal resulted in increased (P<0.05) diet calcium contents. However, increasing *A. tortilis* leaf meal inclusion level in the diet

Table 4.10 Nutrient composition of the experimental *Acacia tortilis* diets

Nutrient	Diet$^{\#}$			
	$H_{As90}AT_{10}$	$H_{As85}AT_{15}$	$H_{As80}AT_{20}$	$H_{As70}AT_{30}$
Dry matter (%)	94.40 ±0.545	94.45 ±0.545	94.50 ±0.546	94.61 ±0.546
Organic matter (%)	87.70 ±0.506	87.67 ±0.506	87.64 ±0.506	87.57 ±0.505
Ash (%)	6.69^{c} ±0.039	6.78^{bc} ±0.039	6.86^{b} ±0.040	7.04^{a} ±0.041
Crude protein (%)	7.69^{d} ±0.044	8.06^{c} ±0.047	8.44^{b} ±0.049	9.20^{a} ±0.053
Neutral detergent fibre (%)	62.33 ±0.360	62.31 ±0.359	62.30 ±0.360	62.26 ±0.359
Acid detergent fibre (%)	40.93^{b} ±0.236	41.28^{b} ±0.238	41.64^{ab} ±0.240	42.34^{a} ±0.245
Fat (%)	1.30^{d} ±0.008	1.40^{c} ±0.008	1.50^{b} ±0.009	1.69^{a} ±0.010
Energy (MJ/kg)	17.78^{b} ±0.112	17.89^{ab} ±0.110	17.99^{ab} ±0.109	18.20^{a} ±0.109
Total phenolics*	0.26^{d} ±0.002	0.39^{c} ±0.002	0.52^{b} ±0.003	0.78^{a} ±0.005
Total tannins*	0.20^{d} ±0.001	0.29^{c} ±0.002	0.39^{b} ±0.002	0.59^{a} ±0.003
Condensed tannins**	0.18^{d} ±0.001	0.26^{c} ±0.002	0.35^{b} ±0.002	0.53^{a} ±0.003
Hydrolysable tannins (mg/g)	0.00 ±0.000	0.00 ±0.000	0.00 ±0.000	0.00 ±0.000
Calcium (%)	0.43^{d} ±0.003	0.50^{c} ±0.003	0.57^{b} ±0.003	0.72^{a} ±0.004
Magnesium (%)	0.13^{b} ±0.001	0.13^{b} ±0.001	0.14^{a} ±0.001	0.14^{a} ±0.001
Potassium (%)	1.77^{a} ±0.010	1.73^{b} ±0.010	1.69^{c} ±0.009	1.61^{d} ±0.009
Sodium (%)	0.04 ±0.000	0.04 ±0.000	0.04 ±0.000	0.04 ±0.000
K/Ca + Mg (%)	1.85^{a} ±0.011	1.76^{b} ±0.010	1.68^{c} ±0.009	1.50^{d} ±0.009
Phosphorus (%)	0.16^{a} ±0.001	0.15^{b} ±0.001	0.15^{b} ±0.001	0.15^{b} ±0.001
Zinc (mg/kg or ppm)	15.00 ±0.087	15.00 ±0.087	15.00 ±0.087	15.00 ±0.087
Copper (mg/kg or ppm)	2.90^{a} ±0.017	2.85^{ab} ±0.016	2.80^{b} ±0.016	2.70^{c} ±0.015
Molybdenum (mg/kg)	45.00^{c} ±0.260	45.50^{bc} ±0.263	46.00^{b} ±0.266	47.00^{a} ±0.271
Iron (mg/kg or ppm)	276^{d} ±1.598	297^{c} ±1.719	318^{b} ±1.840	360^{a} ±2.081

$^{a, b, c, d}$: Means in the same row not sharing a common superscript are significantly different ($P<0.05$)
*: Percentage DM tannic acid equivalent
**: Percentage DM leucocyanidin equivalent
K/Ca + Mg: Potassium/Calcium plus Magnesium
$^{\#}$: Diet codes are explained in Table 3.02, Chapter 3

decreased ($P<0.05$) potassium content and ratio of potassium/calcium plus magnesium. Diets having 20 or 30 % *A. tortilis* leaf meal inclusion levels had higher ($P<0.05$) magnesium (Mg) contents than diets having 10 or 15 % *A. tortilis* leaf meal inclusion levels. However, Diets having 20 or 30 % *A. tortilis* leaf inclusion meal had similar ($P>0.05$) Mg contents. Similarly, diets with 20 or 30 % *A. tortilis* leaf meal inclusion levels had same (P>0.05) Mg contents. A diet having a 10 % *A. tortilis* leaf meal inclusion level had a higher (P<0.05) phosphorus (P) content than those having 15, 20 or 30 % *A. tortilis* leaf meal inclusion levels. However, diets having 15, 20 or 30 % *A. tortilis* leaf meal inclusion levels had similar (P>0.05) P contents.

Acacia tortilis leaf meal inclusion level in the diets based on *Avena sativa* hay had no effect (P>0.05) on diet sodium and zinc contents (Table 4.10). A diet having a 10 % *A. tortilis* leaf meal inclusion level had a higher (P<0.05) copper (Cu) content than diets having 20 or 30 % *A. tortilis* leaf meal inclusion levels. Similarly, diets with 15 or 20 % *A. tortilis* leaf meal inclusion levels had higher (P<0.05) Cu contents than that with a 30 % *A. tortilis* leaf meal inclusion level. However, diets having 10 or 15 % *A. tortilis* leaf meal inclusion levels had similar (P>0.05) Cu contents. Similarly, diets with 15 or 20 % *A. tortilis* leaf meal inclusion levels had same (P>0.05) Cu contents. A diet having a 30 % *A. tortilis* leaf meal inclusion level had a higher (P<0.05) molybdenum (Mo) content than those having 10, 15 or 20 % *A. tortilis* leaf meal inclusion levels. Similarly, a diet having a 20 % *A. tortilis* leaf meal inclusion level had a higher (P<0.05) Mo content than that with a 10 % *A. tortilis* leaf meal inclusion level. However, diets having 10 or 15 % *A. tortilis* leaf meal inclusion levels had similar (P>0.05) Mo contents. Similarly, diets with 15 or 20 % *A. tortilis* leaf meal inclusion levels had same (P>0.05) Mo contents. Increasing *A. tortilis* leaf meal inclusion level increased (P<0.05) diet iron content.

The results of the effect of *A. tortilis* leaf meal inclusion level on intake, digestibility, methane emission, live weight, weight gain and feed conversion ratio (FCR) of yearling male Boer goats fed *Avena sativa* hay-based diets are presented in Table 4.11. *Acacia tortilis* leaf meal inclusion level had no effect (P>0.05) on methane emission, live weight and weight gain per goat. However, *A. tortilis* leaf meal inclusion level affected (P<0.05) diet DM, OM, ash, CP, NDF, ADF, fat and energy intakes of the goats. Male Boer goats on a diet having a 30 % *A. tortilis* leaf meal inclusion level had higher (P<0.05) DM, OM and NDF intakes than those on a diet with a 15 % *A. tortilis* leaf meal inclusion level. However, goats on diets having 10, 15 or 20 % *A. tortilis* leaf meal inclusion levels had similar (P>0.05) DM, OM and NDF intakes. Similarly, goats on diets having 10, 20 or 30 % *A. tortilis* leaf meal inclusion levels had same (P>0.05) DM, OM and NDF intakes.

Male Boer goats on a diet having a 30 % *A. tortilis* leaf meal inclusion level had higher (P<0.05) ash, ADF and energy intakes than those on diets having 10 or 15 % *A. tortilis* leaf meal inclusion levels (Table 4.11). Similarly, goats on a diet having a 20 % *A. tortilis* leaf meal inclusion level had higher (P<0.05) ash, ADF and energy intakes than those on a diet having a 15 % *A. tortilis* leaf meal inclusion level. However, goats on diets having 10 or 15 % *A. tortilis* leaf meal inclusion levels had similar (P>0.05) ash, ADF and energy intakes. Similarly, goats on diets having 10 or 20 % *A. tortilis* leaf meal inclusion levels had same (P>0.05) ash, ADF and energy intakes. Goats on diets having 20 or 30 % *A. tortilis* leaf meal inclusion levels also had similar (P>0.05) ash, ADF and energy intakes. Boer goats on a diet having a 30 % *A. tortilis* leaf meal inclusion level had a higher (P<0.05) CP intake than those on diets having 10, 15 or 20 % *A. tortilis* leaf meal inclusion levels. Similarly, goats on a diet having a 20 % *A. tortilis* leaf meal inclusion level had a higher (P<0.05) CP intake than those on a diet having a 15 % *A. tortilis* leaf meal inclusion level. However, goats on diets having 10 or 20 % *A. tortilis* leaf meal inclusion levels had similar (P>0.05) CP intakes. Boer goats on a diet having a 30 % *A. tortilis* leaf meal inclusion level had a higher (P<0.05) fat intake than those on diets having 10, 15 or 20 % *A. tortilis* leaf meal inclusion levels. Similarly, goats on a diet having a 20 % *A. tortilis* leaf meal inclusion level had a higher (P<0.05) fat intake than those on diets having 10 or 15 % *A. tortilis* leaf meal inclusion levels. However, goats on diets having 10 or 15 % *A. tortilis* leaf meal inclusion levels had similar (P>0.05) fat intakes.

Acacia tortilis leaf meal inclusion level affected (P<0.05) DM, OM, ash, CP, NDF, ADF, fat and energy intakes per metabolic weight of the goats (Table 4.11). Male Boer goats on a diet having a 30 % *A. tortilis* leaf meal inclusion level had higher (P<0.05) DM, OM, NDF, ADF and energy intakes per metabolic weight of the goats than those on a diet with a 15 % *A. tortilis* leaf meal inclusion level. However, goats on diets having 10, 15 or 20 % *A. tortilis* leaf meal inclusion levels had similar (P>0.05) DM, OM, NDF, ADF and energy intakes per metabolic weight of the goats. Similarly, goats on diets having 10, 20 or 30 % *A tortilis* leaf meal inclusion levels had same (P>0.05) DM, OM, NDF, ADF and energy intakes per metabolic weight of the goats. Boer goats on a diet having a 30 % *A. tortilis* leaf meal inclusion level had higher (P<0.05) CP and fat intakes per metabolic weight of the goats than those on diets with 10, 15 or 20 % *A. tortilis* leaf meal inclusion levels. However, goats on diets having 10, 15 or 20 % *A. tortilis* leaf meal inclusion levels had similar (P>0.05) CP and fat intakes per metabolic weight. Goats on a diet having a 30 % *A. tortilis* leaf meal inclusion level had a higher (P<0.05) ash intake per metabolic weight of the goats than those on a diet with a 15 % *A. tortilis* leaf meal inclusion level. However, goats on diets having 10, 15 or 20 % *A. tortilis* leaf meal inclusion levels had similar (P>0.05) ash intakes per metabolic weight. Similarly, goats on diets having 20 or 30 % *A. tortilis* leaf meal inclusion levels had same (P>0.05) ash intakes per metabolic weight.

Acacia tortilis leaf meal inclusion level did not have effect (P>0.05) on diet DM, OM, ash, NDF, fat and energy digestibility values of goats. However, diet CP and ADF digestibilities were affected (P<0.05) by *A. tortilis* leaf meal inclusion level (Table 4.11). Boer goats on a diet having a 15 % *A. tortilis* leaf meal inclusion level had a higher (P<0.05) CP digestibility than those on diets having 10, 20 or 30 % *A. tortilis* leaf meal inclusion levels. Similarly, goats on a diet having a 10 % *A. tortilis* leaf meal inclusion level had a higher (P<0.05) CP digestibility than those on a diet having a 20 % *A. tortilis* leaf meal inclusion level. However, goats on diets containing 10 or 30 % *A. tortilis* leaf meal inclusion levels had similar (P>0.05) CP digestibility values. Similarly, goats on diets containing 20 or 30 % *A. tortilis* leaf meal inclusion levels had same (P>0.05) CP digestibility values. Goats on a diet having a 15 % *A. tortilis* leaf meal inclusion level had a higher (P<0.05) ADF digestibility than those on a diet with a 30 % *A. tortilis* leaf meal inclusion level. However, goats on diets containing 10, 20 or 30 % *A. tortilis* leaf meal inclusion levels had similar (P>0.05) ADF digestibility values. Similarly, goats on diets having 10, 15 or 20 % *A. tortilis* leaf meal inclusion levels had same (P>0.05) ADF digestibilities.

Boer goats on a diet having a 10 % *A. tortilis* leaf meal inclusion level had a better (P<0.05) FCR value than those on diets having 10, 20 or 30 % *A. tortilis* leaf meal inclusion levels (Table 4.11). Similarly, goats on diets with 20 or 30 % *A. tortilis* leaf meal inclusion levels had better (P<0.05) FCR values than goats on a diet having a 10 % *A. tortilis* leaf meal inclusion level. However, goats on diets having 20 or 30 % *A. tortilis* leaf meal inclusion levels had similar (P>0.05) FCR values.

Table 4.11 Effect of *Acacia tortilis* leaf meal inclusion level on diet intake, digestibility, methane emission, live weight change and feed conversion ratio of yearling male Boer goats fed an *Avena sativa* hay-based diet

Variable	Diet[#]			
	$H_{As90}AT_{10}$	$H_{As85}AT_{15}$	$H_{As80}AT_{20}$	$H_{As70}AT_{30}$
Intake (g/goat/day)				
DM	402^{ab} ±18.623	353^{b} ±19.250	424^{ab} ±18.924	466^{a} ±18.767
OM	353^{ab} ±16.320	310^{b} ±16.870	372^{ab} ±16.585	408^{a} ±16.446
Ash	26.95^{bc} ±1.278	23.98^{c} ±1.321	29.13^{ab} ±1.299	32.85^{a} ±1.288
CP	30.98^{bc} ±1.573	28.51^{c} ±1.626	35.84^{b} ±1.599	42.93^{a} ±1.586
NDF	251^{ab} ±11.601	220^{b} ±11.992	264^{ab} ±11.789	290^{a} ±11.691
ADF	164^{bc} ±7.756	146^{c} ±8.017	176^{ab} ±7.881	197^{a} ±7.816
Fat	5.24^{c} ±0.280	4.95^{c} ±0.289	6.37^{b} ±0.284	7.89^{a} ±0.282
Energy intake (MJ/day)	7.16^{bc} ±0.302	6.33^{c} ±0.312	7.63^{ab} ±0.307	8.48^{a} ±0.304
Intake (g/kg $W^{0.75}$)				
DM	38.09^{ab} ±1.712	34.62^{b} ±1.770	38.42^{ab} ±1.740	43.06^{a}±1.726
OM	33.41^{ab} ±1.501	30.36^{b} ±1.551	33.67^{ab} ±1.525	37.71^{a} ±1.512
Ash	2.55^{b} ±0.118	2.35^{b} ±0.121	2.64^{ab} ±0.119	3.03^{a} ±0.118
CP	2.93^{b} ±0.145	2.79^{b} ±0.150	3.24^{b} ±0.147	3.96^{a} ±0.146
NDF	23.74^{ab} ±1.067	21.57^{b} ±1.103	23.93^{ab} ±1.084	26.81^{a} ±1.075
ADF	15.59^{ab} ±0.713	14.29^{b} ±0.737	16.00^{ab} ±0.725	18.23^{a} ±0.719
Fat	0.50^{b} ±0.026	0.48^{b} ±0.027	0.58^{b} ±0.026	0.73^{a} ±0.026
Energy intake (MJ/kg $W^{0.75}$)	0.68^{ab} ±0.028	0.62^{b} ±0.029	0.69^{ab} ±0.028	0.78^{a} ±0.028
Digestibility (decimal)				
DM	0.54 ±0.327	0.52 ±0.118	0.43 ±0.060	0.44 ±0.040
OM	0.54 ±0.318	0.53 ±0.114	0.44 ±0.058	0.43 ±0.039
Ash	0.24 ±0.863	0.13 ±0.311	0.04 ±0.158	0.15 ±0.107
CP	0.28^{b} ±0.267	0.45^{a} ±0.096	0.13^{c} ±0.049	0.19^{bc} ±0.033
NDF	0.42 ±0.372	0.43 ±0.134	0.30 ±0.068	0.27 ±0.046
ADF	0.33^{ab} ±0.523	0.39^{a} ±0.188	0.19^{ab} ±0.096	0.14^{b} ±0.065
Fat	0.22 ±1.023	0.35 ±0.368	0.06 ±0.187	0.13 ±0.127
Energy	0.51 ±0.369	0.50 ±0.133	0.43 ±0.067	0.39 ±0.046
Methane emission (ppm-m)	11.50 ±1.334	12.88±1.334	12.42 ±1.336	13.42 ±1.340
Live weight (g/goat/day)				
Initial (kg)	22.85 ±1.091	22.25 ±1.673	24.53 ±1.093	23.55 ±1.298
Final (kg)	23.50 ±1.146	22.49 ±1.758	24.88 ±1.148	24.00 ±1.363
Weight gain (g/goat/day)	130 ±547.975	48.67 ±197.218	70.00 ±100.094	90.00 ±67.751
Feed conversion ratio	3.10^{c} ±0.317	7.27^{a} ±0.466	6.07^{b} ±0.305	5.18^{b} ±0.299

[a, b, c]: Means in the same row not sharing a common superscript are significantly different ($P<0.05$)

[#]: Diet codes are explained in Table 3.02, Chapter 3

A positive relationship was observed between *A. tortilis* leaf meal inclusion level and diet DM (r^2 = 0.8595), OM (r^2 = 0.591), ash (r^2 = 0.703), CP (r^2 = 0.847), NDF (r^2 = 0.592), ADF (r^2 = 0.670), fat (r^2 = 0.894) and energy (r^2 = 0.647) intakes in male Boer goats (Figures 4.07, 4.08, 4.09, 4.10, 4.11, 4.12, 4.13 and 4.14, respectively, and Table 4.12). Similarly, a positive relationship was observed between *A. tortilis* leaf meal inclusion level and diet DM (r^2 = 0.610), OM (r^2 = 0.606), ash (r^2 = 0.734), CP (r^2 = 0.875), NDF (r^2 = 0.607), ADF (r^2 = 0.698), fat (r^2 = 0.902) and energy (r^2 = 0.649) intakes per metabolic weight of Boer goats, respectively (Figures 4.15, 4.16, 4.17, 4.18, 4.19, 4.20, 4.21 and 4.22, respectively, and Table 4.12). However, a negative relationship was observed between *A. tortilis* leaf meal inclusion level and diet ADF (r^2 = 0.717) digestibility by Boer goats (Figure 4.20 and Table 4.12).

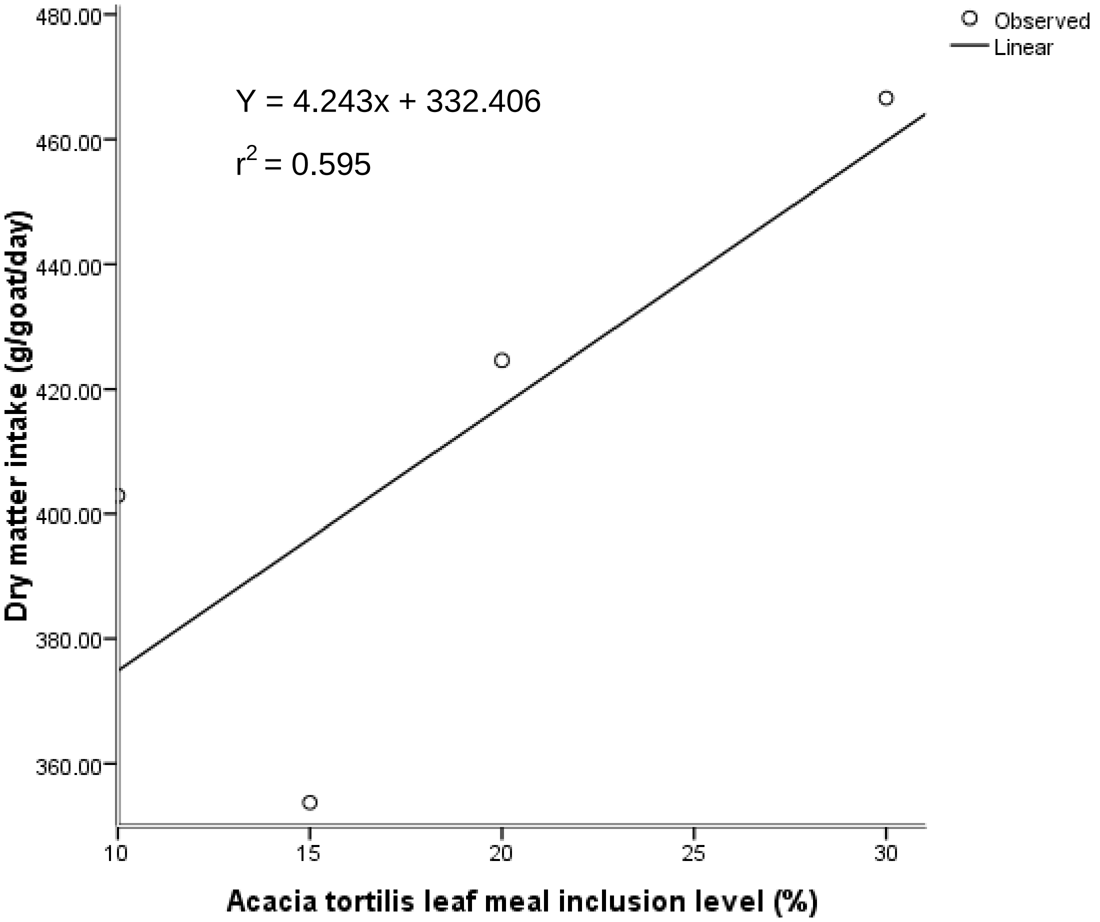

Figure 4.07 Relationship between *Acacia tortilis* leaf meal inclusion level and diet dry matter intake in yearling male Boer goats fed an *Avena sativa* hay-based diet

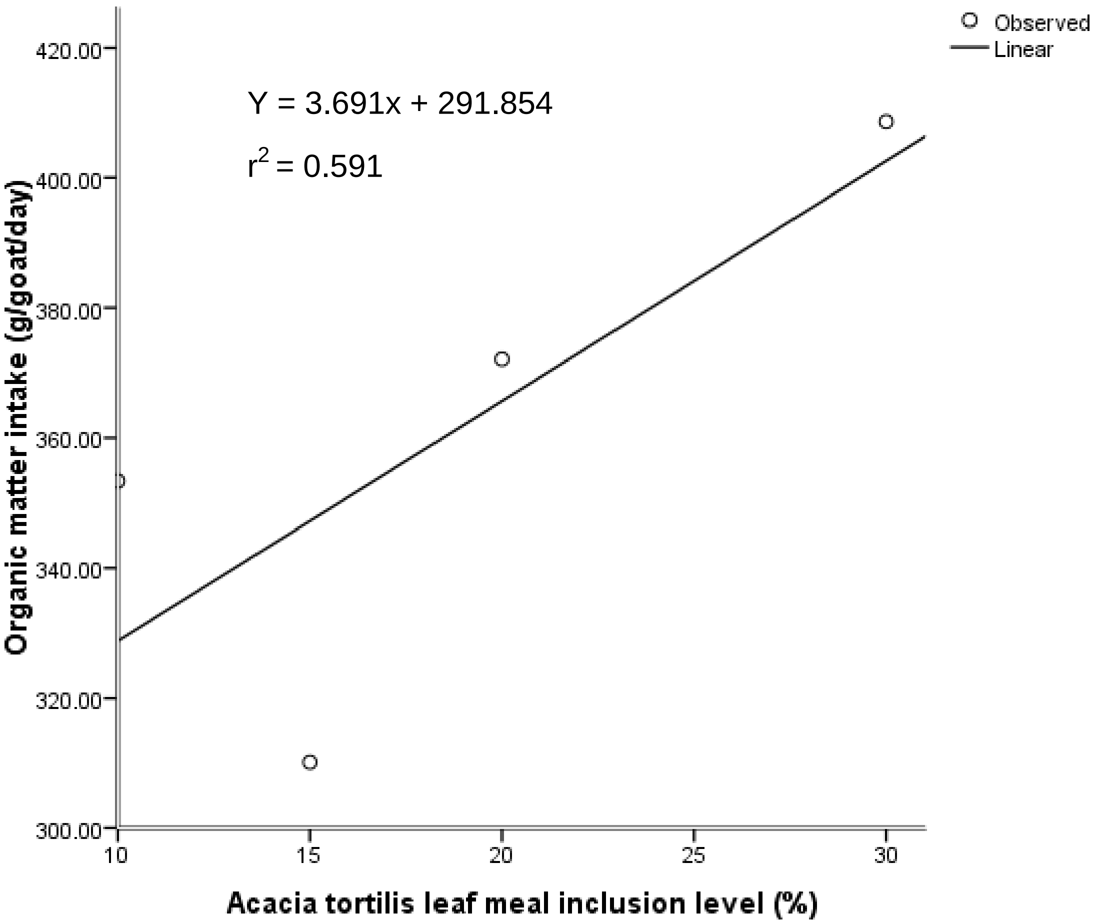

Figure 4.08 Relationship between *Acacia tortilis* leaf meal inclusion level and diet organic matter intake in yearling male Boer goats fed an *Avena sativa* hay-based diet

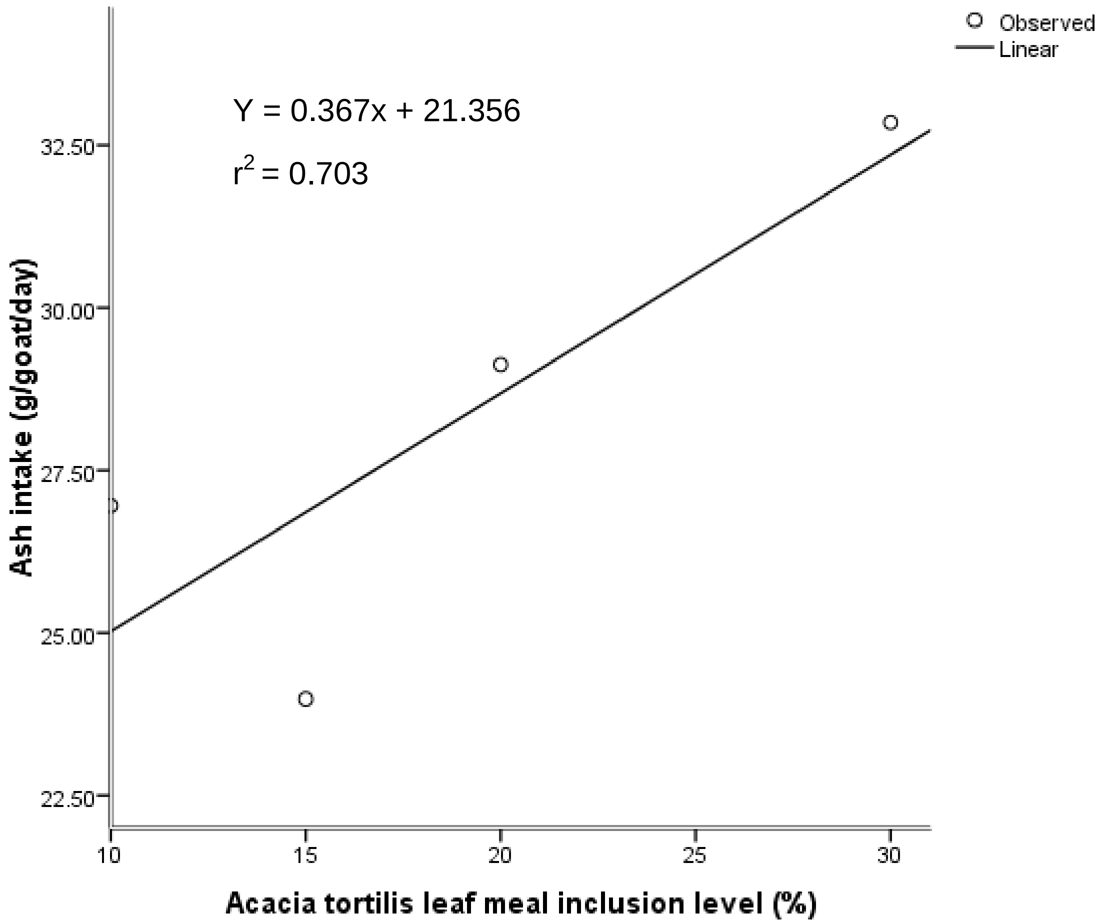

Figure 4.09 Relationship between *Acacia tortilis* leaf meal inclusion level and diet ash intake in yearling male Boer goats fed an *Avena sativa* hay-based diet

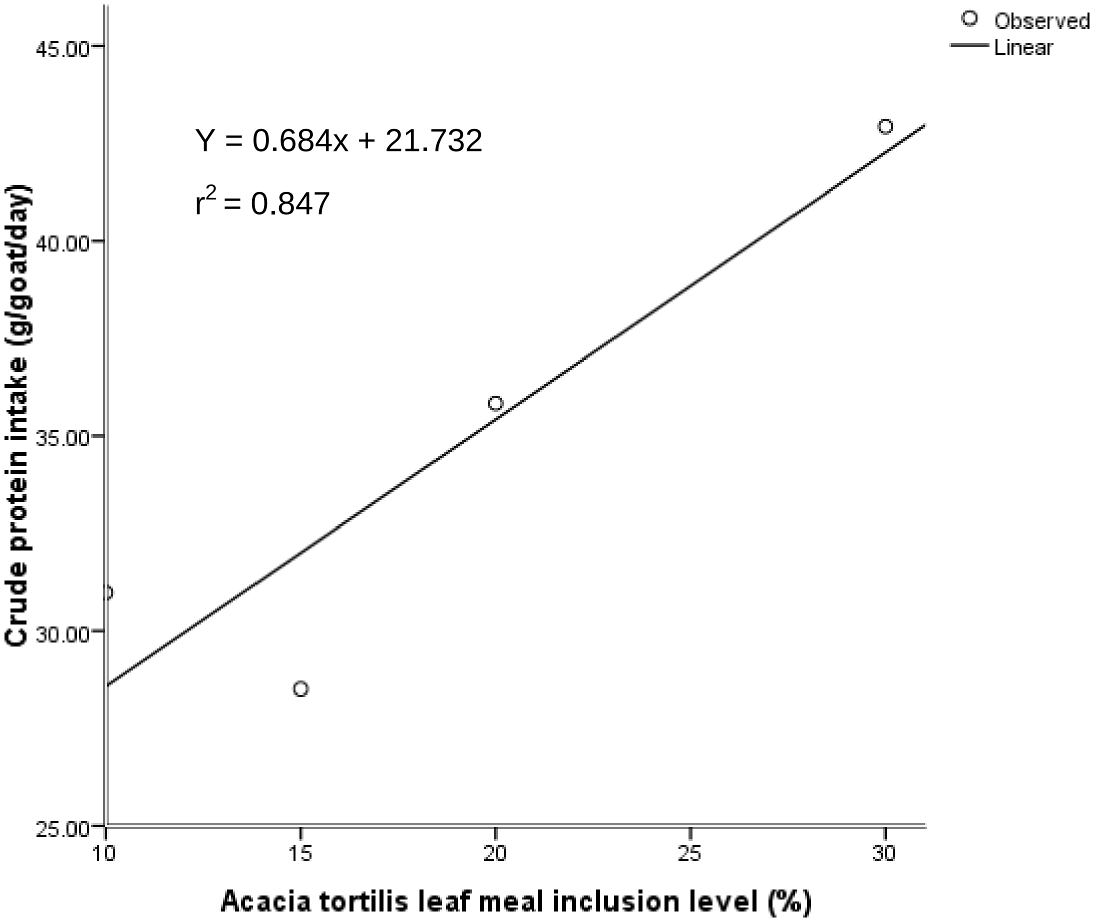

Figure 4.10 Relationship between *Acacia tortilis* leaf meal inclusion level and diet crude protein intake in yearling male Boer goats fed an *Avena sativa* hay-based diet

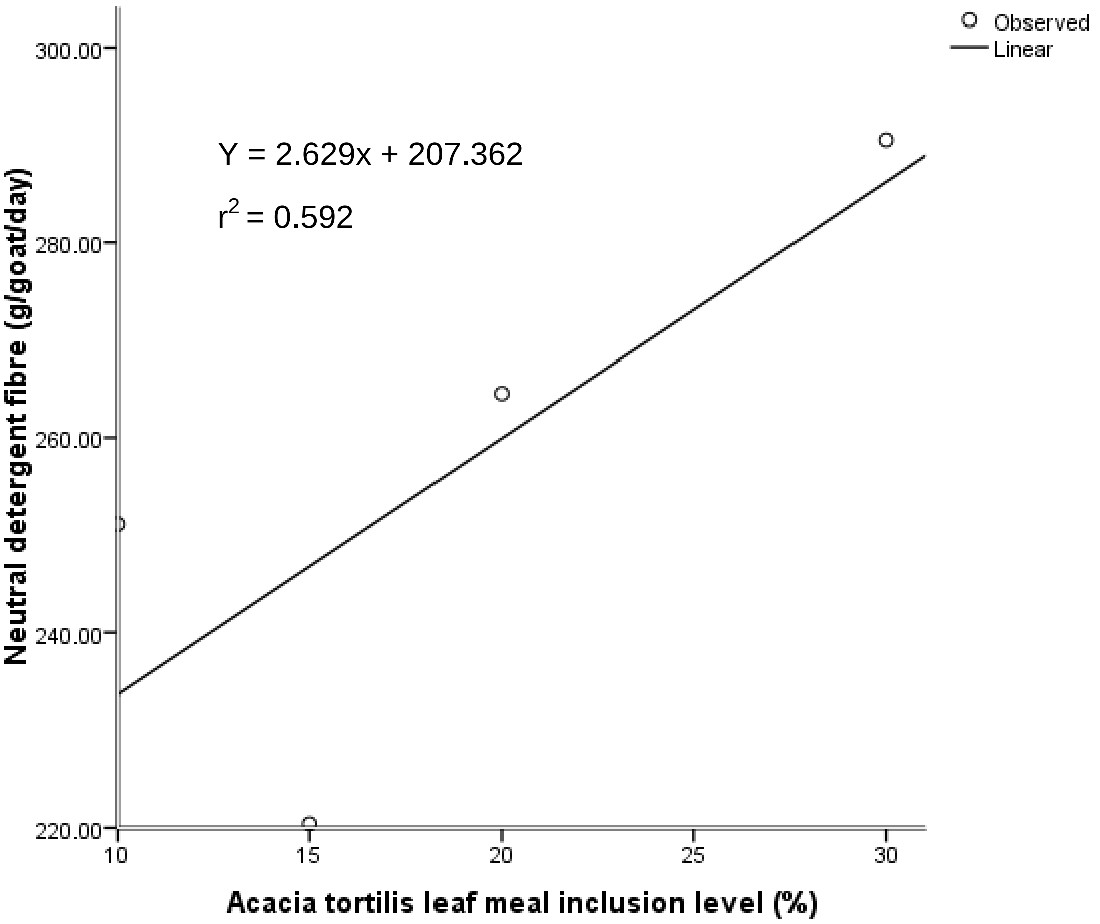

Figure 4.11 Relationship between *Acacia tortilis* leaf meal inclusion level and diet neutral detergent fibre intake in yearling male Boer goats fed an *Avena sativa* hay-based diet

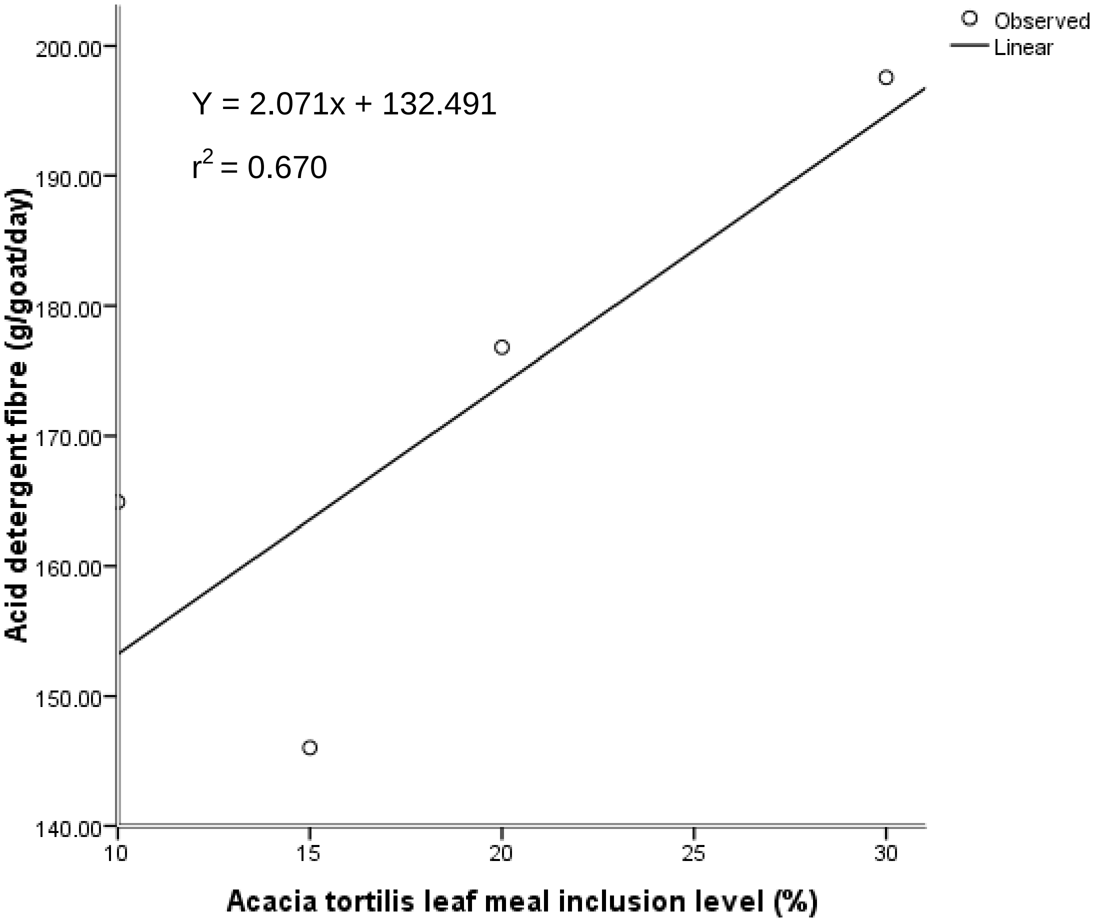

Figure 4.12 Relationship between *Acacia tortilis* leaf meal inclusion level and diet acid detergent fibre intake in yearling male Boer goats fed an *Avena sativa* hay-based diet

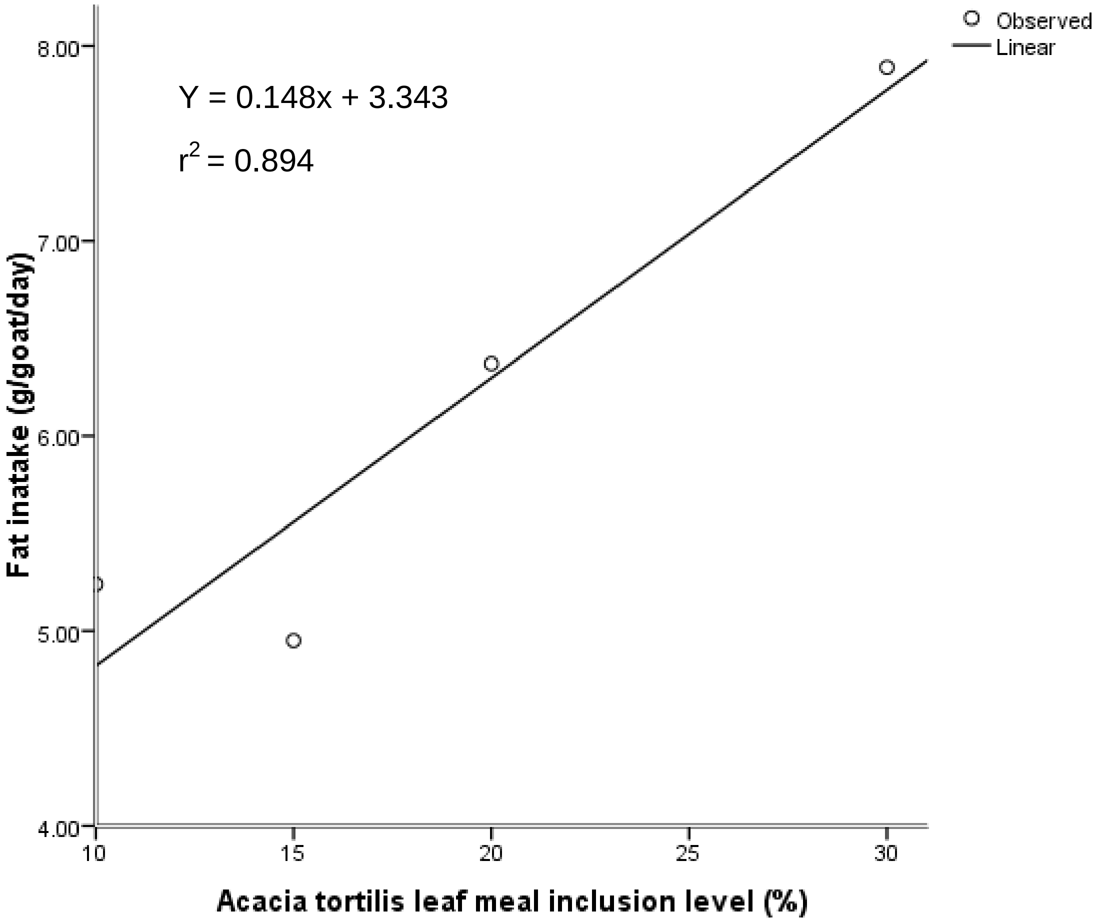

Figure 4.13 Relationship between *Acacia tortilis* leaf meal inclusion level and diet fat intake in yearling male Boer goats fed an *Avena sativa* hay-based diet

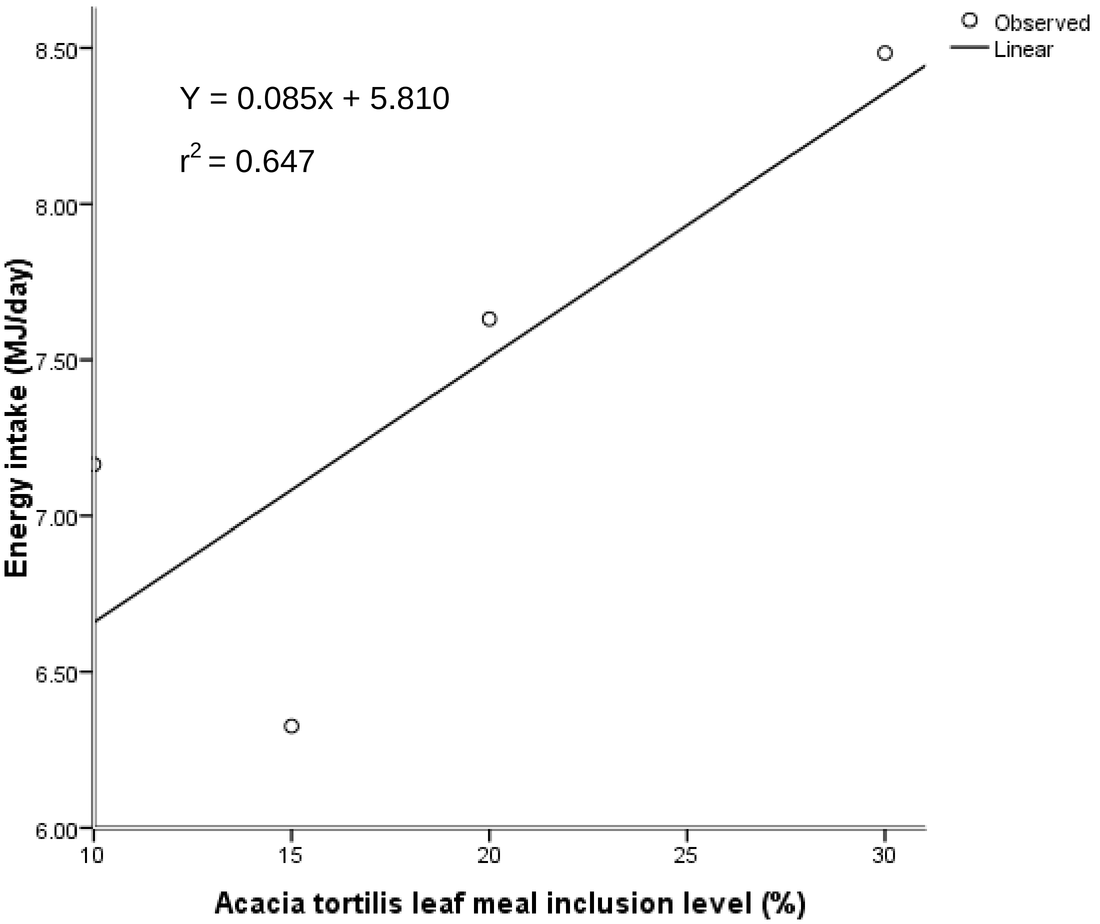

Figure 4.14 Relationship between *Acacia tortilis* leaf meal inclusion level and diet energy intake in yearling male Boer goats fed an *Avena sativa* hay-based diet

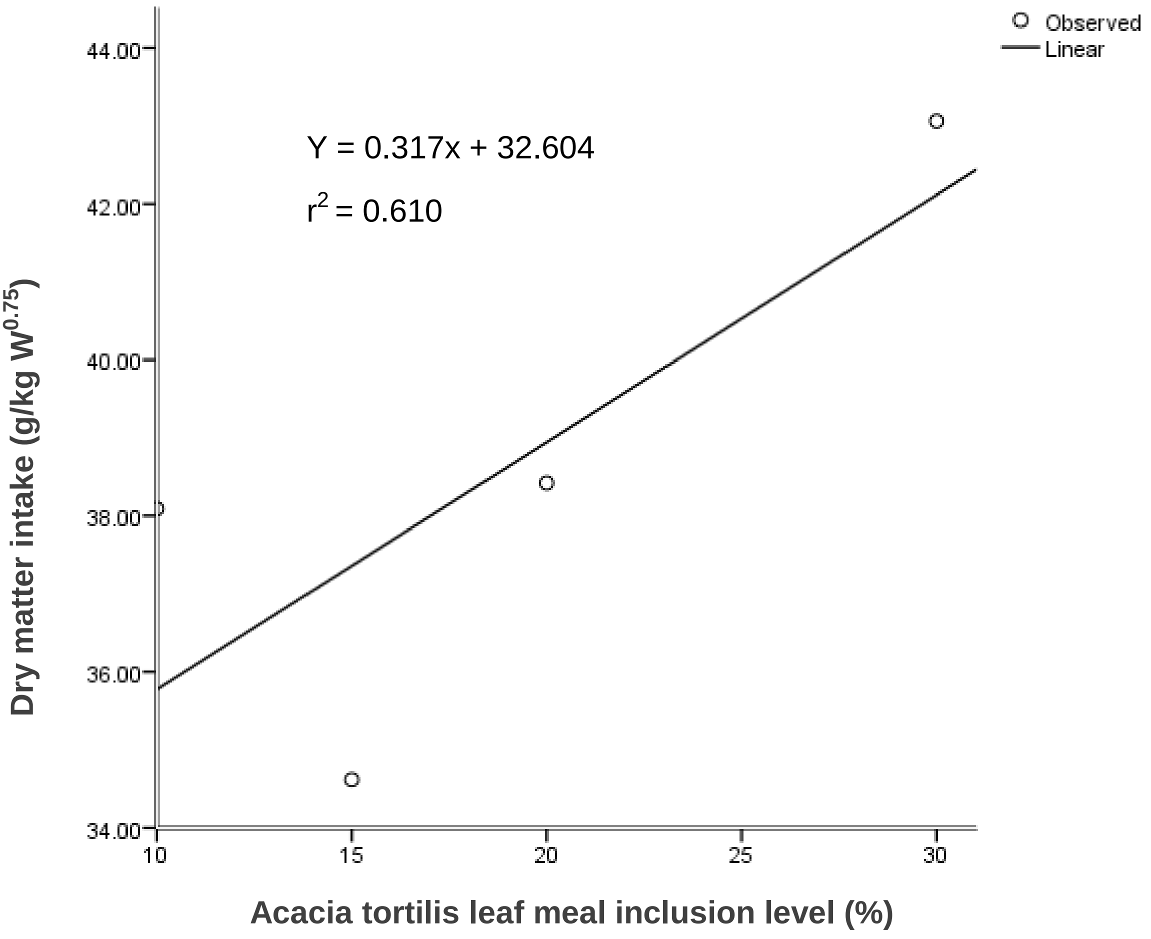

Figure 4.15 Relationship between *Acacia tortilis* leaf meal inclusion level and diet dry matter intake per metabolic weight of yearling male Boer goats fed an *Avena sativa* hay-based diet

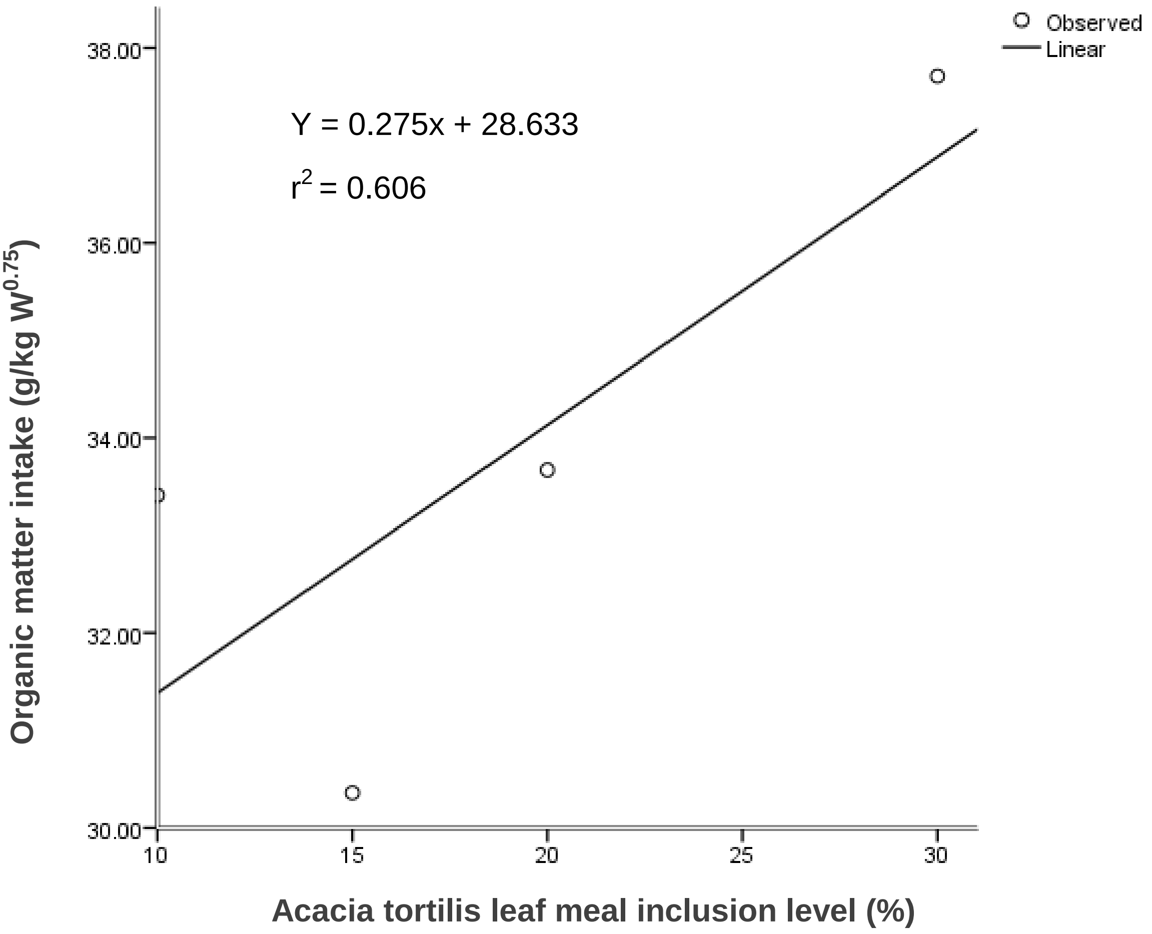

Figure 4.16 Relationship between *Acacia tortilis* leaf meal inclusion level and diet organic matter intake per metabolic weight of yearling male Boer goats fed an *Avena sativa* hay-based diet

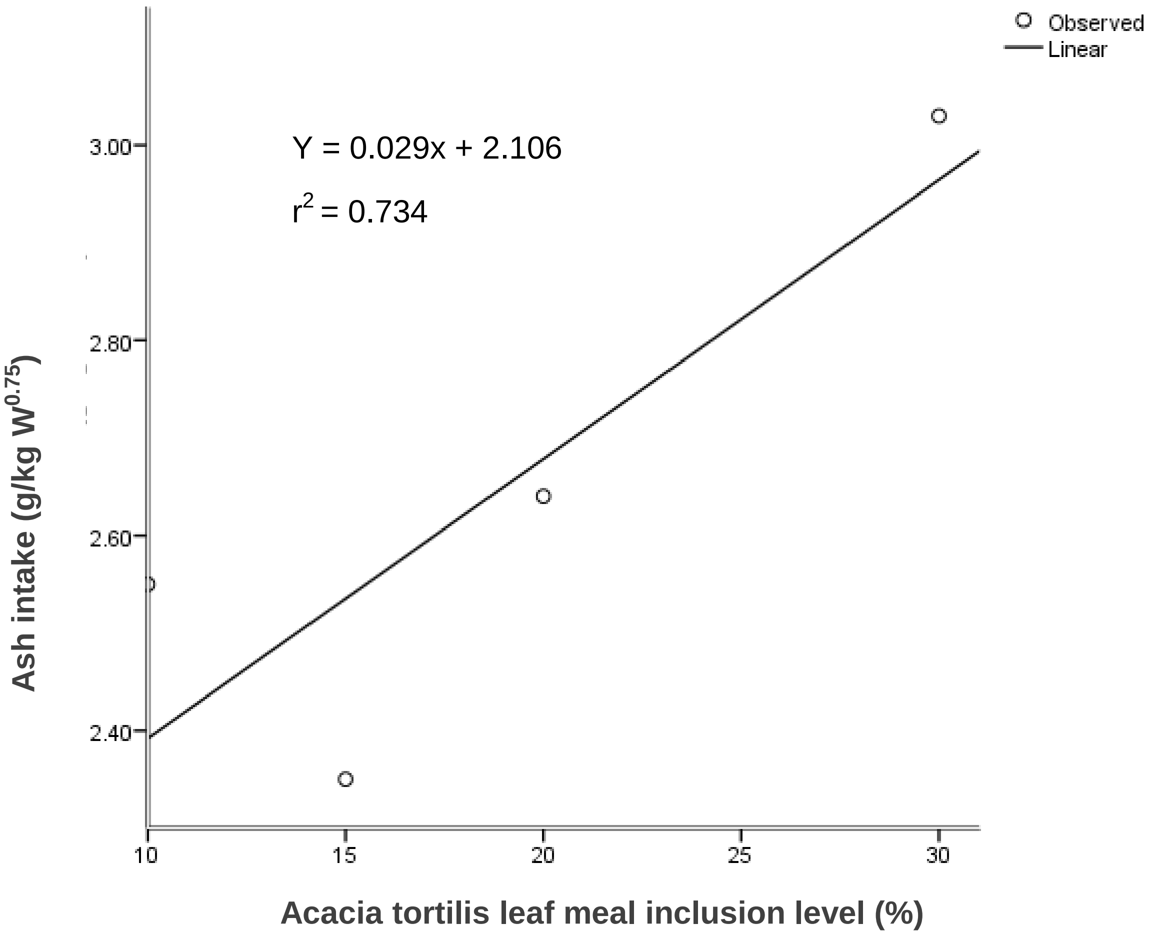

Figure 4.17 Relationship between *Acacia tortilis* leaf meal inclusion level and diet ash intake per metabolic weight of yearling male Boer goats fed an *Avena sativa* hay-based diet

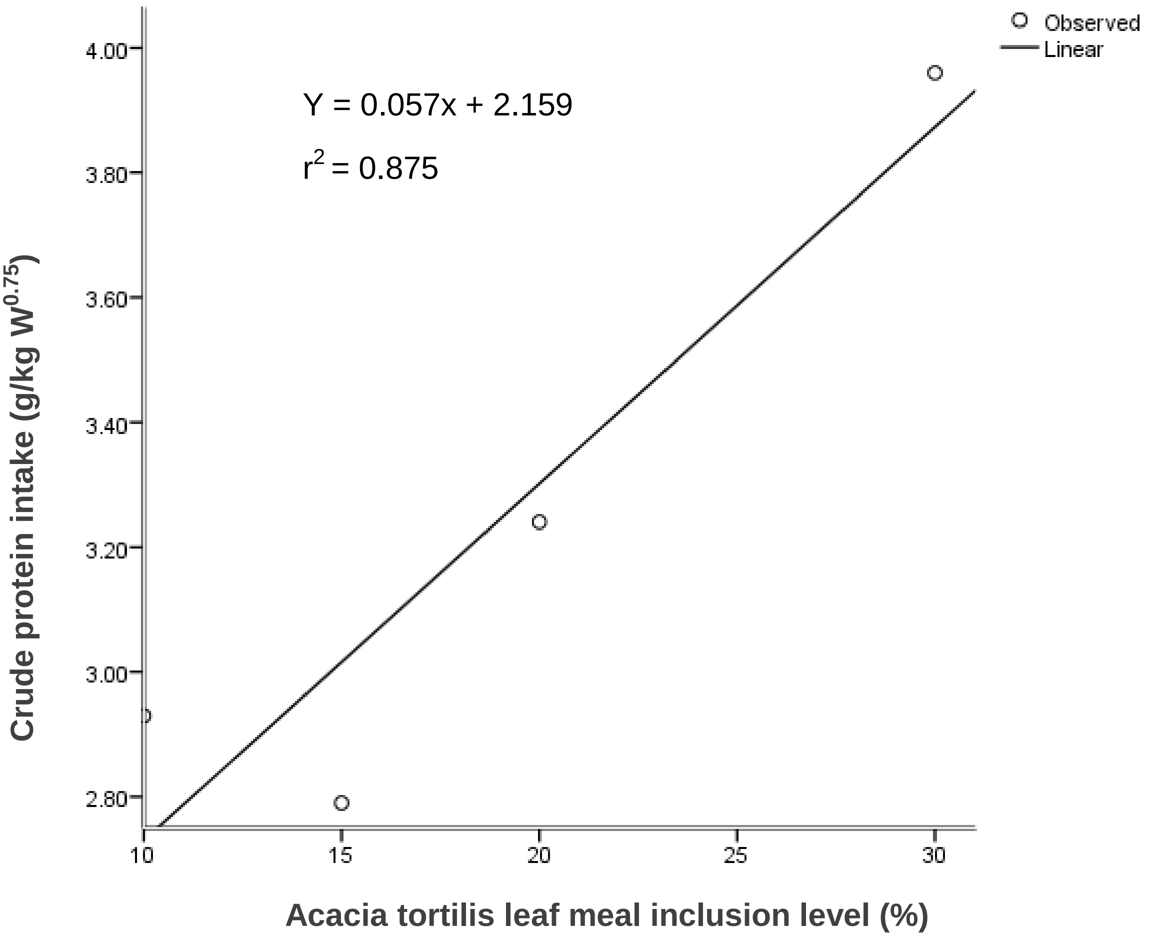

Figure 4.18 Relationship between *Acacia tortilis* leaf meal inclusion level and diet crude protein intake per metabolic weight of yearling male Boer goats fed an *Avena sativa* hay-based diet

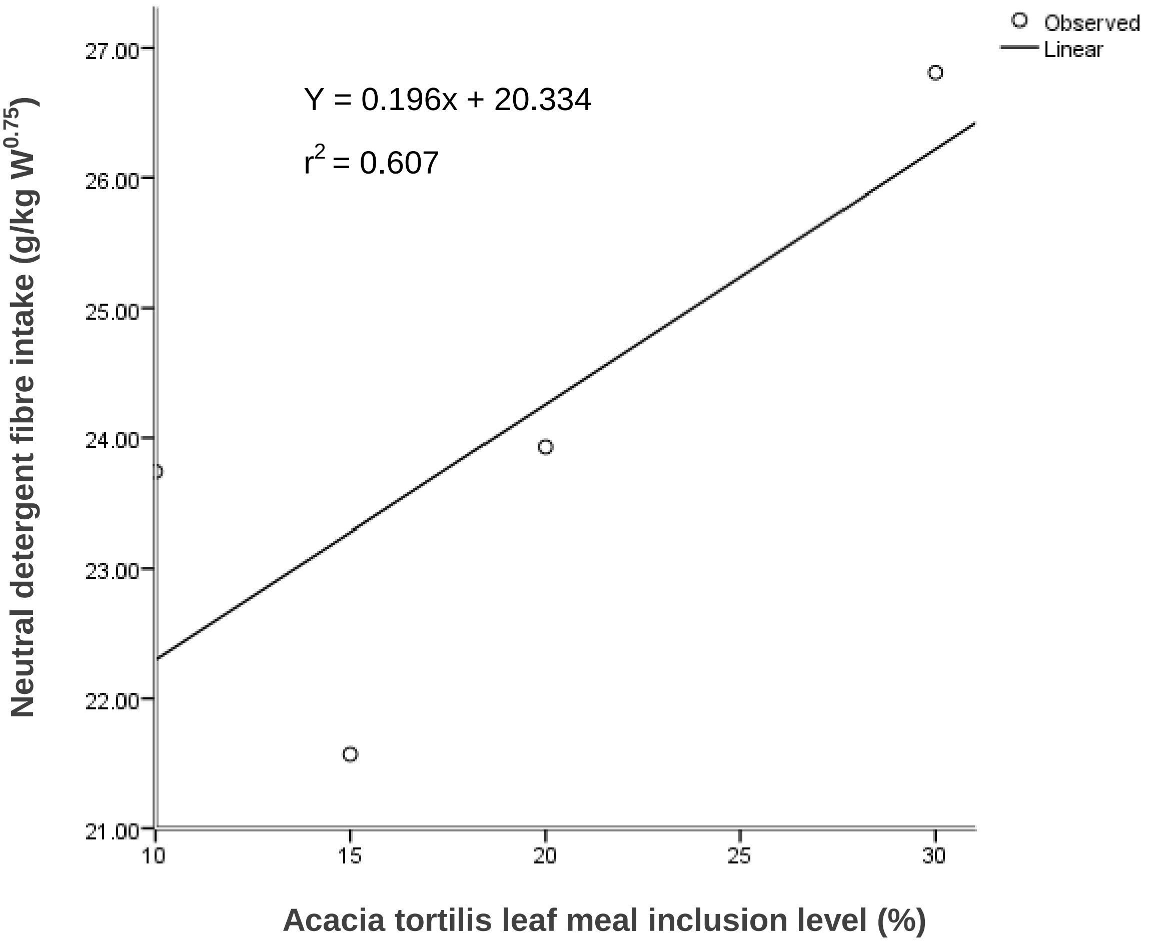

Figure 4.19 Relationship between *Acacia tortilis* leaf meal inclusion level and diet fat intake per metabolic weight of yearling male Boer goats fed an *Avena sativa* hay-based diet

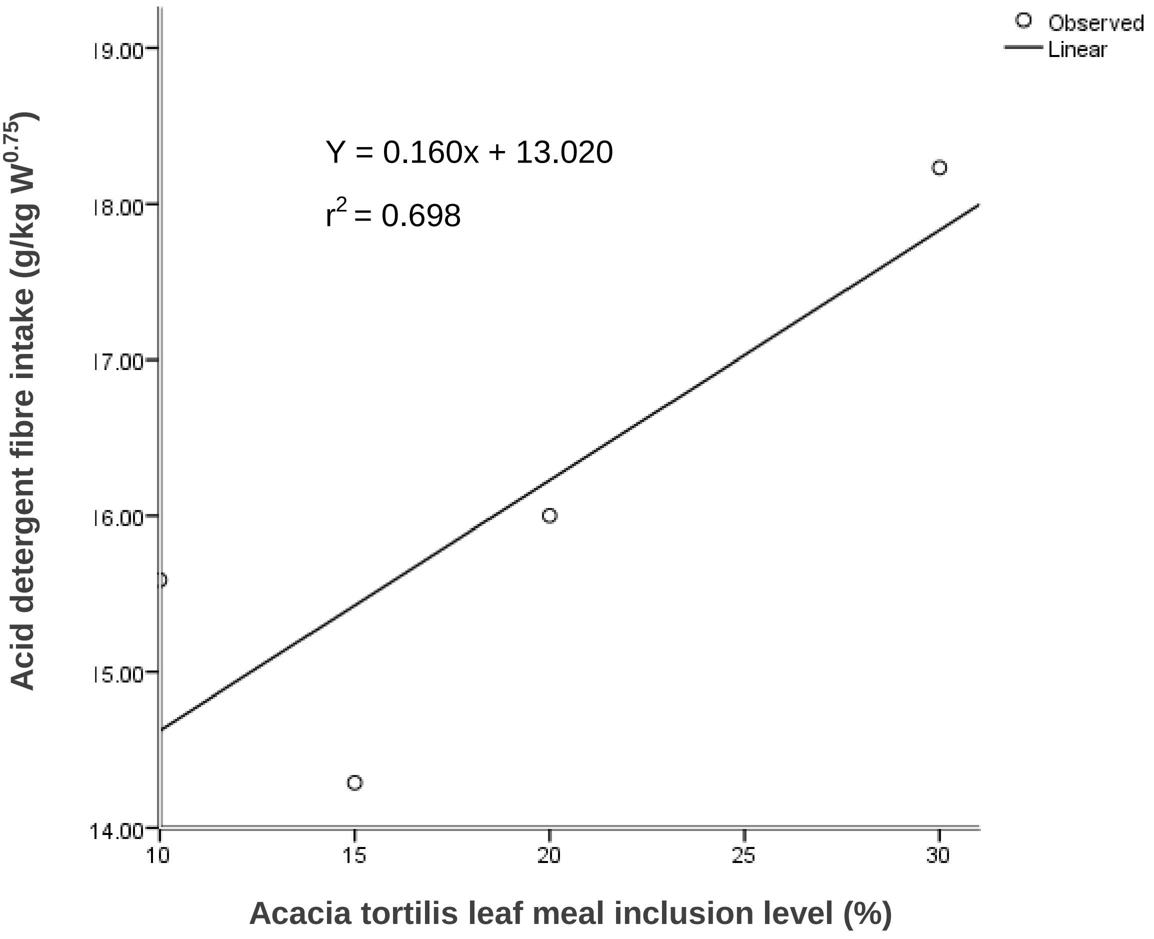

Figure 4.20 Relationship between *Acacia tortilis* leaf meal inclusion level and diet acid detergent fibre intake per metabolic weight of yearling male Boer goats fed an *Avena sativa* hay-based diet

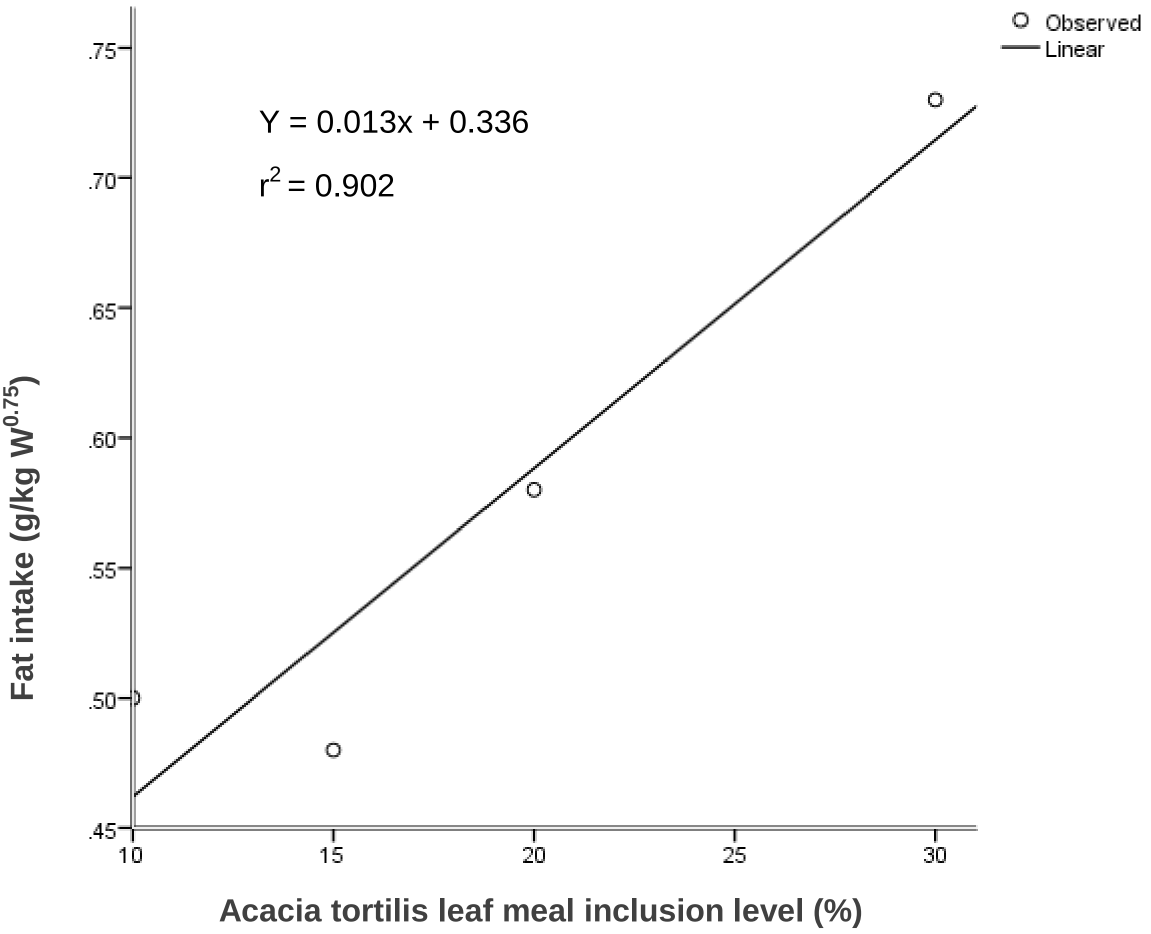

Figure 4.21 Relationship between *Acacia tortilis* leaf meal inclusion level and diet fat intake per metabolic weight of yearling male Boer goats fed an *Avena sativa* hay-based diet

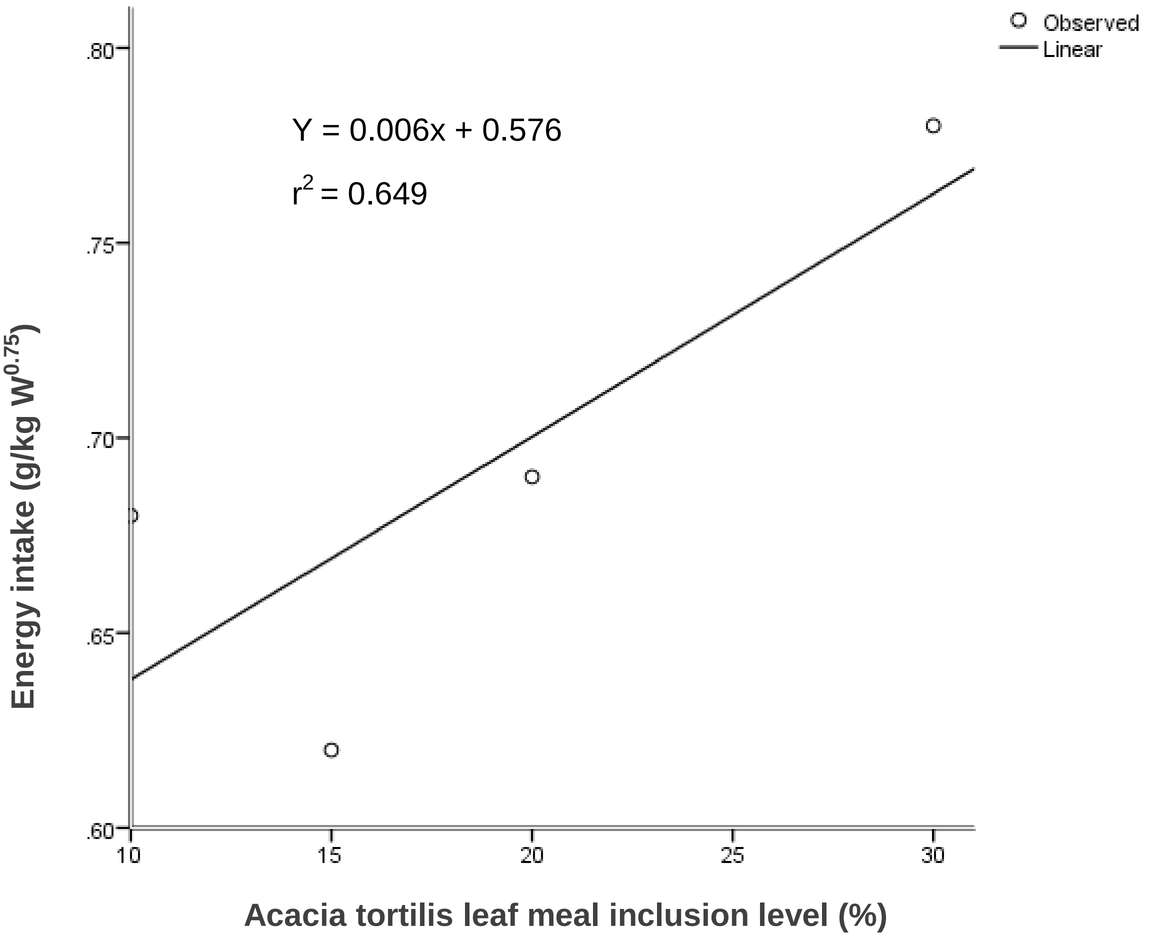

Figure 4.22 Relationship between *Acacia tortilis* leaf meal inclusion level and diet energy intake per metabolic weight of yearling male Boer goats fed an *Avena sativa* hay-based diet

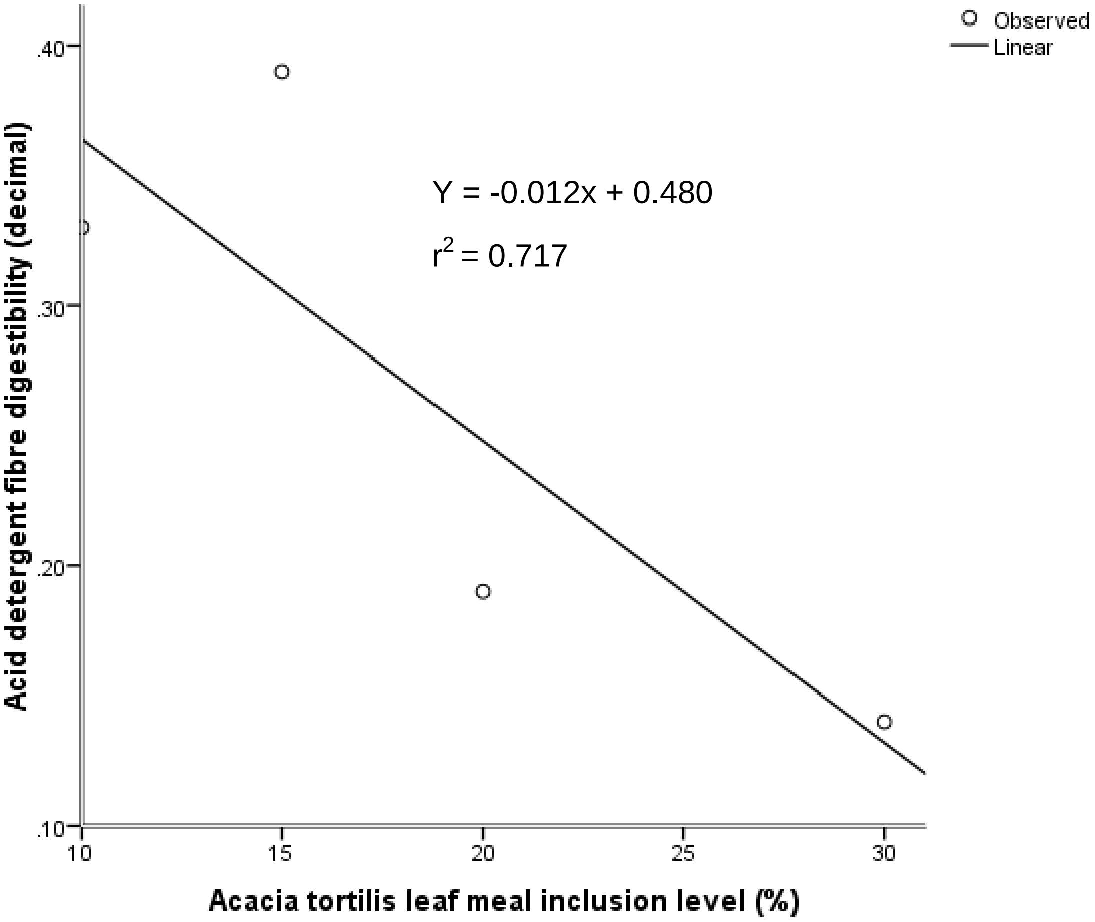

Figure 4.23 Relationship between *Acacia tortilis* leaf meal inclusion level and diet acid detergent fibre digestibility in yearling male Boer goats fed an *Avena sativa* hay-based diet

Table 4.12 Relationships between *Acacia tortilis* leaf meal inclusion level and diet intake and digestibility in yearling male Boer goats fed an *Avena sativa* hay-based diet

Factor	Formula	r^2	Probability
Intake (g/goat/day)			
DM	Y = 4.243x + 332.406	0.595	0.229
OM	Y = 3.691x + 291.854	0.591	0.231
Ash	Y = 0.367x + 21.356	0.703	0.162
CP	Y = 0.684x + 21.732	0.847	0.080
NDF	Y = 2.629x + 207.362	0.592	0.230
ADF	Y = 2.071x + 132.491	0.670	0.181
Fat	Y = 0.148x + 3.343	0.894	0.054
Energy intake (MJ/day)	Y = 0.085x + 5.810	0.647	0.196
Intake (g/kg $W^{0.75}$)			
DM	Y = 0.317x + 32.604	0.610	0.219
OM	Y = 0.275x + 28.633	0.606	0.222
Ash	Y = 0.029x + 2.106	0.734	0.143
CP	Y = 0.057x + 2.159	0.875	0.065
NDF	Y = 0.196x + 20.334	0.607	0.221
ADF	Y = 0.160x + 13.020	0.698	0.164
Fat	Y = 0.013x + 0.336	0.902	0.050
Energy intake (MJ/kg $W^{0.75}$)	Y = 0.006x + 0.576	0.649	0.194
Digestibility (decimal)			
ADF	Y = -0.012x + 0.480	0.717	0.153

r^2: Coefficient of determination

Methane emission values of yearling Boer goats before the start of the experiment and during the experiment involving *A. tortilis* leaf meal inclusion level are presented in Table 4.13. Inclusion of *A. tortilis* leaf meal in the diets of male Boer goats reduced ($P<0.05$) methane emission.

Table 4.13 Effect of *Acacia tortilis* leaf meal inclusion on methane emission of yearling male Boer goats fed an *Avena sativa* hay-based diet

Diet[#]	Methane emission (ppm-m)	
	Before experiment	After experiment
$H_{As90}AT_{10}$	$22.00^{a} \pm 5.033$	$11.50^{b} \pm 0.144$
$H_{As85}AT_{15}$	$22.00^{a} \pm 4.000$	$12.88^{b} \pm 1.516$
$H_{As80}AT_{20}$	$21.67^{a} \pm 4.410$	$12.42^{b} \pm 1.244$
$H_{As70}AT_{30}$	$22.33^{a} \pm 2.333$	$13.42^{b} \pm 0.333$

[a, b]: Means in the same row not sharing a common superscript are significantly different ($P<0.05$)

[#]: Diet codes are explained in Table 3.02, Chapter 3

The haematological indices and blood biochemical components of yearling Boer goats before the start of the experiment are presented in Table 4.14. All the goats had similar (P>0.05) haematological indices and blood biochemical values. The haematological indices and blood biochemical components of yearling Boer goats fed diets having different mixture levels of *A. tortilis* leaf meal and *Avena sativa* hay are presented in Table 4.15. *Acacia tortilis* leaf meal inclusion level had no effect (P>0.05) on the blood metabolites, enzymes and electrolytes of Boer goats. Similarly, *A. tortilis* leaf meal inclusion level did not affect (P>0.05) haematology of the goats except for the white blood cells (WBC). Goats on a diet having a 10 % *A. tortilis* leaf meal inclusion level had a higher (P<0.05) WBC count than those on diets having 15 or 20 % *A. tortilis* leaf meal inclusion levels. However, goats on diets having 15, 20 or 30 % *A. tortilis* leaf meal inclusion levels had same (P>0.05) WBC counts. Similarly, goats on diets having 10 or 30 % *A. tortilis* leaf meal inclusion levels had similar (P>0.05) WBC counts.

Acacia tortilis leaf meal inclusion level effected (P<0.05) serum proteins of Boer goats (Table 4.15). Goats on a diet having a 20 % *A. tortilis* leaf meal inclusion level had a higher (P<0.05) total serum protein content than those on diets having 10 or 15 % *A. tortilis* leaf meal inclusion levels. However, goats on diets having 10, 15 or 30 % *A. tortilis* leaf meal inclusion levels had similar (P>0.05) total serum proteins. Similarly, goats on diets having 20 or 30 % *A. tortilis* leaf meal inclusion levels had same (P>0.05) total serum proteins. Male Boer goats on a diet having a 20 % *A.*

Table 4.14 Haematological indices and blood biochemical components of yearling Boer goats before the start of the experiment on *Acacia tortilis* leaf meal

Variable	Diet$^{\#}$			
	$H_{As90}AT_{10}$	$H_{As85}AT_{15}$	$H_{As80}AT_{20}$	$H_{As70}AT_{30}$
Haematology				
Red blood cell (x10^{12}/L)	1.71 ±0.094	1.77 ±0.147	2.02 ±0.177	5.83 ±3.728
Haemoglobin (g/dL)	8.95 ±0.189	14.08 ±3.145	10.73 ±0.775	10.25 ±1.179
Haematocrit (L/L)	0.66 ±0.057	0.73 ±0.074	0.76 ±0.074	0.79 ±0.080
White blood cell (x10^{9}/L)	22.55 ±1.694	25.73 ±2.512	25.11 ±3.011	25.06 ±3.508
Metabolites (mmol/L)				
Urea	5.25 ±0.479	5.25 ±0.479	4.25 ±0.629	4.50 ±0.646
Glucose	3.43 ±0.175	3.43 ±0.165	3.25 ±0.150	3.38 ±0.210
Cholesterol	1.62 ±0.140	1.90 ±0.399	1.80 ±0.218	1.90 ±0.447
Proteins (g/L)				
Total Protein	76.00 ±2.160	78.00 ±4.546	72.00 ±5.802	68.00 ±7.948
Albumin	16.50 ±1.323	15.50 ±1.041	15.75 ±1.250	16.00 ±1.080
Enzymes (IU/L)				
ALP	123 ±70.494	156 ±84.605	169 ±98.297	235 ±109.041
ALT	26.75 ±2.562	24.25 ±2.287	22.00 ±2.550	24.25 ±1.931
AST	64.75 ±6.019	67.00 ±6.014	67.00 ±6.412	72.25 ±2.136
Electrolytes (mmol/L)				
Sodium	142 ±1.474	144 ±0.470	144 ±0.764	144 ±0.610
Potassium	4.86 ±0.169	5.02 ±0.128	4.92 ±0.290	4.91 ±0.181
Chloride	110 ±0.743	109 ±0.509	109 ±1.186	110 ±0.719
Total Calcium	2.21 ±0.033	2.24 ±0.066	2.23 ±0.069	2.26 ±0.039
Corrected Calcium	2.19 ±0.024	2.23 ±0.060	2.25 ±0.071	2.27 ±0.039
Inorganic Phosphate	2.44 ±0.305	2.23 ±0.297	2.11 ±0.295	2.28 ±0.252
Magnesium	1.00 ±0.032	0.92 ±0.034	0.95 ±0.077	0.99 ±0.045

ALP: Alkaline phosphate; ALT: Alanine transaminase; AST: Aspartate transaminase

$^{\#}$: Diet codes are explained in Table 3.02, Chapter 3

Table 4.15 Effect of *Acacia tortilis* leaf meal inclusion level on haematological indices and blood biochemical components of yearling male Boer goats fed an *Avena sativa* hay-based diet

Variable	Diet[#]			
	$H_{As90}AT_{10}$	$H_{As85}AT_{15}$	$H_{As80}AT_{20}$	$H_{As70}AT_{30}$
Haematology				
Red blood cell ($\times10^{12}$/L)	2.25 ±2.284	2.05 ±1.416	2.13 ±0.938	2.03 ±0.364
Haemoglobin (g/dL)	9.05 ±4.248	9.60 ±0.770	9.43 ±0.685	8.93 ±0.715
Haematocrit (L/L)	0.39 ±0.078	0.22 ±0.062	0.38 ±0.063	0.37 ±0.067
White blood cell ($\times10^{9}$/L)	21.42^{a} ±1.748	15.46^{b} ±1.478	16.26^{b} ±1.438	20.01^{ab} ±1.436
Metabolites (mmol/L)				
Urea	5.50 ±0.504	6.45 ±0.504	6.00 ±0.501	5.93 ±0.463
Glucose	2.59 ±0.100	2.52 ±0.101	2.62 ±0.109	2.37 ±0.987
Cholesterol	2.04 ± 0.192	2.21 ±0.154	2.18 ±0.153	1.88 ±0.154
Proteins (g/L)				
Total Protein	69.50^{b} ±4.735	70.50^{b} ±4.535	84.33^{a} ±3.981	78.00^{ab} ±4.240
Albumin	23.50^{b} ±1.070	26.50^{ab} ±1.069	27.33^{a} ±1.043	25.33^{ab} ±1.040
Enzymes (IU/L)				
ALP	56.00 ±32.352	86.50 ±30.299	110 ±30.147	62.00 ±31.826
ALT	24.50 ±2.501	23.00 ±2.192	25.00 ±2.474	23.33 ±2.192
AST	95.00 ±6.231	81.50 ±6.003	91.67 ±6.001	81.33 ±9.428
Electrolytes (mmol/L)				
Sodium	138 ±1.167	141 ±1.099	138 ±1.113	139 ±1.162
Potassium	8.60 ±0.434	8.85 ±0.455	8.93 ±0.423	8.67 ±0.423
Chloride	108 ±1.018	110 ±0.982	108 ±0.994	111 ±0.987
Total Calcium	2.24 ±0.037	2.26 ±0.033	2.27 ±0.033	2.22 ±0.035
Corrected Calcium	2.48 ±0.022	2.47 ±0.015	2.46 ±0.015	2.46 ±0.017
Inorganic Phosphate	2.49 ±0.183	2.35 ±0.174	2.22 ±0.181	2.77 ±0.174
Magnesium	1.39 ±0.090	1.20 ±0.096	1.20 ±0.075	1.27 ±0.078

[a, b]: Means in the same row not sharing a common superscript are significantly different ($P<0.05$)

ALP: Alkaline phosphate; ALT: Alanine transaminase; AST: Aspartate transaminase

[#]: Diet codes are explained in Table 3.02, Chapter 3

tortilis leaf meal inclusion level had a higher ($P<0.05$) albumin level than those on a diet with a 10 % *A. tortilis* leaf meal inclusion level. However, goats on diets having 10, 15 or 30 % *A. tortilis* leaf meal inclusion levels had similar ($P>0.05$) albumin levels. Similarly, goats on diets having 15, 20 or 30 % *A. tortilis* leaf meal inclusion levels had same ($P>0.05$) albumin levels.

White blood cells, total proteins and albumin were optimised at *A. tortilis* leaf meal inclusion levels of 20.27 ($r^2 = 0.880$), 23.78 ($r^2 = 0.671$) and 21.75 ($r^2 = 0.991$) in Boer goats, respectively (Figures 4.24, 4.25 and 4.26, respectively, and Table 4.16).

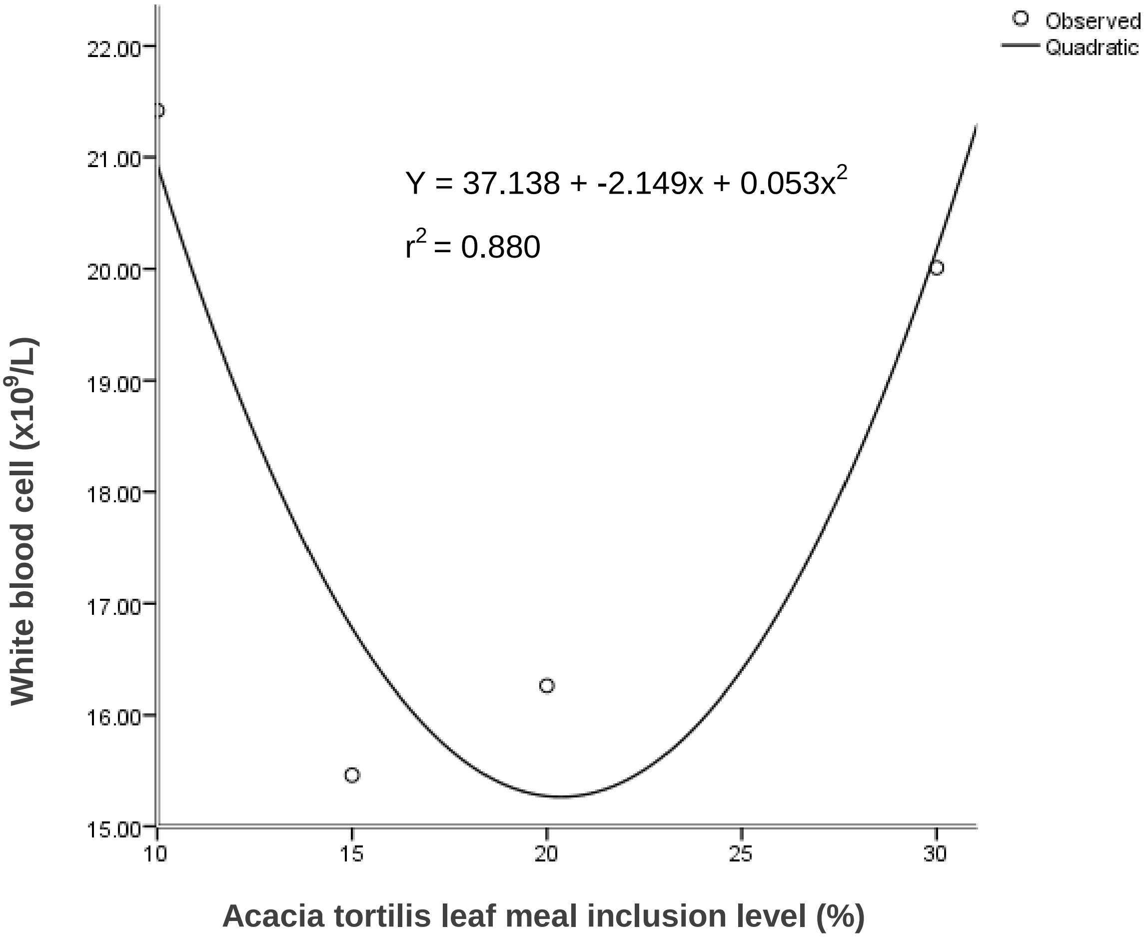

Figure 4.24 Effect of *Acacia tortilis* leaf meal inclusion level on white blood cell count of yearling male Boer goats fed an *Avena sativa* hay-based diet

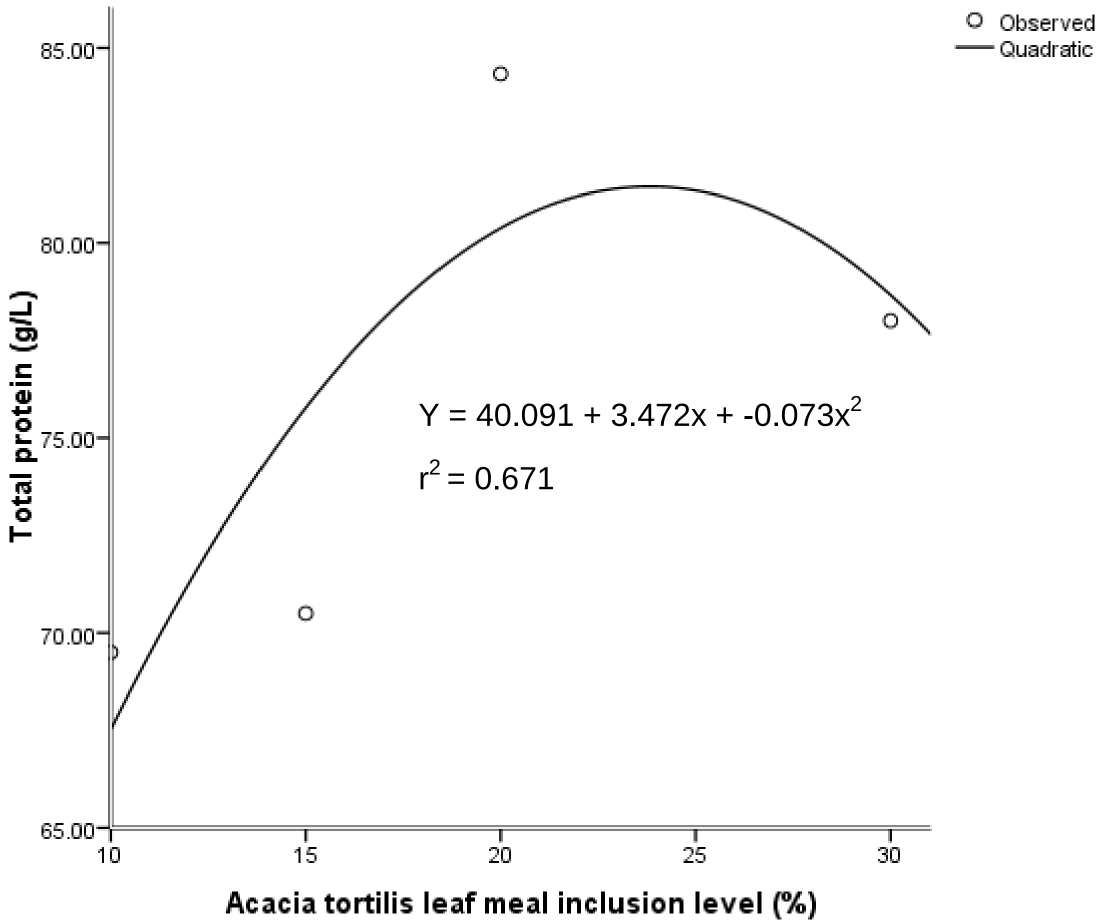

Figure 4.25 Effect of *Acacia tortilis* leaf meal inclusion level on blood total protein of yearling male Boer goats fed an *Avena sativa* hay-based diet

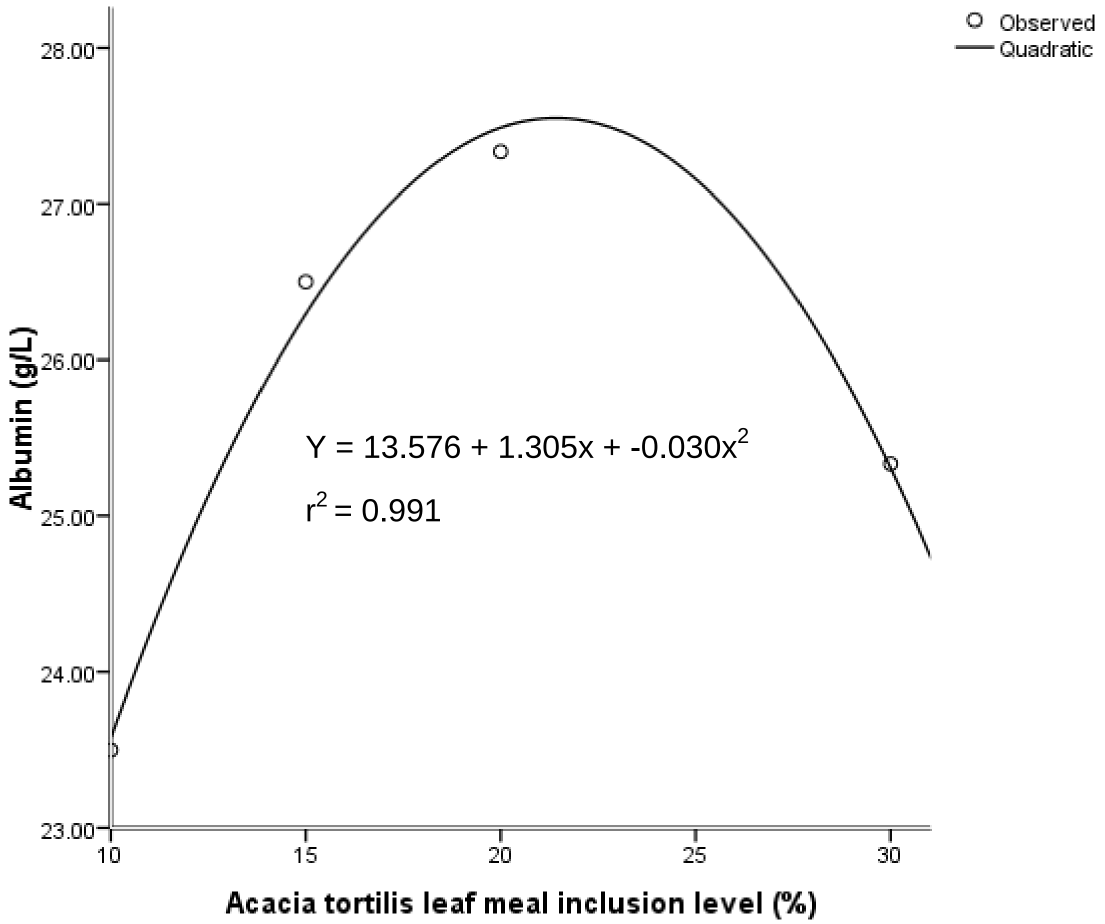

Figure 4.26 Effect of *Acacia tortilis* leaf meal inclusion level on blood albumin of yearling male Boer goats fed an *Avena sativa* hay-based diet

Table 4.16 *Acacia tortilis* leaf meal inclusion levels for optimal haematological induces and blood protein components of yearling male Boer goats fed an *Avena sativa* hay-based diet

Factor	Formula	X	Y	r^2	P
Haematology ($x10^9$/L)					
WBC	$Y = 37.138 + -2.149x + 0.053x^2$	20.27	15.35	0.880	0.347
Proteins (g/L)					
Protein	$Y = 40.091 + 3.472x + -0.073x^2$	23.78	81.38	0.671	0.574
Albumin	$Y = 13.576 + 1.305x + -0.030x^2$	21.75	27.77	0.991	0.094

X: Inclusion level for optimal value

Y: Optimal Y-level

r^2: Coefficient of determination

P: Probability

Major haematological indices and blood biochemical component values of yearling Boer goats before the start of the experiment and during the experiment involving *A. tortilis* leaf meal inclusion level are presented in Table 4.17. Inclusion of *A. tortilis* leaf meal in the diets of male Boer goats had no effect (P>0.05) on serum urea and total serum proteins. However, an increase (P<0.05) in glucose levels of goats was observed when *A. tortilis* leaf meal was included in the diets. In the case of red blood cell (RBC) counts, a diet having a 10 % *A. tortilis* leaf meal inclusion level reduced (P<0.05) RBC counts. However, Boer goats on diets having 15, 20 or 30 % *A. tortilis* leaf meal inclusion levels had similar (P>0.05) RBC counts as those on diets without *A. tortilis* leaf meals. Reduction (P<0.05) in haematocrit levels of goats fed diets having 15, 20 or 30 % *A. tortilis* leaf meal inclusion levels was observed. However, level of haematocrit in goats fed a diet having a 10 % *A. tortilis* leaf meal inclusion level remained similar (P>0.05) to those on a diet without *A. tortilis* leaf meal. Inclusion levels of 10 or 30 % *A. tortilis* leaf meals in the diets of male Boer goats had no effect (P>0.05) on white blood cell (WBC) counts. However, goats fed diets having 15 or 20 % *A. tortilis* leaf meal inclusion levels had lower (P<0.05) WBC counts than those on diets without *A. tortilis* leaf meals.

Table 4.17 Effect of *Acacia tortilis* leaf meal inclusion level on major haematological indices and blood biochemical components of yearling male Boer goats fed an *Avena sativa* hay-based diet

Variable$^{\#}$	Before experiment	After experiment
Red blood cell (x10^{12}/L)		
$H_{As90}AT_{10}$	1.71^{b} ±0.094	2.25^{a} ±0.118
$H_{As85}AT_{15}$	1.77 ±0.147	2.05 ±0.198
$H_{As80}AT_{20}$	2.02 ±0.177	2.13 ±0.352
$H_{As70}AT_{30}$	5.83 ±3.728	2.03 ±0.499
Haematocrit (L/L)		
$H_{As90}AT_{10}$	0.66 ±0.057	0.39 ±0.100
$H_{As85}AT_{15}$	0.73^{a} ±0.074	0.22^{b} ±0.027
$H_{As80}AT_{20}$	0.76^{a} ±0.074	0.38^{b} ±0.054
$H_{As70}AT_{30}$	0.79^{a} ±0.080	0.37^{b} ±0.023
White blood cell (x10^{9}/L)		
$H_{As90}AT_{10}$	22.55 ±1.694	21.42 ±0.898
$H_{As85}AT_{15}$	25.73^{a} ±2.512	15.46^{b} ±0.955
$H_{As80}AT_{20}$	25.11^{a} ±3.011	16.26^{b} ±1.859
$H_{As70}AT_{30}$	25.06 ±3.508	20.01 ±1.076
Urea (mmol/L)		
$H_{As90}AT_{10}$	5.25 ±0.479	5.50 ±0.696
$H_{As85}AT_{15}$	5.25 ±0.479	6.45 ±0.797
$H_{As80}AT_{20}$	4.25 ±0.629	6.00 ±0.535
$H_{As70}AT_{30}$	4.50 ±0.646	5.93 ±0.201
Glucose (mmol/L)		
$H_{As90}AT_{10}$	3.43^{a} ±0.175	2.59^{b} ±0.149
$H_{As85}AT_{15}$	3.43^{a} ±0.165	2.52^{b} ±0.065
$H_{As80}AT_{20}$	3.25^{a} ±0.150	2.62^{b} ±0.031
$H_{As70}AT_{30}$	3.38^{a} ±0.210	2.37^{b} ±0.043
Total protein (g/L)		
$H_{As90}AT_{10}$	76.00 ±2.160	69.50 ±5.511
$H_{As85}AT_{15}$	78.00 ±4.546	70.50 ±1.837
$H_{As80}AT_{20}$	72.00 ±5.802	84.33 ±2.494
$H_{As70}AT_{30}$	68.00 ±7.948	78.00 ±2.944

$^{a, b}$: Means in the same row not sharing a common superscript are significantly different ($P<0.05$)

$^{\#}$: Diet codes are explained in Table 3.02, Chapter 3

4.4 Effect of *Acacia nilotica* leaf meal inclusion level on diet intake, digestibility, methane emission, live weight, feed conversion ratio, haematological indices and blood biochemical components of yearling male Boer goats fed an *Avena sativa* hay-based diet

The nutrient composition of mixtures of *A. nilotica* and *Avena sativa* hay are presented in Table 4.18. *Acacia nilotica* leaf meal inclusion level had no effect (P>0.05) on diet dry matter (DM) and organic matter (OM) contents. However, *A. nilotica* leaf meal inclusion level affected (P<0.05) diet ash, crude protein (CP), acid detergent fibre (ADF), neutral detergent fibre (NDF), fat and energy contents. Diet CP and fat contents increased (P<0.05) with increased *A. nilotica* leaf meal inclusion levels. However, dietary NDF and ADF contents decreased (P<0.05) with increased *A. nilotica* leaf meal inclusion levels. A diet having a 30 % *A. nilotica* leaf meal inclusion level resulted in a higher (P<0.05) ash content than diets having 10, 15 or 20 % *A. nilotica* leaf meal inclusion levels. Similarly, a diet having a 20 % *A. nilotica* leaf meal inclusion level resulted in a higher (P<0.05) ash content than that with a 10 % *A. nilotica* leaf meal inclusion level. However, diets having 15 or 20 % *A. nilotica* leaf meal inclusion levels had similar (P>0.05) ash contents. Similarly, diets with 10 or 15 % *A. nilotica* leaf meal inclusion levels had same (P>0.05) ash contents. A diet having a 30 % *A. nilotica* leaf meal inclusion level resulted in a higher (P<0.05) energy content than that with a 10 % *A. nilotica* leaf meal inclusion level. However, diets having 10, 15 or 20 % *A. nilotica* leaf meal inclusion levels had similar (P>0.05) energy contents. Similarly, diets having 15, 20 or 30 % *A. nilotica* leaf meal inclusion levels had same (P>0.05) energy contents.

Increasing *A. nilotica* leaf meal inclusion level in the diet increased (P<0.05) total phenolics, total tannins, condensed tannins (CT) and hydrolysable tannins (HT). Similarly, increased inclusion levels of *A. nilotica* leaf meal resulted in increased (P<0.05) diet calcium content (Table 4.18). However, increasing *A. nilotica* leaf meal inclusion level in the diet decreased (P<0.05) potassium content and the ratio of potassium/calcium plus magnesium. A diet having a 10 % *A. nilotica* leaf meal inclusion level had a lower (P<0.05) magnesium (Mg) content than diets having 10, 15 or 20 % *A. nilotica* leaf meal inclusion levels. However, diets having 10, 15 or 20 % *A. nilotica* leaf meal inclusion levels had similar (P>0.05) Mg contents. A diet

Table 4.18 Nutrient composition of the experimental *Acacia nilotica* diets

Nutrient	Diet$^{\#}$			
	$H_{As90}AN_{10}$	$H_{As85}AN_{15}$	$H_{As80}AN_{20}$	$H_{As70}AN_{30}$
Dry matter (%)	94.31 ±0.544	94.31 ±0.544	94.32 ±0.545	94.34 ±0.545
Organic matter (%)	87.57 ±0.506	87.47 ±0.505	87.37 ±0.504	87.17 ±0.503
Ash (%)	6.74^{c} ±0.039	6.86^{bc} ±0.040	6.97^{b} ±0.040	7.19^{a} ±0.042
Crude protein (%)	7.48^{d} ±0.043	7.75^{c} ±0.045	8.03^{b} ±0.046	8.58^{a} ±0.050
Neutral detergent fibre (%)	59.36^{a} ±0.343	57.86^{b} ±0.334	56.36^{c} ±0.325	53.36^{d} ±0.308
Acid detergent fibre (%)	38.15^{a} ±0.220	37.12^{b} ±0.214	36.08^{c} ±0.208	34.02^{d} ±0.196
Fat (%)	1.21^{d} ±0.007	1.27^{c} ±0.007	1.32^{b} ±0.008	1.43^{a} ±0.008
Energy (MJ/kg)	17.73^{b} ±0.088	18.84^{ab} ±0.100	17.93^{ab} ±0.094	18.11^{a} ±0.081
Total phenolics*	0.41^{d} ±0.002	0.61^{c} ±0.004	0.81^{b} ±0.005	1.22^{a} ±0.007
Total tannins*	0.37^{d} ±0.002	0.56^{c} ±0.003	0.75^{b} ±0.004	1.12^{a} ±0.007
Condensed tannins**	0.15^{d} ±0.001	0.22^{c} ±0.001	0.30^{b} ±0.002	0.45^{a} ±0.003
Hydrolysable tannins (mg/g)	12.84^{d} ±0.741	19.26^{c} ±1.112	25.68^{b} ±1.483	38.51^{a} ±2.223
Calcium (%)	0.43^{d} ±0.003	0.50^{c} ±0.003	0.57^{b} ±0.003	0.72^{a} ±0.004
Magnesium (%)	0.12^{b} ±0.001	0.13^{a} ±0.001	0.13^{a} ±0.001	0.13^{a} ±0.001
Potassium (%)	1.77^{a} ±0.010	1.72^{b} ±0.009	1.68^{c} ±0.009	1.60^{d} ±0.009
Sodium (%)	0.04^{a} ±0.000	0.04^{a} ±0.000	0.04^{a} ±0.000	0.03^{b} ±0.000
K/Ca + Mg (%)	1.85^{a} ±0.011	1.76^{b} ±0.010	1.68^{c} ±0.009	1.50^{d} ±0.009
Phosphorus (%)	0.15^{a} ±0.001	0.15^{a} ±0.001	0.15^{a} ±0.001	0.14^{b} ±0.001
Zinc (mg/kg or ppm)	15.40^{c} ±0.089	15.60^{bc} ±0.090	15.80^{b} ±0.091	16.20^{a} ±0.094
Copper (mg/kg or ppm)	3.70^{d} ±0.021	4.05^{c} ±0.023	4.40^{b} ±0.025	5.10^{a} ±0.029
Molybdenum (mg/kg)	45.60^{c} ±0.263	46.40^{bc} ±0.268	47.20^{b} ±0.273	48.80^{a} ±0.282
Iron (mg/kg or ppm)	262^{d} ±1.517	276^{c} ±1.598	290^{b} ±1.678	318^{a} ±1.838

$^{a, b, c, d}$: Means in the same row not sharing a common superscript are significantly different ($P<0.05$)

*: Percentage DM tannic acid equivalent

**: Percentage DM leucocyanidin equivalent

K/Ca + Mg: Potassium/Calcium plus Magnesium

$^{\#}$: Diet codes are explained in Table 3.03, Chapter 3

having a 30 % *A. nilotica* leaf meal inclusion level had a lower ($P<0.05$) sodium (Na) and phosphorus (P) contents than those having 10, 15 or 20 % *A. nilotica* leaf meal inclusion levels. However, diets having 10, 15 or 20 % *A. nilotica* leaf meal inclusion had similar ($P>0.05$) Na and P contents.

A diet having a 30 % *A. nilotica* leaf meal inclusion level had a higher (P<0.05) zinc (Zn) and molybdenum (Mo) contents than diets having 10, 15 or 20 % *A. nilotica* leaf meal inclusion levels (Table 4.18). Similarly, a diet with a 20 % *A. nilotica* leaf meal inclusion level had higher (P<0.05) Zn and Mo contents than that with a 10 % *A. nilotica* leaf meal inclusion level. However, diets having 10 or 15 % *A. nilotica* leaf meal inclusion levels had similar (P>0.05) Zn and Mo contents. Similarly, diets with 15 or 20 % *A. nilotica* leaf meal inclusion levels had same (P>0.05) Zn and Mo contents. Increasing *A. nilotica* leaf meal inclusion levels in the diet resulted in increased (P<0.05) copper and iron contents.

The results of the effect of *A. nilotica* leaf meal inclusion level on intake, digestibility, methane emission, live weight, weight gain and feed conversion ratio (FCR) of yearling male Boer goats fed *Avena sativa* hay-based diets are presented in Table 4.19. *Acacia nilotica* leaf meal inclusion level had no effect (P>0.05) on diet intake, methane emission, live weight and weight gain per goat. Similarly, *A. nilotica* leaf meal inclusion level did not affect (P>0.05) diet digestibility by goats except for fat digestibility. Male Boer goats on a diet having a 30 % *A. nilotica* leaf meal inclusion level had a higher (P<0.05) fat digestibility than those on a diet having a 15 % *A. nilotica* leaf meal inclusion level. However, goats on diets having 10, 15 or 20 % *A. nilotica* leaf meal inclusion levels had similar (P>0.05) fat digestibility values. Similarly, goats on diets having 10, 20 or 30 % *A. nilotica* leaf meal inclusion levels had same (P>0.05) fat digestibility values. Boer goats on a diet containing a 30 % *A. nilotica* leaf meal inclusion level had a better (P<0.05) FCR value than those on diets having 10, 15 or 20 % *A. nilotica* leaf meal inclusion levels. Similarly, goats on a diet with a 20 % *A. nilotica* leaf meal inclusion level had a better (P<0.05) FCR value than goats on a diet having a 10 % *A. nilotica* leaf meal inclusion level. However, goats on diets having 10 or 15 % *A. nilotica* leaf meal inclusion levels had similar (P>0.05) FCR values. Similarly, goats on diets containing 15 or 20 % *A. nilotica* leaf meal inclusion levels had same (P>0.05) FCR values. Positive relationships were observed between *A. nilotica* leaf meal inclusion level and diet fat digestibility (r^2 = 0.867) and FCR (r^2 = 0.977) in male Boer goats, respectively (Figures 4.27 and 4.28, respectively, and Table 4.20).

Table 4.19 Effect of *Acacia nilotica* leaf meal inclusion level on diet intake, digestibility, methane emission, live weight change and feed conversion ratio of yearling male Boer goats fed an *Avena sativa* hay-based diet

Variable	Diet$^{\#}$			
	$H_{As90}AN_{10}$	$H_{As85}AN_{15}$	$H_{As80}AN_{20}$	$H_{As70}AN_{30}$
Intake (g/goat/day)				
DM	341 ±47.705	319 ±44.151	383 ±44.465	310 ±44.861
OM	229 ±39.940	279 ±38.582	335 ±38.857	270 ±39.203
Ash	23.01 ±3.177	21.92 ±3.069	26.73 ±3.091	22.33 ±3.118
CP	25.54 ±3.650	24.76 ±3.526	30.80 ±3.551	26.65 ±3.583
NDF	202 ±25.881	184 ±25.001	216 ±25.179	165 ±25.403
ADF	130 ±16.574	118 ±16.011	138 ±16.125	105 ±16.268
Fat	4.13 ±0.599	4.06 ±0.579	5.06 ±0.583	4.44 ±0.582
Energy intake (MJ/day)	6.06 ±0.851	5.70 ±0.822	6.89 ±0.828	5.63 ±0.836
Intake (g/kg $W^{0.75}$)				
DM	31.24 ±3.788	31.21 ±3.659	35.23 ±3.685	31.19 ±3.718
OM	27.36 ±3.311	27.30 ±3.198	30.78 ±3.221	27.19 ±3.250
Ash	2.11 ±0.263	2.14 ±0.254	2.46 ±0.256	2.24 ±0.258
CP	2.34 ±0.301	2.42 ±0.291	2.83 ±0.293	2.68 ±0.296
NDF	18.54 ±2.152	18.06 ±2.079	19.85 ±2.093	16.65 ±2.112
ADF	11.92 ±1.378	11.59 ±1.332	12.71 ±1.341	10.61 ±1.353
Fat	0.38 ±0.049	0.40 ±0.048	0.47 ±0.048	0.45 ±0.049
Energy intake (MJ/kg $W^{0.75}$)	0.55 ±0.071	0.56 ±0.068	0.63 ±0.069	0.56 ±0.069
Digestibility (decimal)				
DM	0.50 ±0.350	0.57 ±0.147	0.57 ±0.051	0.60 ±0.226
OM	0.48 ±0.306	0.57 ±0.129	0.57 ±0.045	0.59 ±0.198
Ash	0.37 ±1.199	0.32 ±0.505	0.30 ±0.177	0.47 ±0.774
CP	0.42 ±0.652	0.42 ±0.274	0.52 ±0.096	0.54 ±0.421
NDF	0.35 ±0.362	0.44 ±0.152	0.44 ±0.054	0.44 ±0.234
ADF	0.19 ±0.481	0.30 ±0.202	0.33 ±0.071	0.28 ±0.310
Fat	0.08^{ab} ±0.510	0.05^{b} ±0.215	0.14^{ab} ±0.075	0.34^{a} ±0.329
Energy	0.46 ±0.387	0.54 ±0.163	0.54 ±0.057	0.56 ±0.250
Methane emission (ppm-m)	15.00 ±1.357	16.20 ±1.351	14.87 ±1.358	15.60 ±1.356
Live weight (g/goat/day)				
Initial (kg)	23.48 ±2.234	22.75 ±3.097	23.85 ±2.388	22.05 ±2.799
Final (kg)	24.17 ±2.518	23.25 ±3.294	24.35 ±2.691	22.30 ±3.154
Weight gain (g/goat/day)	136 ±394.252	100 ±165.981	100 ±58.046	50 ±254.527
Feed conversion ratio	2.50^{c} ±0.635	3.20^{bc} ±0.249	3.84^{b} ±0.249	6.21^{a} ±0.277

$^{a, b, c}$: Means in the same row not sharing a common superscript are significantly different ($P<0.05$)

$^{\#}$: Diet codes are explained in Table 3.03, Chapter 3

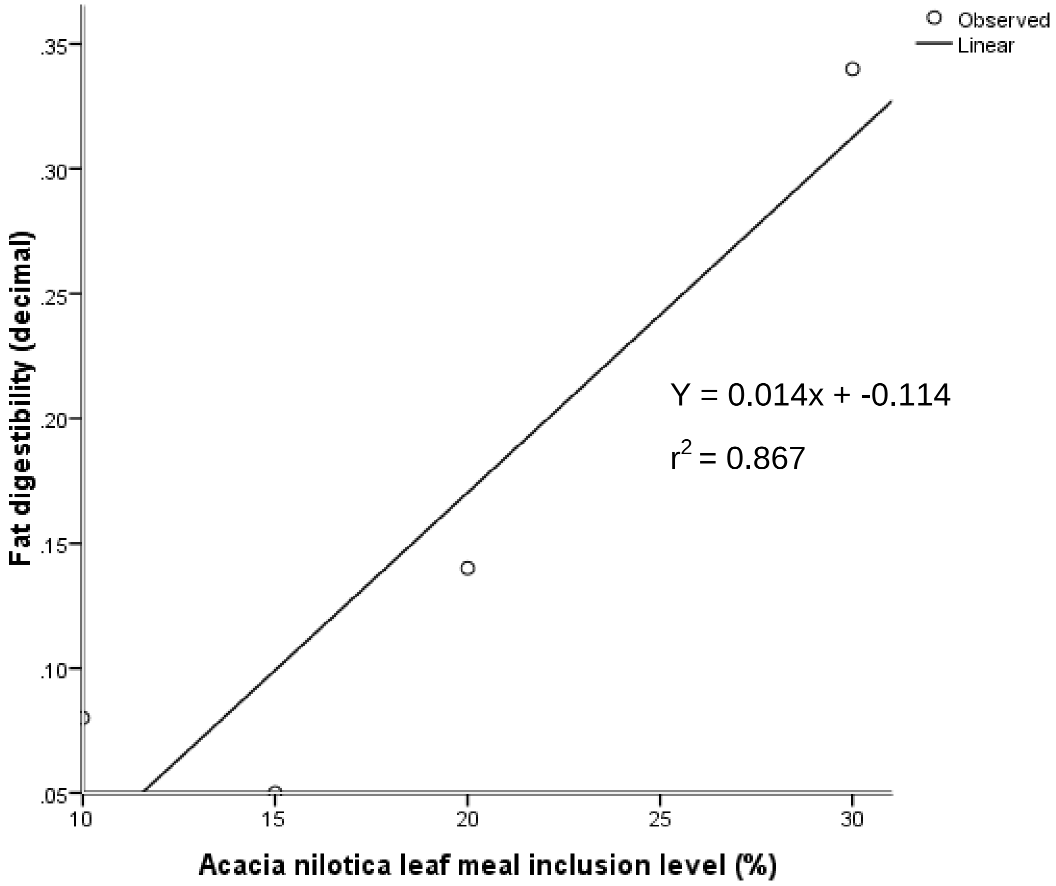

Figure 4.27 Relationship between *Acacia nilotica* leaf meal inclusion level and diet fat digestibility in yearling male Boer goats fed an *Avena sativa* hay-based diet

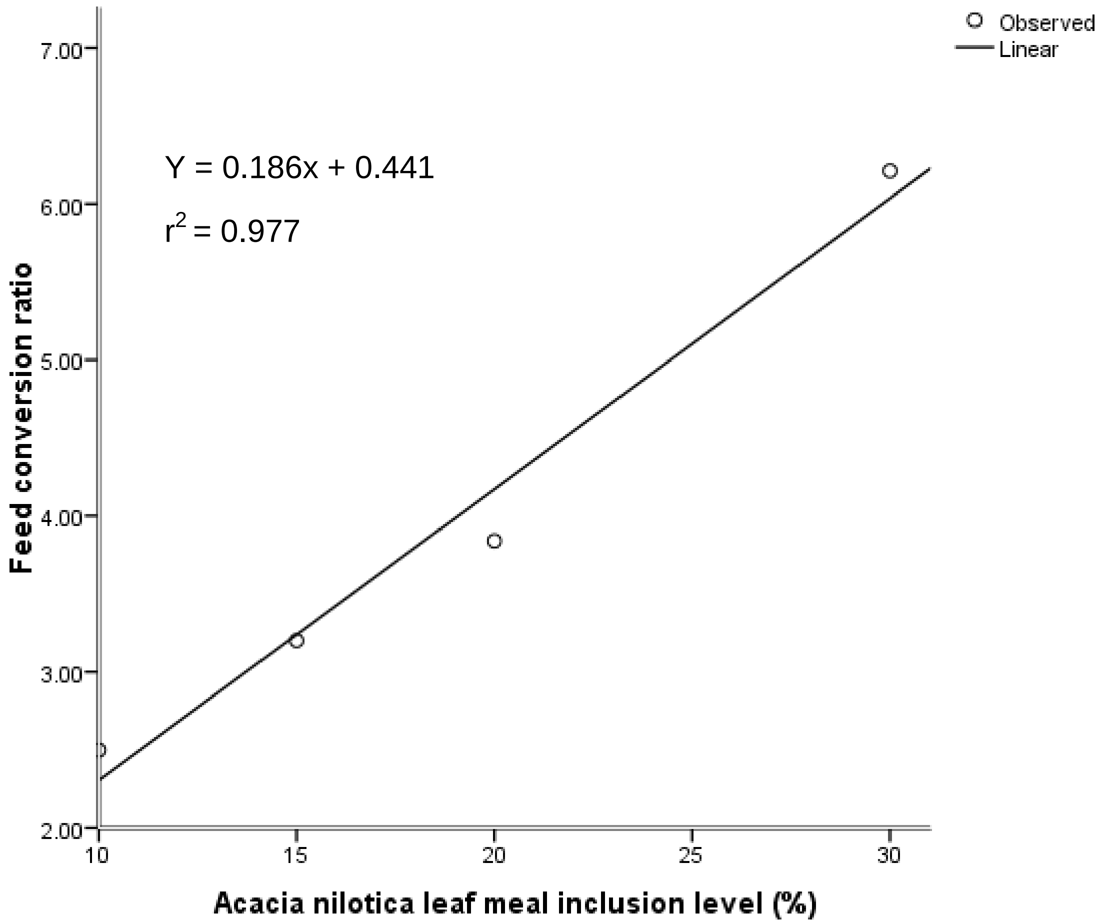

Figure 4.28 Relationship between *Acacia nilotica* leaf meal inclusion level and feed conversion ratio in yearling male Boer goats fed an *Avena sativa* hay-based diet

Table 4.20 Relationships between *Acacia nilotica* leaf meal inclusion level and diet digestibility and feed conversion ratio in yearling male Boer goats fed an *Avena sativa* hay-based diet

Factor	Formula	r^2	Probability
Fat digestibility (decimal)	Y = 0.014x + -0.114	0.867	0.069
FCR	Y = 0.186x + 0.441	0.997	0.012

r^2: Coefficient of determination

Methane emission values of yearling Boer goats before the start of the experiment and during the experiment involving *A. nilotica* leaf meal inclusion level are presented in Table 4.21. Inclusion of *A. nilotica* leaf meal in the diets of male Boer goats reduced (P<0.05) methane emission.

Table 4.21 Effect of *Acacia nilotica* leaf meal inclusion on methane emission of yearling male Boer goats fed an *Avena sativa* hay-based diet

Diet[#]	Methane emission (ppm-m)	
	Before experiment	After experiment
$H_{As90}AN_{10}$	23.33^a ±5.457	15.00^b ±1.858
$H_{As85}AN_{15}$	22.67^a ±3.712	16.20^b ±0.462
$H_{As80}AN_{20}$	22.00^a ±4.000	14.87^b ±0.874
$H_{As70}AN_{30}$	22.33^a ±2.028	15.60^b ±0.116

[a, b]: Means in the same row not sharing a common superscript are significantly different (P<0.05)

[#]: Diet codes are explained in Table 3.03, Chapter 3

Similar (P>0.05) haematological indices and blood biochemical levels were observed in Boer goats before the start of the experiment (Table 4.22). The haematological indices and blood biochemical components of yearling Boer goats fed diets having different mixture levels of *A. nilotica* leaf meal and *Avena sativa* hay are presented in Table 4.23. *Acacia nilotica* leaf meal inclusion level had no effect (P>0.05) on blood electrolytes of Boer goats. Similarly, *A. nilotica* leaf meal inclusion level had no effect (P>0.05) on haematological indices of the Boer goats except for the white blood cell (WBC) count. Goats on diets having 10 or 20 % *A. nilotica* leaf meal inclusion levels had higher (P<0.05) WBC counts than those on a diet having a 15 % *A. nilotica* leaf meal inclusion level. However, goats on diets having 10, 20 or 30 % *A. nilotica* leaf meal inclusion levels had similar (P>0.05) WBC counts. Similarly, goats on diets having 15 or 30 % *A. nilotica* leaf meal inclusion levels had same (P>0.05) WBC counts.

Blood metabolites were affected (P<0.05) by *A. nilotica* leaf meal inclusion level (Table 4.23). Male Boer goats on a diet having a 15 % *A. nilotica* leaf meal inclusion level had a higher (P<0.05) blood urea than those on a diet having a 30 % *A. nilotica* leaf meal inclusion level. However, goats on diets having 10, 20 or 30 % *A. nilotica* leaf meal inclusion levels had similar (P>0.05) blood urea levels. Similarly, goats on diets having 10, 15 or 20 % *A. nilotica* leaf meal inclusion levels had same (P>0.05) blood urea levels. Boer goats on diets having 15 or 20 % *A. nilotica* leaf meal inclusion level had higher (P<0.05) blood glucose levels than those on a diet having a 10 % *A. nilotica* leaf meal inclusion level. However, goats on diets having 15, 20 or 30 % *A. nilotica* leaf meal inclusion levels had similar (P>0.05) blood glucose levels. Similarly, goats on diets having 10 or 30 % *A. nilotica* leaf meal inclusion levels had same (P>0.05) blood glucose levels. Boer goats on a diet having a 15 % *A. nilotica* leaf meal inclusion level had a higher (P<0.05) blood cholesterol level than those on diets having 10, 20 or 30 % *A. nilotica* leaf meal inclusion levels. However, goats on diets having 10, 20 or 30 % *A. nilotica* leaf meal inclusion levels had similar (P>0.05) blood cholesterol levels.

Serum proteins were affected (P<0.05) by *A. nilotica* leaf meal inclusion level (Table 4.23). Male Boer goats on a diet having a 15 % *A. nilotica* leaf meal inclusion level had a higher (P<0.05) total serum protein than those on a diet having a 30 % *A. nilotica* leaf meal inclusion level. However, goats on diets having 10, 20 or 30 % *A. nilotica* leaf meal inclusion levels had similar (P>0.05) total serum proteins. Similarly, goats on diets having 10, 15 or 20 % *A. nilotica* leaf meal inclusion levels had same (P>0.05) serum total proteins.

Acacia nilotica leaf meal inclusion level had effect (P<0.05) on serum enzymes (Table 4.23). Boer goats on a diet having a 30 % *A. nilotica* leaf meal inclusion level had a higher (P<0.05) blood alkaline phosphate (ALP) than those on a diet having a 15 % *A. nilotica* leaf meal inclusion level. However, goats on diets having 10, 20 or 30 % *A. nilotica* leaf meal inclusion levels had similar (P>0.05) blood ALP levels.

Table 4.22 Haematological indices and blood biochemical components of yearling Boer goats before the start of the experiment on *Acacia nilotica* leaf meal

Variable	Diet[#]			
	$H_{As90}AN_{10}$	$H_{As85}AN_{15}$	$H_{As80}AN_{20}$	$H_{As70}AN_{30}$
Haematology				
Red blood cell ($x10^{12}/L$)	1.85 ±0.224	1.82 ±0.117	1.87 ±0.163	5.82 ±3.734
Haemoglobin (g/dL)	8.85 ±0.533	11.05 ±1.320	9.55 ±0.758	11.00 ±1.265
Haematocrit (L/L)	0.72 ±0.108	0.72 ±0.077	0.75 ±0.083	0.75 ±0.081
White blood cell ($x10^{9}/L$)	24.55 ±2.834	26.71 ±3.472	24.78 ±2.621	25.69 ±4.737
Metabolites (mmol/L)				
Urea	5.00 ±0.408	5.25 ±0.479	4.75 ±0.750	4.75 ±0.750
Glucose	3.45 ±0.119	3.18 ±0.063	3.75 ±0.419	3.88 ±0.138
Cholesterol	1.52 ±0.055	2.32 ±0.264	1.54 ±0.193	2.18 ±0.421
Proteins (g/L)				
Total Protein	67.75 ±0.409	69.75 ±4.973	70.00 ±4.882	69.25 ±4.854
Albumin	16.00 ±0.707	16.25 ±1.182	17.25 ±1.031	16.50 ±0.646
Enzymes (IU/L)				
ALP	224 ±65.202	75.25 ±7.857	172 ±99.055	182 ±116.220
ALT	24.25 ±1.436	30.00 ±1.958	23.00 ±2.345	27.50 ±5.545
AST	71.25 ±4.589	72.50 ±3.524	71.00 ±8.583	73.50 ±7.665
Electrolytes (mmol/L)				
Sodium	143 ±1.224	143 ±0.978	145 ±0.572	144 ±0.630
Potassium	4.92 ±0.172	5.01 ±0.138	4.79 ±0.259	5.08 ±0.181
Chloride	110 ±0.772	109 ±0.534	110 ±0.497	109 ±1.393
Total Calcium	2.28 ±0.021	2.27 ±0.062	2.26 ±0.065	2.17 ±0.057
Corrected Calcium	2.26 ±0.030	2.25 ±0.055	2.28 ±0.067	2.18 ±0.057
Inorganic Phosphate	2.21 ±0.293	2.33 ±0.334	2.25 ±0.360	2.16 ±0.303
Magnesium	2.21 ±0.048	2.33 ±0.024	2.25 ±0.067	2.17 ±0.040

ALP: Alkaline phosphate; ALT: Alanine transaminase; AST: Aspartate transaminase

[#]: Diet codes are explained in Table 3.03, Chapter 3

Table 4.23 Effect of *Acacia nilotica* leaf meal inclusion level on haematological indices and blood biochemical components of yearling male Boer goats fed an *Avena sativa* hay-based diet

Variable	Diet[#]			
	$H_{As90}AN_{10}$	$H_{As85}AN_{15}$	$H_{As80}AN_{20}$	$H_{As70}AN_{30}$
Haematology				
Red blood cell ($x10^{12}$/L)	2.32 ±0.860	2.18 ±1.616	2.16 ±1.121	2.15 ±0.346
Haemoglobin (g/dL)	10.30 ±1.111	8.30 ±0.709	9.37 ±0.714	10.43 ±0.708
Haematocrit (L/L)	0.73 ±0.083	0.72 ±0.083	0.76 ±0.083	0.74 ±0.084
White blood cell ($x10^{9}$/L)	16.58^{a} ±1.362	9.36^{b} ±1.371	14.50^{a} ±1.355	13.12^{ab} ±1.342
Metabolites (mmol/L)				
Urea	6.17^{ab} ±0.571	6.70^{a} ±0.608	5.10^{ab} ±0.575	4.37^{b} ±0.575
Glucose	1.95^{b} ±0.260	3.05^{a} ±0.843	2.81^{a} ±0.236	2.39^{ab} ±0.376
Cholesterol	2.56^{b} ±0.329	3.05^{a} ±0.113	2.49^{b} ±0.120	2.71^{b} ±0.089
Proteins (g/L)				
Total Protein	81.00^{ab} ±2.216	84.00^{a} ±2.176	80.33^{ab} ±2.182	75.33^{b} ±2.172
Albumin	27.67 ±0.910	26.00 ±0.849	28.33 ±0.914	26.67 ±0.843
Enzymes (IU/L)				
ALP	83.67^{ab} ±18.426	33.00^{b} ±106.376	75.67^{ab} ±16.221	103^{a} ±16.268
ALT	20.00^{b} ±1.666	23.00^{b} ±1.978	29.00^{a} ±1.671	19.00^{b} ±1.327
AST	69.00^{b} ±3.733	91.00^{a} ±3.723	86.67^{a} ±3.723	81.67^{a} ±3.735
Electrolytes (mmol/L)				
Sodium	134 ±1.571	134 ±1.703	134 ±2.232	134 ±1.700
Potassium	7.77 ±0.404	6.93 ±0.416	7.95 ±0.428	7.57 ±0.435
Chloride	105 ±2.178	105 ±2.145	106 ±2.299	108 ±2.132
Total Calcium	2.18 ±0.114	2.08 ±0.085	2.14 ±0.084	2.09 ±0.105
Corrected Calcium	2.32 ±0.047	2.31 ±0.044	2.31 ±0.046	2.30 ±0.052
Inorganic Phosphate	2.59 ±0.154	2.50 ±0.155	2.41 ±0.153	2.39 ±0.155
Magnesium	1.08 ±0.060	0.99 ±0.078	1.06 ±0.057	1.00 ±0.065

[a, b]: Means in the same row not sharing a common superscript are significantly different ($P<0.05$)

ALP: Alkaline phosphate; ALT: Alanine transaminase; AST: Aspartate transaminase

[#]: Diet codes are explained in Table 3.03, Chapter 3

Similarly, goats on diets having 10, 15 or 20 % *A. nilotica* leaf meal inclusion levels had same (P>0.05) blood ALP levels. Male Boer goats on a diet having a 20 % *A. nilotica* leaf meal inclusion level had a higher (P<0.05) blood alanine transaminase (ALT) level than those on diets having 10, 15 or 30 % *A. nilotica* leaf meal inclusion levels. However, goats on diets having 10, 15 or 30 % *A. nilotica* leaf meal inclusion levels had similar (P>0.05) blood ALT levels. Boer goats on a diet having a 10 % *A. nilotica* leaf meal inclusion level had a lower (P<0.05) blood aspartate transaminase (AST) level than those on diets having 15, 20 or 30 % *A. nilotica* leaf meal inclusion levels. However, goats on diets having 15, 20 or 30 % *A. nilotica* leaf meal inclusion levels had similar (P>0.05) blood AST levels.

A negative relationship was observed between *A. nilotica* leaf meal inclusion level and blood urea (r^2 = 0.771) in male Boer goats (Figure 4.29). Blood glucose, total protein, ALP, ALT and AST contents in Boer goats were optimised at *A. nilotica* leaf meal inclusion levels of 21.56 (r^2 = 0.785), 14.83 (r^2 = 0.883), 217.58 (r^2 = 0.607), 20.02 (r^2 = 0.856) and 21.59 (r^2 = 0.772), respectively (Figures 4.30, 4.31, 4.32, 4.33 and 4.34, respectively, and Table 4.24).

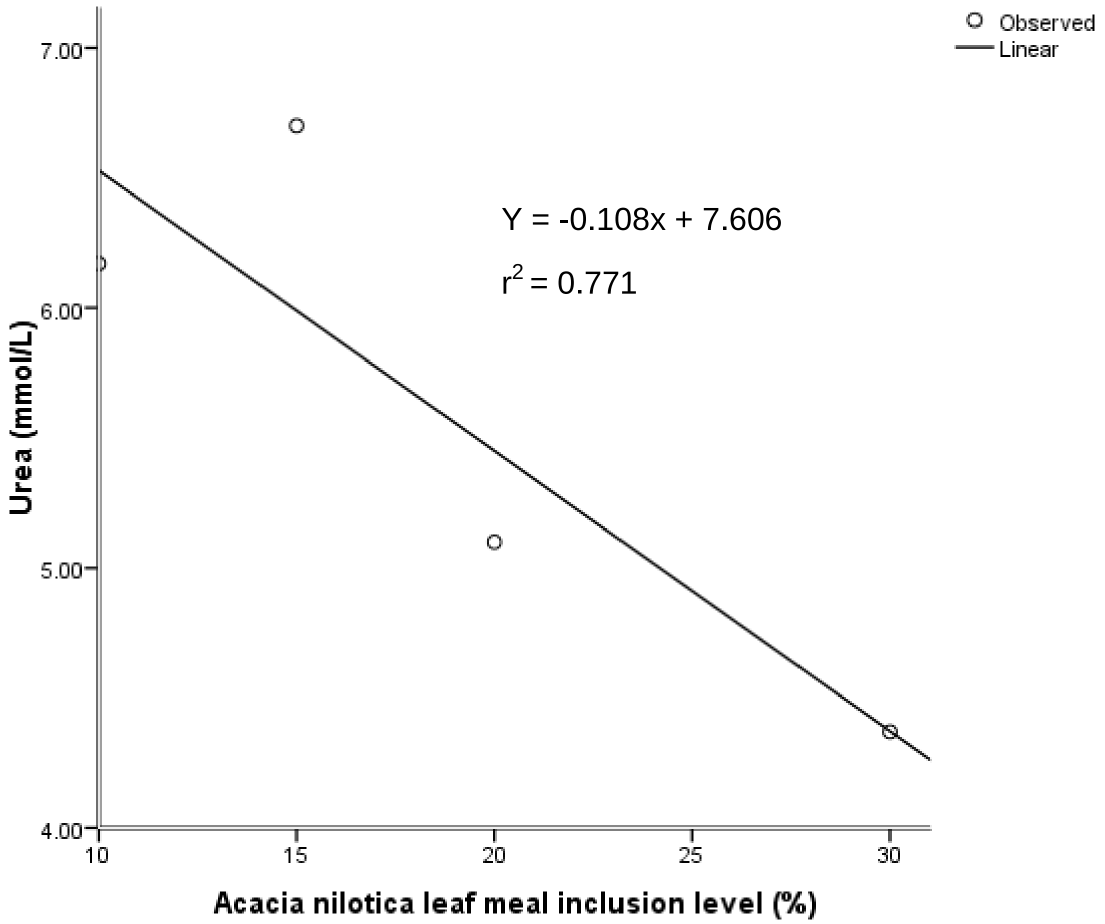

Figure 4.29 Relationship between *Acacia nilotica* leaf meal inclusion level and blood urea in yearling male Boer goats fed an *Avena sativa* hay-based diet

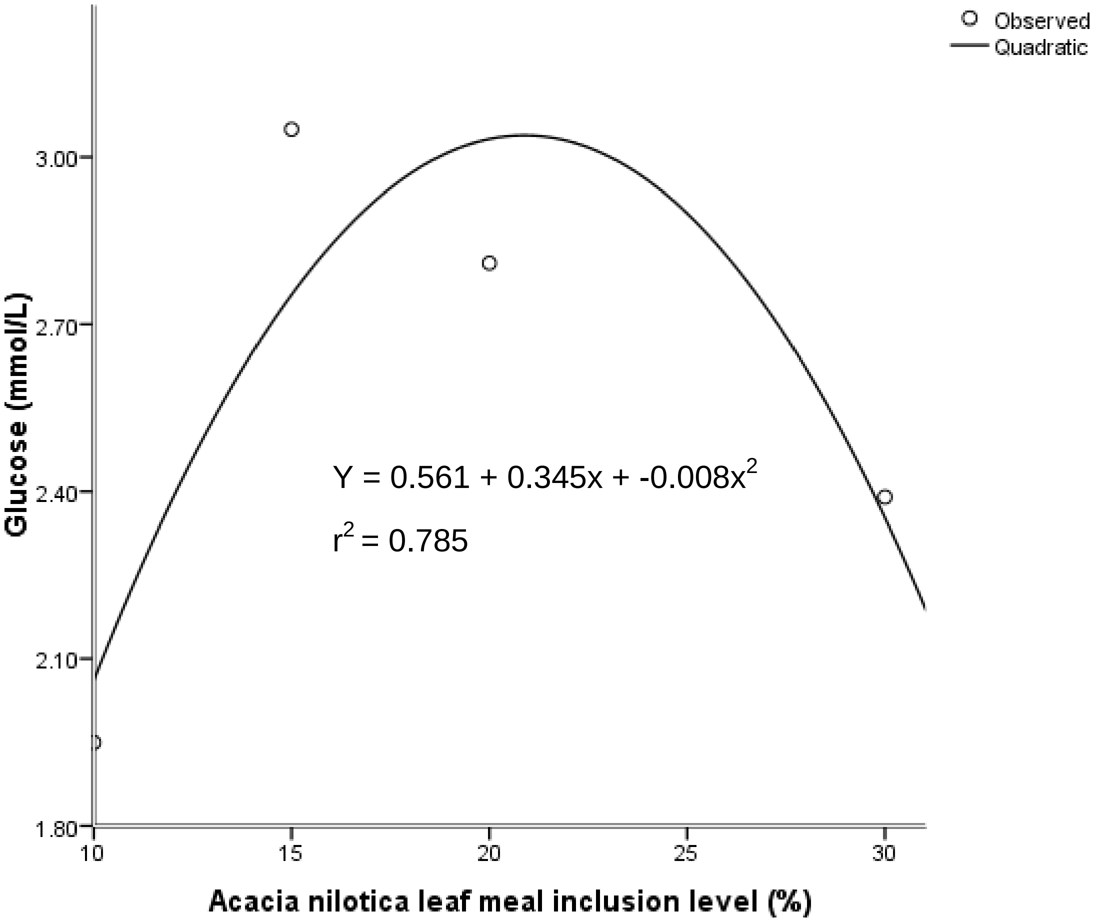

Figure 4.30 Effect of *Acacia nilotica* leaf meal inclusion level on blood glucose of yearling male Boer goats fed an *Avena sativa* hay-based diet

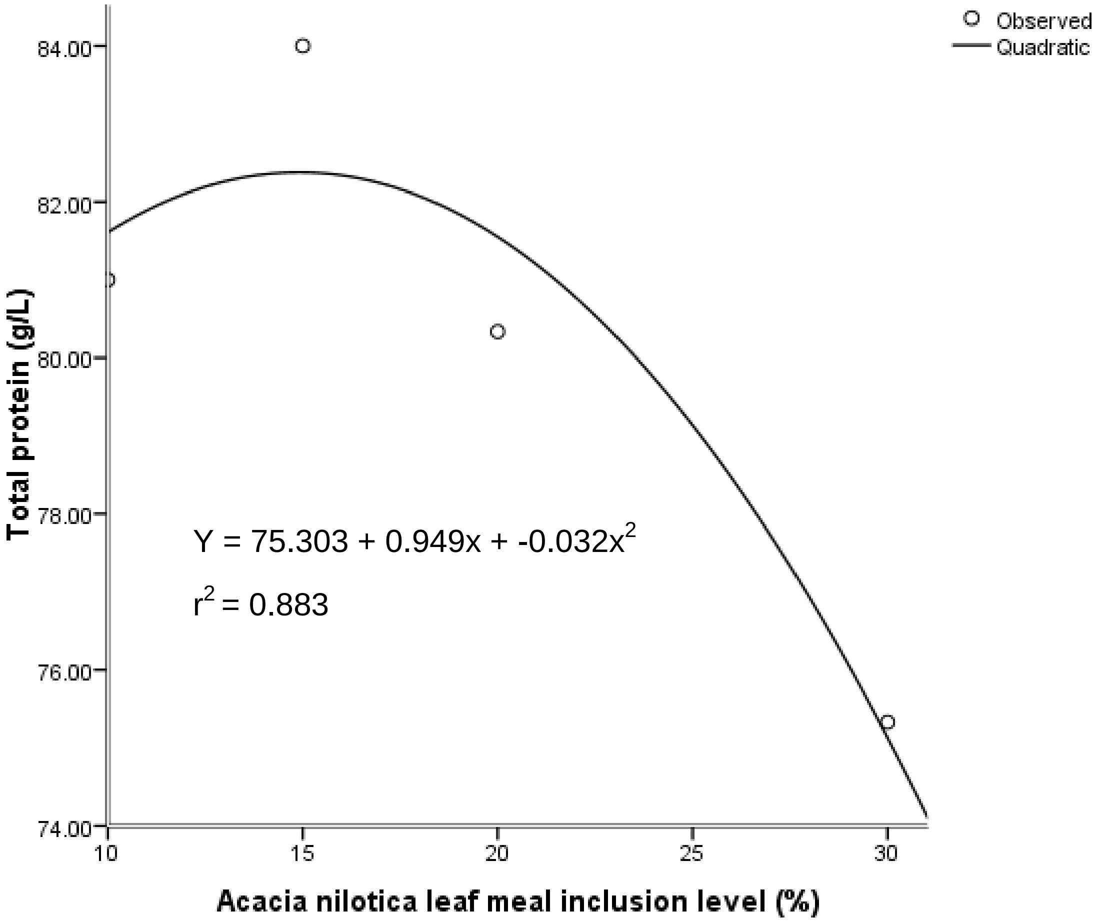

Figure 4.31 Effect of *Acacia nilotica* leaf meal inclusion level on blood total protein of yearling male Boer goats fed an *Avena sativa* hay-based diet

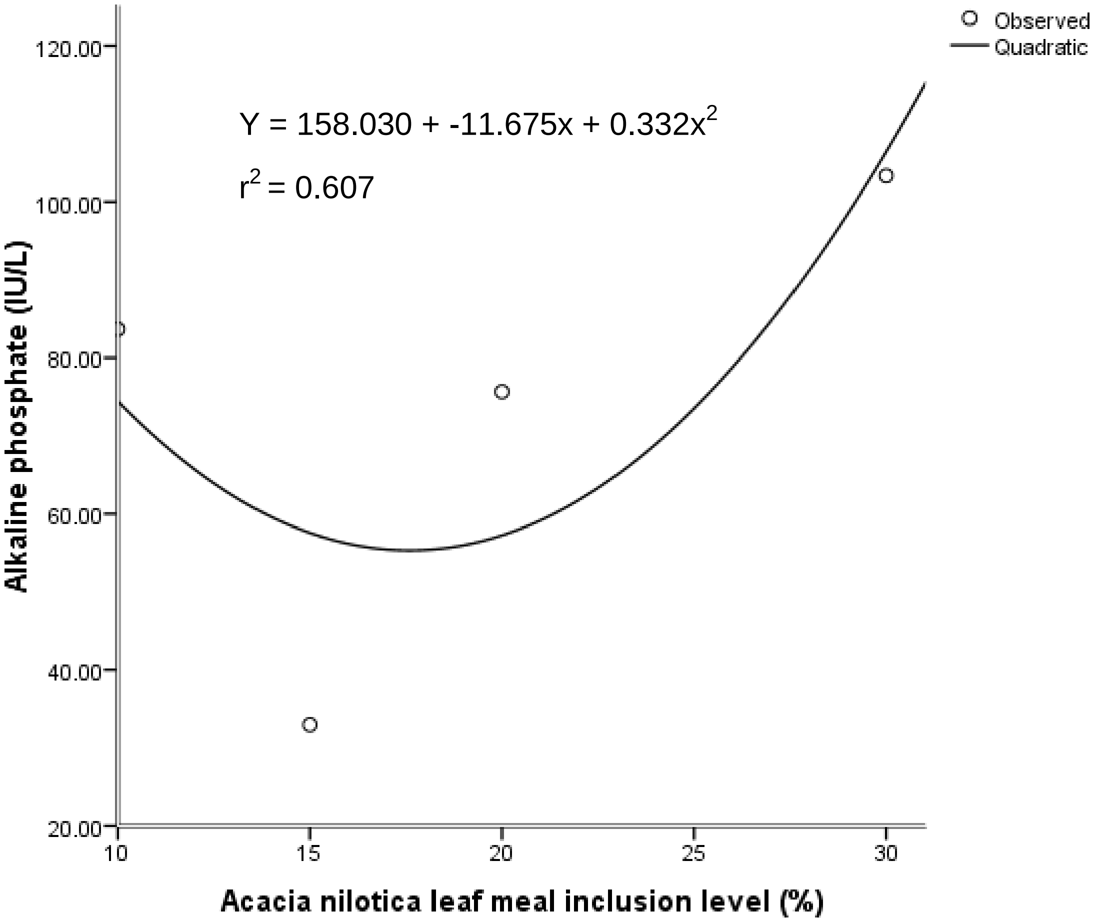

Figure 4.32 Effect of *Acacia nilotica* leaf meal inclusion level on blood alkaline phosphate of yearling male Boer goats fed an *Avena sativa* hay-based diet

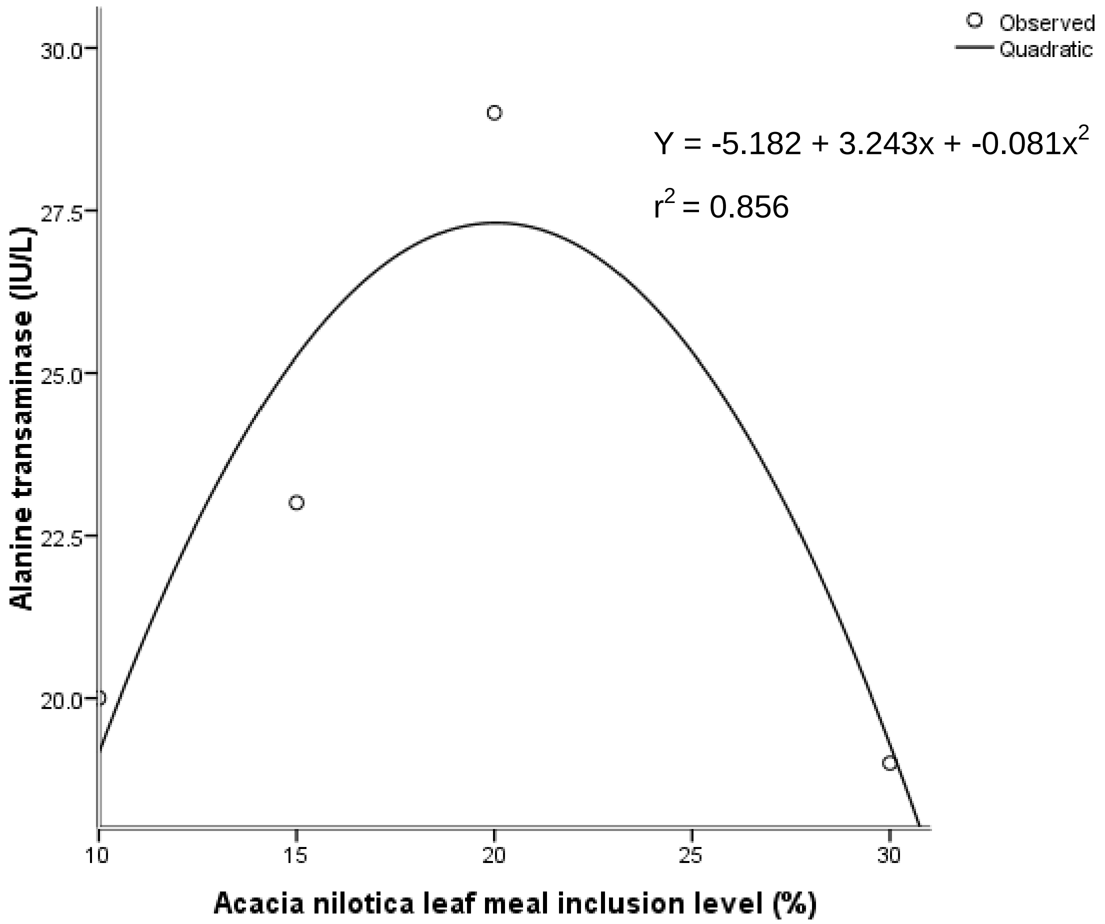

Figure 4.33 Effect of *Acacia nilotica* leaf meal inclusion level on blood alanine transaminase of yearling male Boer goats fed an *Avena sativa* hay-based diet

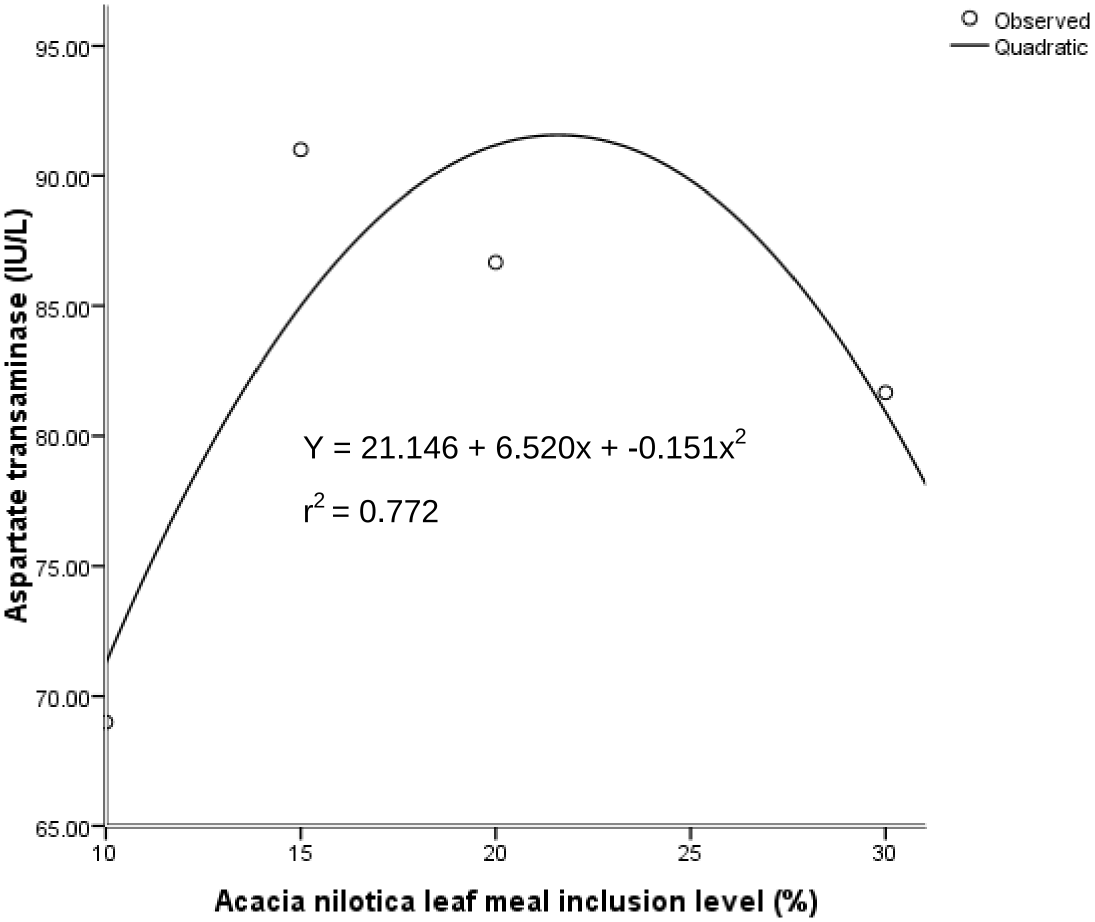

Figure 4.34 Effect of *Acacia nilotica* leaf meal inclusion level on blood aspartate transaminase of yearling male Boer goats fed an *Avena sativa* hay-based diet

Table 4.24 *Acacia nilotica* leaf meal inclusion levels for optimal blood metabolites, proteins and enzyme components of yearling male Boer goats fed an *Avena sativa* hay-based diet

Factor	Formula	X	Y	r^2	P
Metabolites (mmol/L)					
Glucose	$Y = -0.561 + 0.345x + -0.008x^2$	21.56	3.16	0.785	0.464
Proteins (g/L)					
Protein	$Y = 75.303 + 0.949x + -0.032x^2$	14.83	82.84	0.883	0.342
Enzymes (IU/L)					
ALP	$Y = 158.030 + -11.675x + 0.332x^2$	17.58	55.39	0.607	0.627
ALT	$Y = -5.182 + 3.243x + -0.081x^2$	20.02	27.28	0.856	0.379
AST	$Y = 21.146 + 6.520x + -0.151x^2$	21.59	91.53	0.772	0.478

X: Inclusion level for optimal value

Y: Optimal Y-level

r^2: Coefficient of determination

P: Probability

Major haematological indices and blood biochemical component values of yearling Boer goats before the start of the experiment and during the experiment involving *A. nilotica* leaf meal inclusion level are presented in Table 4.25. Inclusion of *A. nilotica* leaf meal in the diets of male Boer goats had no effect (P>0.05) on red blood cell counts and haematocrit levels. However, a reduction (P<0.05) in white blood cell counts of goats was observed when *A. nilotica* leaf meal was included in the diets. In the case of urea values, diets having 10 or 15 % *A. nilotica* leaf meal inclusion levels increased (P<0.05) blood urea levels. However, Boer goats on diets having 20 or 30 % *A. nilotica* leaf meal inclusion levels had similar (P>0.05) blood urea levels as those on diets without *A. nilotica* leaf meals. Reduction (P<0.05) in blood glucose levels of goats fed diets having 10 or 30 % *A. nilotica* leaf meal inclusion levels was observed. However, levels of blood glucose in goats fed diets having 15 or 20 % *A. nilotica* leaf meal inclusion levels remained similar (P>0.05) to those on diets without *A. nilotica* leaf meals. Inclusion levels of 15, 20 or 30 % *A. nilotica* leaf meals in the diets of male Boer goats had no effect (P>0.05) on total serum proteins. However, goats fed a diet having a 10 % *A. nilotica* leaf meal inclusion level had higher

($P<0.05$) total serum protein levels than those of goats on a diet without *A. nilotica* leaf meal.

Table 4.25 Effect of *Acacia nilotica* leaf meal inclusion level on major haematological indices and blood biochemical components of yearling male Boer goats fed an *Avena sativa* hay-based diet

Variable[#]	Before experiment	During experiment
Red blood cell (x10^{12}/L)		
$H_{As90}AN_{10}$	1.85 ±0.224	2.32 ±0.548
$H_{As85}AN_{15}$	1.82 ±0.117	2.18 ±0.506
$H_{As80}AN_{20}$	1.87 ±0.163	2.16 ±0.199
$H_{As70}AN_{30}$	5.82 ±3.734	2.15 ±0.091
Haematocrit (L/L)		
$H_{As90}AN_{10}$	0.72 ±0.108	0.73 ±0.125
$H_{As85}AN_{15}$	0.72 ±0.077	0.72 ±0.102
$H_{As80}AN_{20}$	0.75 ±0.083	0.76 ±0.075
$H_{As70}AN_{30}$	0.75 ±0.081	0.74 ±0.039
White blood cell (x10^{9}/L)		
$H_{As90}AN_{10}$	24.55^{a} ±2.834	16.58^{b} ±1.566
$H_{As85}AN_{15}$	26.71^{a} ±3.472	9.36^{b} ±0.382
$H_{As80}AN_{20}$	24.78^{a} ±2.621	14.50^{b} ±1.621
$H_{As70}AN_{30}$	25.69^{a} ±4.737	13.12^{b} ±0.611
Urea (mmol/L)		
$H_{As90}AN_{10}$	5.00^{b} ±0.408	6.17^{a} ±0.246
$H_{As85}AN_{15}$	5.25^{b} ±0.479	6.70^{a} ±0.274
$H_{As80}AN_{20}$	4.75 ±0.750	5.10 ±0.521
$H_{As70}AN_{30}$	4.75 ±0.750	4.37 ±0.781
Glucose (mmol/L)		
$H_{As90}AN_{10}$	3.45^{a} ±0.119	1.95^{b} ±0.387
$H_{As85}AN_{15}$	3.18 ±0.063	3.05 ±0.125
$H_{As80}AN_{20}$	3.75 ±0.419	2.81 ±0.162
$H_{As70}AN_{30}$	3.88^{a} ±0.138	2.39^{b} ±0.244
Total protein (g/L)		
$H_{As90}AN_{10}$	67.75^{b} ±4.090	81.00^{a} ±1.780
$H_{As85}AN_{15}$	69.75 ±4.973	84.00 ±3.429
$H_{As80}AN_{20}$	70.00 ±4.882	80.33 ±2.249
$H_{As70}AN_{30}$	69.25 ±4.854	75.33 ±3.325

[a, b]: Means in the same row not sharing a common superscript are significantly different ($P<0.05$)

[#]: Diet codes are explained in Table 3.03, Chapter 3

CHAPTER 5

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 DISCUSSION

5.1.1 The nutrient and tannin composition of *Acacia karroo*, *Acacia tortilis* and *Acacia nilotica* leaf meals and *Avena sativa* hay

Acacia species are abundant throughout South Africa and are preferred by goats for browsing. According to Mapiye *et al. (*2009), *Acacia* species are considered as cheap sources of protein and can be fed as leaf meals to browsers like goats (Mapiye *et al.,* 2009). All the three *Acacia* species (*A. karroo, A. tortilis* and *A. nilotica* leaves) and *Avena sativa* hay in this study had similar dry matter (DM). The DM results of *Acacia* species are in line with the findings of Mokoboki *et al*. (2005). The authors reported similar DM values of 945.4, 947.7 and 951.6 g/kg for *A. karroo, A. tortilis* and *A. nilotica* leaves, respectively. The DM in *Avena sativa* hay in the present study was slightly higher than DM values reported in previous studies. Alcalde *et al*. (2011) and Castagnara *et al*. (2012) reported an average of 89.2 % DM in *Avena sativa* hay. This implies that *Avena sativa* hay in this study had low but acceptable DM contents. This is supported by the fact that the nutritional profile of *Avena sativa* hay can vary considerably depending on the time it is harvested (Suttie & Reynolds, 2004).

Dietary proteins are needed to carry out the normal metabolic activities in animals. All the three *Acacia* species had higher crude protein (CP) contents than *Avena sativa* hay. The low CP value in *Avena sativa* hay in this study may be because *Avena sativa* hay is a non-fodder tree while *Acacia* species are fodder trees. A crude protein content of 6.93 % in *Avena sativa* hay in this study fell below acceptable range of 7 - 14 % reported by NRC (1981). The low CP value in *Avena sativa* hay in this study is comparable to the findings of INRA (2007), who reported a CP value of 6.3 % at dough stage. Values of CP below the critical level are associated with depressed feed intake (Minson, 1990). The low CP value in Avena sativa hay indicates that this hay is a low quality roughage and may require protein supplementation to improve its feeding value.

Acacia tortilis leaves contained a higher CP level than *A. karroo* and *A. nilotica* leaves. Similar results have been reported. For example, Mokoboki (2011) reported a CP level of 17.35 % for *A. tortilis* which was higher than 11.08 and 14.65 % for *A. karroo* and *A. nilotica* leaves, respectively. This could mean that *A. tortilis* leaves may have a better impact on animal production as compared to *A. karroo* and *A. nilotica* leaves. The variations in CP contents could be due to species variety, plant maturity stage or climatic conditions (Bamikole *et al.*, 2004). In spite of this, all the three *Acacia* species in this study had high CP contents. The high CP contents in these *Acacia* species were comparable to those reported by Abdulrazak *et al*. (2000) and Rubanza *et al*. (2003). The high CP levels obtained in *A. karroo, A. tortilis* and *A. nilotica* leaves indicate that these species can be used as protein supplements for goats feeding on poor quality roughages. According to Rubanza *et al*. (2005), CP content in leaves of the majority of fodder trees remain above 10 % even during the dry season. This may imply that fodder trees like *Acacia* species can be used as a source of protein even during periods of no rain, especially in winter when concentration of CP in grasses tends to decrease (Aganga & Tshwenyane, 2003).

Goats, as ruminants, require adequate dietary fibre for a normal rumen function. Generally, neutral detergent fibre (NDF) contents are higher than acid detergent fibre (ADF) contents in plant species (INRA, 2007). *Acacia tortilis* leaves and *Avena sativa* hay in the present study had higher NDF and ADF levels than *A. karroo* and *A. nilotica* leaves. High NDF and ADF contents in *Avena sativa* hay were comparable to the findings of INRA (2007), who reported NDF and ADF contents of 64 and 38 % for *Avena sativa*, respectively. Similar results were, also, reported by Alcalde *et al*. (2011) and Castagnara *et al*. (2012). The authors reported averages of NDF and ADF contents of 61.7 and 38.1 % for *Avena sativa*, respectively. Low CP and high fibre contents indicate that *Avena sativa* hay is a poor quality forage.

With respect to NDF in *Acacia* species, Mokoboki (2011) observed similar results. The author reported an NDF level of 67.51 % in *A. tortilis* leaves which was higher than 50.59 and 35.30 % NDF in *A. karroo* and A. *nilotica* leaves, respectively. However, with respect to ADF, Mokoboki (2011) reported a higher ADF level in *A. karroo* leaves than in *A. tortilis* and *A. nilotica* leaves. Generally, higher levels of NDF and ADF contents in A. *tortilis* leaves could be attributed to high cell-wall constituents, usually present in the leaf meal (Dey *et al*., 2008; Dubey *et al*., 2012). According to Van Soest (1982), high contents of cell wall and lignin are normally found in tropical forages and have serious implications on the digestibility of forages. This is because fibre level is inversely related to digestibility. On the other hand, low NDF and ADF levels in *A. nilotica* leaves were comparable to those reported by

Rubunza *et al*. (2003), Rubunza *et al*. (2005) and Mokoboki (2011). Low NDF and ADF values in *A. nilotica* leaves could be associated with high digestibility values of the species.

No tannins were detected in *Avena sativa* hay. This is expected for grasses (van Dorland *et al*., 2007; MacAdam, 2013). A*cacia nilotica* contained higher total phenolic and total tannin contents than *A. karroo* and *A. tortilis* leaves. Mokoboki (2011), also, reported higher total phenolic contents in *A. nilotica* leaves than in *A. karroo* and *A. tortilis* leaves. However, Mokoboki *et al*. (2005) reported higher total phenolic contents in *A. tortilis* leaves than in *A. karroo* and *A. nilotica* leaves. The high total phenolic and total tannin contents in *A. nilotica* leaves can have toxic effects in ruminants (Pathak *et al*., 2014; Dey & De, 2014). The different total phenolic and total tannin contents observed in *A. karroo, A. tortilis* and *A. nilotica* leaves may be attributed to differences among *Acacia* species (Rad *et al*., 2009).

All the three *Acacia* species had similar contents of condensed tannins (CT). The CT contents in *A. karroo, A. tortilis* and *A. nilotica* leaves were lower than the low to moderate concentrations of <55 g/kg, which have beneficial effects in ruminants (Pawelek *et al*., 2008). This means all the three *Acacia* species contained CT levels within safe limits to pose any adverse effects in the ruminants. Thus, *Acacia* species used in this study may provide suitable protein supplementation for ruminants. No hydrolysable tannins (HT) were detected in *A. karroo* and *A. tortilis* leaves. The results are similar to the findings of Mokoboki (2011) and Haroun *et al*. (2013). The authors found flat peaks in *A. karroo* and *A. tortilis* except for *A. nilotica* which showed significant quantities. According to Okuda *et al*. (2000), HT may have inhibitory effects on various enzymes. This implies that HT in *A. nilotica* leaves may interfere with enzymes that facilitate digestion and metabolism in animals and, thus, resulting in poor growth of the animals.

Ash in a feed represents the mineral contents which mainly include phosphorus, calcium or potassium (Verma, 2006). Generally, calcium and potassium contents are higher than other minerals. Minerals play important roles in proving essential nutrients that the animals need for normal metabolic functions to enhance growth and performance. Although mineral contents between the three *Acacia* species and

Avena sativa hay showed some significant differences, they seemed adequate (Mokoboki *et al.,* 2005).

It is concluded that nutrient composition of *A. karroo, A. tortilis* and *A. nilotica* leaves in this study appeared adequate for ruminant growth. These species contained more than 12 % of crude protein. This is quite high and ideal for protein supplementation in animal nutrition (Makkar, 2003). In general, it is advisable to use *A. karroo, A. tortilis* and *A. nilotica* species as a source of protein. This is, also, supported by the fact that *Acacia* species can easily meet nutrient requirements, mainly proteins and minerals relative to other palatable indigenous plants (Mokoboki *et al.,* 2005). Additionally, the low tannin contents in *A. karroo, A. tortilis* and *A. nilotica* leaves indicate that these *Acacia* species can be safe to use in animal nutrition if used sparingly (Dey & De, 2014).

5.1.2 Effect of *Acacia karroo* leaf meal inclusion level on diet intake, digestibility, methane emission, live weight, feed conversion ratio, haematological indices and blood biochemical components of yearling male Boer goats fed an *Avena sativa* hay-based diet

Effect of *Acacia karroo* leaf meal inclusion level on productivity of male Boer goats

Acacia karroo leaf meal inclusion levels of 10 - 30 % in the present study had no effect on nutrient intake per goat and nutrient intake per metabolic weight of the goats. The intakes, irrespective of dietary treatments, are consistent with the previous reports (Bwire *et al*., 2004; Pathak *et al*., 2014; Dey & De, 2014). These authors reported that moderate levels of 1 - 4 % of CT in the diet from various plant sources exerted no significant effect on diet intake. Values of CT of 0.16 - 0.48 % in *A. karroo* leaf meal diets in the current study fell below the moderate levels of CT reported. The non-significant effect of *A. karroo* leaf meal inclusion on intake by goats may be attributed to low concentration of CT in the diets. Pathak *et al*. (2013b), also, reported non-significant differences in total intake of DM, OM and ADF in lambs fed on diets with or without tannin leaf meal mixtures. It has been reported that diets containing up to 5 % tannins are utilised efficiently by the animals without any harmful effect on intake (Barry & McNabb, 1999).

Diet neutral detergent fibre and ADF digestibilities were affected by *A. karroo* leaf meal inclusion level. Diet NDF and ADF digestibilities were optimised at 13.50 and 16.75 % *A. karroo* leaf meal inclusion levels, respectively. Boer goats on diets having 30 % *A. karroo* leaf meal inclusion level had the lowest diet NDF and ADF digestibility values. The reduction in NDF and ADF digestibilities has, also, been attributed to the negative effect of tannins and phenolics through formation of indigestible complexes with proteins and other nutrients (Dubey *et al*., 2012). This is also supported by the findings of Salem *et al*. (2006). The authors reported that ingestion of tannin-containing feed by ruminants may reduce nutrient digestibility. In other studies, digestibilities of OM, CP, NDF and ADF in sheep were decreased by adding CT of *A. mearnsii* to grass-based diets (Carulla *et al*., 2005). Thus, effects of CT on NDF and ADF digestion, in the present experiment, were expected.

Daily gain indicates production performance of animals which is determined by the feeding value of the feed consumed (Waghorn, 2008). In the present study, the goats attained desired live weight gains and remained in good health condition throughout the experiment. Initial and final live weights of Boer goats were similar irrespective of *A. karroo* leaf meal inclusion levels. This accounted for comparable daily weight gains of the goats. These comparable results are in conformity with the findings of several workers (Anbarasu *et al*., 2001). The authors observed similar body condition in animals on various tannin-rich forage meals. Waghorn (2008), also, reported improved live weight gain in sheep fed temperate forages with CT. Increased protein due to higher levels of *A. karroo* leaf meal inclusion might have, also, contributed to improvements in live weight gains. Feed conversion ratio (FCR) measures the amount of feed an animal requires to gain per unit body weight. In the current study, FCR improved linearly with increased *A. karroo* leaf meal inclusion level. The results from the current study indicate that increasing inclusion level of *A. karroo* leaf meal resulted in better FCR values. This may be attributed to an increase in CP level when *A. karroo* leaf meal inclusion level increased.

Effect of *Acacia karroo* leaf meal inclusion level on methane emission by male Boer goats

The values of methane (CH_4) emissions for goats are still being estimated (IPCC, 2006; Moeletsi, 2017). In previous studies, enteric CH_4 production/emission was normally reported as grams per day (Animut *et al*., 2008; Puchala *et al*., 2012). However, in the current study enteric CH_4 is expressed as parts per million per metre (ppm-m) as suggested by Chagunda *et al*. (2009). It should be noted that this study focused on measuring total CH_4 emissions by Boer goats using a laser methane detector (LMD). There are reports indicating a decrease in CH_4 emission with inclusion of CT-containing forage (Carulla *et al*., 2005; Puchala *et al*., 2005). However, not much has been done on *Acacia* leaf meal inclusion levels for optimal CH_4 reduction in goats using an LMD. In the current study, variations in *A. karroo* leaf meal inclusion level had comparable effects on the enteric CH_4 emission by the goats. Similar effects of *A. karroo* leaf meal inclusion levels on CH_4 emission may indicate that inclusion level of CT (0.16 - 0.48 %) in this study were above the required effective level. The results are in agreement with the findings of Mbanzamihigo *et al*. (2002) who reported no effect of dietary legume proportion (0.16, 0.35, 0.41 and 0.51) on CH_4 emission of sheep grazing ryegrass-white clover pastures.

Table 4.05 shows the CH_4 emission of yearling Boer goats at the commencement of the experiment and during the experiment involving different *A. karroo* leaf meal inclusion levels. This served as a reference to monitor the changes in CH_4 emission by the goats as affected by *A. karroo* leaf meal inclusion in the diets. Inclusion of *A. karroo* leaf meal in the diets of male Boer goats reduced CH_4 emission. This indicates that tannins in *A. karroo* leaf meal were enough to inhibit methanogens. Similar effects of CT on CH_4 emission have been previously observed (Woodward *et al*., 2001). For example, Woodward *et al*. (2001) reported lower (decreased by 24 - 29 %) CH_4 production relative to digestible dry matter intake (DMI) in sheep when CT-containing forage, *Lotus pedunculatus*, was fed compared with ryegrass or alfalfa. A similar decrease of 23 % in CH_4 emission relative to DMI was observed by the same authors when cows were fed *Lotus corniculatus* silage compared with ryegrass silage. This is because CH_4 emission is less in animals fed legumes than grasses (Benchaar *et al*., 2001; Van Dorland *et al*., 2007). Grobler *et al*. (2014), also, did a study comparing CH_4 production in parts per million per metre (ppm-m) on 3 cattle breeds fed different feed sources. The authors reported that Bonsmara, Jersey and Nguni cattle produced less CH_4 of 15.3, 14.5 and 16.5 ppm-m, respectively, on forage sorghum compared to 32.7, 25.8 and 30.6 ppm-m, respectively, on natural pasture. The same authors further concluded that less CH_4 production in forage sorghum is possibly due to the tannin content found in forage sorghum which inhibits methanogens. Carulla *et al.* (2005) reported that inhibition of methanogens by CT was primarily the result of suppressed fibre degradation that limits hydrogen gas (H_2) derived from synthesis of acetate. Results of the present study revealed that tannin contents in *A. karroo* leaf meal inclusions were enough for suppressing CH_4 production and emission by Boer goats.

Effect of *Acacia karroo* leaf meal inclusion level on blood profiles of male Boer goats

Blood is commonly used to detect nutritional problems (Ajao, 2013). The absence of signs of tannin toxicity and mortality in these animals confirms the non-toxic level of CT in the experimental diets. In the current study, different inclusion levels of tannins in *A. karroo* leaf meal induced no adverse effect on target haematological parameters (red blood cells, haematocrit, haemoglobin and white blood cells) as shown in Table 4.06. These results are in line with the findings of Dey *et al*. (2008). Red blood cells (RBC) are the most common type of blood cells and they contain haemoglobin. It is the haemoglobin which permits them to transport oxygen. They also remove carbon dioxide from the animal’s body and transport it to the lungs to be exhaled. The RBC count in this study remained similar for Boer goats fed diets having different *A. karroo* leaf meal inclusion levels, which clearly indicates that inclusion levels of *A. karroo* leaf meal did not have any adverse effects on the health of the goats. This, also, suggests that the general health of goats supplemented with low CT (0.16 - 0.48 %) remained satisfactory throughout the experiment. This agrees with the findings of Dey *et al*. (2008) in lambs, Dubey *et al*. (2012) in kids and Pathak *et al*. (2013b) in sheep given diets containing 0 - 2 % of CT.

Haemoglobin is the iron-containing protein molecule inside red blood cells that carries oxygen from the lungs to the tissues within the body and returns carbon dioxide from the tissues back to the lungs (Soetan *et al.,* 2013; Isaac *et al.,* 2013).

The values of haemoglobin reported in this study were not influenced by *A. karroo* leaf meal inclusion level and were within the range of 7 - 15 and 8.15 - 10.75 g/dL reported for West African Dwarf (WAD) goats and WAD sheep by Daramola *et al*. (2005) and Akinyemi *et al*. (2010), respectively. *Acacia karroo* leaf meal inclusion levels supported relatively normal haemoglobin levels, which indicate that the experimental goats were capable of supporting high oxygen carrying capacity (Akinrinmade & Akinrinde, 2012).

Haematocrit, also known as Packed Cell Volume (PCV), is the volume percentage of red blood cells in the blood (Purves *et al*., 2003; Ndlovu *et al*., 2007). It is useful when evaluating an animal for anaemia. Haematocrit values of male Boer goats showed no significant variation due to inclusion levels of *A. karroo* leaf meal in the diet and are in agreement with the findings of Solaiman *et al.* (2010) and Brown *et al.* (2016), who reported non-significant haematocrit values when goats were fed various levels of tannin-rich *Sericea lespedeza* and *Vachellia karroo* diets, respectively. The values obtained in this study suggest that *A. karroo* leaf meal inclusion did not have adverse effects on blood formation and that the goats were not anaemic.

The major functions of the white blood cells (WBC) are to fight infections and to produce, transport and distribute antibodies in immune responses. There was no significant variation in WBC counts of Boer goats fed diets having different *A. karroo* leaf meal inclusion levels. The values obtained in this study were an indication that there were no microbial infections or presence of foreign bodies or antigens (Ahamefule *et al*. 2008). The results were similar to the findings of Brown *et al*. (2016), who reported non-significant differences in WBC counts of indigenous Pedi goats fed varying levels of *Vachellia karroo* leaf meal in *Setaria verticillata* hay-based diets.

Urea is produced by the liver as a waste product of protein digestion and it is passed out of the animal’s body in the form of urine. It is useful when evaluating the function of the kidney. The values obtained for blood urea of Boer goats fed diets having *A. karroo* leaf meal showed no significant variation and fall within the normal physiological range of 0.8 - 9.7 mmol/L reported for WAD goats by Daramola *et al*.

(2005). These values indicate that the quality of dietary protein was satisfactory (Roy, 1970).

Serum glucose represents the amount of sugar that the bloodstream carries to all the cells in the body to supply energy. An increased or decreased level of serum glucose level indicates stress to the animals (Midaoui & de Champlain, 2005). Goats on diets having 15, 20 or 30 % *A. karroo* leaf meal inclusion levels had higher blood glucose levels than those on a diet having a 10 % *A. karroo* leaf meal inclusion level. Blood glucose was optimised at 23.50 % level of *A. karroo* leaf meal inclusion. The results in the current study are in agreement with the findings of Olafadehan (2011) who indicated that inclusion of tannin - rich diets affect glucose level. Glucose levels of goats on diets having 10, 15 or 20 % *A. karroo* leaf meal inclusion levels were within the normal range of 1.1 - 3.0 mmol/L reported for healthy goats (Žubčić, 2001). However, goats on a diet having a 30 % *A. karroo* leaf meal inclusion level had a slightly higher glucose level than the normal range of 1.1 - 3.0 mmol/L reported for healthy goats (Žubčić, 2001). This requires further investigation.

Cholesterol is a fat that the body needs to function properly. However, too much cholesterol contributes to heart diseases (Siri-Tarino *et al*., 2010). Cholesterol level in the current study was higher in goats fed a diet having a 10 % *A. karroo* leaf meal inclusion level than those on diets having 15, 20 or 30 % *A. karroo* leaf meal inclusion levels. Blood cholesterol was optimised at 21.08 % level of *A. karroo* leaf meal inclusion. These results contradict with findings of other researchers (Olafadehan *et al*., 2014; Brown *et al*., 2016), who reported non-significant cholesterol levels when goats were fed CT-rich diets. The higher levels of cholesterol obtained in goats fed a diet having a 10 % *A. karroo* leaf meal inclusion level may indicate presence of hypercholesterolemia (Olafadehan *et al*., 2014). However, more research on the degree of hypercholesterolemia in the case of goats fed a diet having a 10 % *A. karroo* leaf meal inclusion level is needed to further understand the mechanisms behind the observed results.

Serum proteins include any variety of proteins normally found in the blood. They transport hormones, vitamins, lipids and minerals (Jain, 1986). The blood protein indices in the current study were not affected by inclusion levels of *A. karroo* leaf meal and were within the ranges of 56 - 96 g/L and 18.9 - 44.5 g/L for total protein and albumin, respectively, for healthy goats as indicated by Žubčić (2001). Although dietary CP was highest in diets having 20 or 30 % *A. karroo* leaf meal inclusion levels, the goats had the same total serum protein levels as those on diets having 10 or 15 % *A. karroo* leaf meal inclusion levels, which may be an indication of underutilisation of the proteins in the diets. This negative relationship between dietary CP and serum protein is in agreement with the findings of Yusuf *et al*. (2012) and Brown *et al*. (2016). These results may be due to the protein binding capacity of the tannins and concentration of dietary CP (Jayanegara *et al.*, 2009). The non-significant albumin level is similar to the findings of Olafadehan *et al*. (2014) and Brown *et al*. (2016) in goats.

Serum enzymes are used for diagnosing hepatic damage and to detect bile obstruction (Thapa & Walia, 2007). In the present study, *A. karroo* leaf meal inclusion level had no influence on the serum enzymes (alkaline phosphate (ALP), alanine transaminase (ALT) and aspartate transaminase (AST)) levels. Dey *et al*. (2008) reported non-significant effects on serum enzymes (ALT and AST) in lambs fed *Ficus infectoria* leaves with 0 - 2 % of CT. Similarly, Olafadehan *et al*. (2014) reported non-significant differences in ALT and AST of goats fed tannin-rich forages. This observation suggests that no serious condition arose which posed danger to the health of the goats. Thus, *A. karroo* leaf meal inclusion levels used in this study did not have any adverse effect on the vital organs of the goats like liver, kidney, heart and other organs. The values fall within the reported normal range, suggesting that *A. karroo* leaf meal inclusion level had high quality protein as reported by Akinmutimi (2004). This, also, suggests no damage occurred to the liver and kidney of the goats, especially those consuming relatively high concentration of CT. The normal physiological ranges for ALT, AST and ALP are 7 - 24 IU/L, 43 - 132 IU/L and 7 - 30 IU/L, respectively (Daramola *et al*., 2005). Alanine transaminase and AST in the current study fell within the normal physiological ranges except for ALP whose values were higher than the normal range reported. Similarly, ALP values reported in this study were slightly higher than the range of 30.73 - 79.18 IU/l reported by Ikhimioya & Imasuen (2007) for WAD goats. The present results require further investigation. However, ruminants such as goats have the ability to develop defensive mechanisms that increase their tolerance to tannin toxicity (Lamy *et al*., 2011). Such defensive mechanisms are as a result of condensed tannin binding with salivary proteins which provide protection to goats against toxic or anti-nutritional effects (Shimada, 2006).

Apart from inorganic phosphate, the blood electrolytes and mineral values were not affected by *A. karroo* leaf meal inclusion level. Blood inorganic phosphate increased linearly with increase in *A. karroo* leaf meal inclusion level. The significantly low inorganic phosphate level obtained in goats fed 10, 15 or 20 % *A. karroo* leaf meal inclusion levels indicated appetite related disorders. Sowande *et al.* (2008), also, reported a significant decrease in phosphorus concentration in the blood of WAD goats and sheep grazing natural pastures. However, contrary to our observations, Olafadehan *et al*. (2014) reported no differences in blood phosphorus levels of goats fed tannin-containing forage in varying proportions. Despite the significant differences in levels of phosphorus, all the blood electrolytes and mineral indices in this study were within ranges of normal values for healthy goats as indicated by Daramola *et al*. (2005) and Opara *et al.* (2010). This is an indication that *A. karroo* leaf meal inclusion level did not interfere with mineral absorption within the gastrointestinal tract (Sowande *et al.,* 2008).

Table 4.09 shows the major haematological indices and blood biochemical components of yearling Boer goats at the commencement of the experiment and during the experiment involving different *A. karroo* leaf meal inclusion levels. This served as a reference to monitor the changes in blood profiles of the goats as affected by *A. karroo* leaf meal inclusion in the diets. Inclusion of *A. karroo* leaf meal in the diets did not have an effect on red blood cell counts and total serum proteins of Boer goats. However, reductions in haematocrit, white blood cell, urea and glucose were observed. Despite significant differences in some haematocrit, white blood cell, urea and glucose levels, the general health of the goats in the present study remained satisfactory throughout the experiment. The values obtained in the present study were comparable to normal physiological values obtained for WAD goats by other workers (Daramola *et al.*, 2005; Opara *et al.*, 2010).

5.1.3 Effect of *Acacia tortilis* leaf meal inclusion level on diet intake, digestibility, methane emission, live weight, feed conversion ratio, haematological indices and blood biochemical components of yearling male Boer goats fed an *Avena sativa* hay-based diet

Effect of *Acacia tortilis* leaf meal inclusion level on productivity of male Boer goats

In the present study, *A. tortilis* leaf meal inclusion levels of 10 - 30 % affected nutrient intake of Boer goats. The results are in agreement with the findings of Landau *et al*. (2000). The authors reported that inclusion of CT-containing forages in the diets at low levels has adverse effects on diet intake. Intake of DM, OM, ash, CP, NDF, ADF, fat and energy in the present study increased linearly with increased *A. tortilis* leaf meal inclusion level. Thus, higher inclusion levels resulted in higher nutrient intake. These results probably reflect presence of tannins in *A. tortilis* leaf meals (Yadav *et al*., 2013; Dey & De, 2014).

Acid detergent fibre digestibility tended to decrease with increasing dietary CT levels as evidenced from a significant linear trend. Different CP and ADF digestibility coefficients might be attributed to different inclusion levels of tannins in the diets. Effects of tannins on dietary nutrients are associated with tannin ability to bind with proteins, carbohydrates and minerals with an overall effect of lowering the bioavailability of nutrients in the gastro-intestinal tract (Ndluvo, 2000). In the current study, inclusion levels of CT (0.18 - 0.53) fell below the moderate level of CT reported by Pathak *et al*. (2014) and Dey & De (2014) that could not possibly exert negative effects on nutrient digestion. However, other CT-containing forages when included in the diets at low levels have adversely affected nutrient digestion (Landau *et al*., 2000). This may imply that inclusion levels of tannins in this study might have interfered with digestibility of CP and ADF in the gastro-intestinal tract.

Since consumption of tannins present in *A. tortilis* leaf meal tends to affect diet intake and digestibility, there are likely to be consequences on the productivity and performance of the animals that consume them. Although the goats gained weight, live weight chances were similar among *A. tortilis* leaf meal inclusion levels. This could be attributed to the immediate concentrations of CP and CT levels in the diet.

The results from the present study contradicts with the findings of Dey *et al*. (2008) who showed significant improvement in body growth in lambs fed diets having moderate levels of CT (1 - 2 %) provided through tropical tree leaves with wheat straw based diets. Boer goats on a diet having a 10 % *A. tortilis* leaf meal inclusion level had a better FCR compared to other treatments. The FCR results in this study are unclear and require further investigation.

Effect of *Acacia tortilis* leaf meal inclusion level on methane emission by male Boer goats

There are few reports available concerning methane emission by goats (Animut *et al*., 2008; Puchala *et al*., 2012; Du Toit *et al*., 2013; Broucek, 2014). The results of the present study support previous speculations concerning an association between tannins and CH_4 emission in goats. From Table 4.11 it would seem that feeding of different inclusion levels of *A. tortilis* leaf meal had no antimethanogenic effects. The results are in line with the findings of Beauchemin *et al*. (2007) who also did not find any effects on CH_4 production when *Quebracho* tannin extracts of 10 - 20 g/kg dry matter intake (DMI) were fed to beef cattle for 28 days. Similar effects of *A. tortilis* leaf meal inclusion level on CH_4 indicate that smaller CT variations in the diets were not enough to influence CH_4 emission. However, these results are in contrast with most other studies which reported a lower CH_4 production/emission as the level of CT-containing forage increases in the diets (Hariadi *et al*., 2010; Guglielmelli *et al.,* 2011). Similarly, Bhatta *et al*. (2009) reported that *Quebracho* tannins inhibited CH_4 production linearly by 13 - 45 % with increasing doses of 5 - 25 % substrates.

On the other hand, inclusion of *A. tortilis* leaf meal in the diets of male Boer goats reduced CH_4 emission (Table 4.13). Such differences among studies may be attributable to CT content, with a much higher concentration in *A. tortilis* leaf meal inclusion in our experiment compared with natural pasture (before the experiment). This is supported by Min *et al*. (2006) who did not find any effect on methanogenesis when cattle were grazing wheat grass in vegetative stage. This is simply because grasses do not contain tannins (MacAdam, 2013). Pinares-Patino *et al.* (2003) reported CH_4 emission of 0.08, 0.05 and 0.03 to gross energy (GE) intake by sheep grazing perennial ryegrass-based pasture, lucerne and a CT-containing legume *Lotus corniculatus,* respectively. The conclusion was that CT in such forages is not solely responsible for differences in CH_4 emission compared with grass diets. In another study, CH_4 production was reduced by 57 % when goats were fed *Lespedeza cuneata* containing CT compared to when fed a mixture of *Digitaria ischaemum* and *Festuca arundinacea* (Puchala *et al*., 2005). Similar reduction (24 %) in CH_4 emission was found by Tiemann *et al*. (2008) when lambs were fed tannin containing *Callinada calothyrsus* and *Fleminga macrophylla*. Reduction in CH_4 production in Boer goats fed a diet having *A. tortilis* leaf meal may possibly be due to reduction in fibre digestion (Van Dorland *et al*., 2007). This results in reduced H_2 production, which in turn slows down methanogenesis and, therefore, less substrate to create CH_4 (Carulla *et al*., 2005). Therefore, there is some evidence to confirm that *A. tortilis* leaf meal inclusion in the diets provides a suitable alternative to mitigate CH_4 production and emission.

Effect of *Acacia tortilis* leaf meal inclusion level on blood profiles of male Boer goats

Haematological and biochemical values of blood can provide baseline information and are often used to determine nutrient deficiency, physiological status, management practice and health status of animals (Daramola *et al*., 2005). Red blood cells serve as a carrier of haemoglobin. There was no significant variation in RBC of the goats fed different *A. tortilis* leaf meal inclusion levels (Table 4.15). Non-significant RBC counts obtained in this study are similar to the findings of Solaiman *et al.* (2010), who reported non-significant differences in RBC counts when kids were fed different levels of tannin-rich *Sericea lespedeza* diets. The results obtained in this study indicate that Boer goats on *A. tortilis* leaf meal inclusion were not anaemic as reported by Olafadehan *et al*. (2011). According to Isaac *et al.* (2013), haemoglobin is involved in the transport of oxygen and absorbed nutrients. Besides being responsible for the transportation of oxygen and carbon dioxide, haemoglobin is, also, involved in aiding oxidation of ingested food in the body tissue in order to release energy for normal functioning of the body (Isaac *et al.,* 2013). The values of haemoglobin reported in this study were similar and within the range of 7 - 15 and 8.15 - 10.75 g/dL reported for WAD goats and WAD sheep by Daramola *et al*. (2005) and Akinyemi *et al*. (2010), respectively. This is an indication that goats fed *A. tortilis* leaf meal had enough supporting system for normal functioning of their body and sufficient oxygen carrying capacity in their blood (Akinrinmade & Akinrinde, 2012).

Acacia tortilis leaf meal inclusion level had no influence on haematocrit. Non-significant haematocrit values obtained in this study are similar to the findings of Solaiman *et al.* (2010) and Brown *et al.* (2016), who reported non-significant differences in haematocrit when goats were fed different levels of tannin-rich *Sericea lespedeza* and *Vachellia karroo* diets, respectively.

White blood cells are the cells of the immune system. *Acacia tortilis* leaf meal inclusion level had an influence on WBC count. Goats on a diet having a 10 % *A. tortilis* leaf meal inclusion level had a higher WBC count than those on diets having 15 or 20 % *A. tortilis* leaf meal inclusion levels. White blood cell count was optimised at 20.27 % level of *A. tortilis* leaf meal inclusion. According to Soetan *et al*. (2013), animals with high WBC counts are capable of generating antibodies in the process of phagocytosis and are highly resistant to diseases. However, animals with low WBC counts are exposed to high risk of disease infection (Soetan *et al*. 2013) and this may imply that the animals must have ingested a considerable amount of tannin in their diet (Olafadehan, 2011). The results obtained in this study suggest that goats on a diet containing a 10 % *A. tortilis* leaf meal inclusion level are more resistant to diseases as compared to those on diets having 15 or 20 % *A. tortilis* leaf meal inclusion levels. Despite the significant differences in WBC counts, the concentration of CTs in *A. tortilis* leaf meal inclusion was below the level that could cause any toxic effect in the animals (Olafadehan *et al*., 2014).

No significant differences in blood metabolites (urea, glucose and cholesterol) were observed irrespective of different *A. tortilis* leaf meal inclusion levels. Serum urea level indicates the degree of protein degradation in the rumen. The urea levels in the current study were within the normal range of 3.5 - 10.7 mmol/L reported for healthy goats by Sirois (1995). The values reported in this study indicate that the quality of dietary protein was satisfactory (Roy, 1970). Glucose levels were within the variation range of 1.1 - 3.0 mmol/L indicated for healthy goats by Žubčić (2001). Non-significant glucose levels observed in this study were in agreement with the findings of Solaiman *et al*. (2010), who indicated that glucose was not affected by inclusion of tannin-rich *Sericea lespedeza* in the diets of male kids. Serum cholesterol was not influenced by feeding Boer goats diets having *A. tortilis* leaf meal inclusion. Similar cholesterol levels in the current study indicate absence of hypercholesterolemia and no adverse effect on the liver (Olafadehan *et al*., 2014). Similar findings were reported by Olafadehan *et al.* (2014) and Brown *et al*. (2016) when goats were fed tannin-rich diets.

Serum proteins are important in osmotic regulation, immunity and transport of solvents in the animal body (Jain, 1986). The serum protein indices in the present study were within the ranges of 56 - 96 g/L and 18.9 - 44.5 g/L for total protein and albumin, respectively, for healthy goats as indicated by Žubčić (2001). *Acacia tortilis* leaf meal inclusion level had an influence on serum proteins. Total protein and albumin levels were optimised at 23.78 and 21.75 % levels of *A. tortilis* leaf meal inclusions, respectively. Goats on diets having 20 or 30 % *A. tortilis* leaf meal inclusion levels had the highest total protein and albumin levels. High total protein and albumin levels in goats fed diets having 20 or 30 % *A. tortilis* leaf meal inclusion levels were due to high dietary CP in the diets. This served as an indication of adequate utilisation of the protein in diets having 20 or 30 % *A. tortilis* leaf meal inclusion levels. This positive relationship between dietary CP and serum protein contradicts with the findings of Yusuf *et al*. (2012) and Brown *et al*. (2016). The authors reported negative relationship between dietary CP and serum protein.

Despite variations in *A. tortilis* leaf meal inclusion levels, the serum ALP, ALT and AST levels were similar in this study. Non-significant ALT and AST values were similar to those reported by others (Dey *et al*., 2008; Olafadehan *et al*., 2014). Alanine transaminase is a liver-specific hepatocellular enzyme used to assess liver damage (Mahgoub *et al.*, 2008). Similar ALP, ALT and AST values confirmed that the use of tannin-rich feeds like *A. tortilis* leaves had no adverse effect on liver and muscles. Serum ALT and AST in the current study fell within the normal physiological ranges of 7 - 24 IU/L and 43 - 132 IU/L, respectively, (Daramola *et al*., 2005). However, ALT values of goats on a diet having a 20 % *A. tortilis* leaf meal inclusion level were slightly higher than the normal physiological range of 7 - 24 IU/L reported by Daramola *et al*. (2005). With ALP, goats on diets having 10 or 30 % *A. tortilis* leaf meal inclusion levels fell within the range of 30.73 - 79.18 IU/I reported for WAD goats by Ikhimioya & Imasuen (2007). However, goats on diets having 15 or 20 % *A. tortilis* leaf meal inclusion levels had higher ALP values than the normal range of 30.73 - 79.18 IU/I reported for WAD goats. Serum enzyme activities above the normal ranges are abnormal and are an indication that the animals might have suffered liver and/or kidney damages. These findings agree with earlier observations

(Olafadehan, 2011). However, normally, ruminants consuming tannin-rich feeds appear to develop defensive mechanisms against tannin toxicity (Lamy *et al*., 2011).

Mean values of blood electrolytes and minerals of goats on different *A. tortilis* leaf meal inclusion levels did not differ significantly and were comparable to normal values obtained for WAD goats by other workers (Daramola *et al.*, 2005; Opara *et al.*, 2010). This is similar to the findings of Brown *et al*. (2016), who reported non-significant differences in blood electrolytes and minerals of indigenous Pedi goats fed varying levels of *Vachellia karroo* leaf meal and a *Setaria verticillata* hay-based diet. The results obtained in this study imply that inclusion level of CT did not interfere with dietary mineral availability and absorption.

Table 4.17 shows the major haematological indices and blood biochemical components of yearling Boer goats at the commencement of the experiment and during the experiment involving different *A. tortilis* leaf meal inclusion levels. *Acacia tortilis* leaf meal inclusion levels supported relatively same serum urea and total serum proteins of Boer goats. However, changes in some red blood cell, haematocrit, white blood cell and glucose were observed. Despite variations in some red blood cell, haematocrit, white blood cell and glucose levels, the values were within the normal physiological range for normal healthy goats (Daramola *et al.*, 2005; Opara *et al.*, 2010).

5.1.4 Effect of *Acacia nilotica* leaf meal inclusion level on diet intake, digestibility, methane emission, live weight, feed conversion ratio, haematological indices and blood biochemical components of yearling male Boer goats fed an *Avena sativa* hay-based diet

Effect of *Acacia nilotica* leaf meal inclusion level on productivity of male Boer goats

Inclusion levels of *A. nilotica* leaf meal resulted in similar intakes. Goats maintained their intake in all the treatments (10 - 30 % *A. nilotica* leaf meal inclusion levels) during the entire experimental period. Thus, *A. nilotica* leaf meal inclusion level did not adversely affect diet intake. This may be due to the fact that dietary CT concentrations were not above the level that could possibly have effect on dietary intake (Dey *et al*., 2008; Pathak *et al*., 2014). The lack of effect of *A. nilotica* leaf meal inclusion on nutrient intake agrees with previous findings (Komolong *et al*., 2001; Dey *et al*., 2008; Pathak *et al*., 2014). The authors reported that moderate levels (1 - 4 %) of CT in the diet from various plant sources exerted no significant effect on feed intake. However, in other studies, intake of diets of various forages containing CT varied depending on the concentration of CT in the diet, ranging from medium to low (Landau *et al*., 2000; Bhatta *et al*., 2002; Carulla *et al*., 2005; Animut *et al*., 2008). Thus, different inclusion levels of CT in other forages containing tannins below medium levels exerted some effect on diet intake. However, this is not the case in the present study. Hydrolysable tannins found in *A. nilotica* leaf meal did not influence diet intake and digestibility. Similarly, Frutos *et al*. (2004) found no reduction in feed intake among sheep fed soya bean meal treated with HT (20.8 g HT kg^{-1} DM of feed). This may be due to the fact that HT in the diets of the present study were below critical level that could possibly exert adverse effects on diet intake and digestibility.

Digestibility coefficients of all nutrients were similar among all the diets except those of fat. Goats on a diet containing 15 % *A. nilotica* leaf meal had lower fat digestibility values. Reasons for this are not clear. Ngwa *et al*. (2002), also, reported non-significant differences in digestibility coefficients of DM, OM, NDF and ADF in South African Merino sheep fed pasture hay supplemented with wheat bran and silage of *Acacia sieberiana*. Dey & De (2014), also, reported that inclusion of CT at 1.5 % did not seem to interfere with rumen microbial fermentation and digestion, resulting in similar digestibility values for various nutrients. Non-significant nutrient digestibility differences are probably due to presence of only low to moderate amount of tannins in the diet (Pathak *et al*., 2014; Dey & De, 2014). It has been reported that diets containing up to 5 % tannins are used efficiently by the animals without any harmful effect on nutrient digestibility (Barry & McNabb, 1999). However, reasons for variability in fat digestibility in this study are not clear. Fat digestibility increased linearly with increased *A. nilotica* leaf meal inclusion level.

In the present study, *A. nilotica* leaf meal inclusion did not affect live weight changes in goats. The absence of any detectable adverse effect on the performance of the goats suggests that tannins in the diets did not adversely affect growth of the goats. The present results suggest that overall animal productivity was not adversely affected by CT present in *A. nilotica* leaf meal. Diet intake and digestibility was not influenced but animal performance was good. All the goats in the present study gained weight and weight gain is associated with good animal performance. Good animal performance is, also, attributed to increased concentration of protein which might be due to more availability of feed protein. According to Waghorn *et al*. (1987) and McNabb *et al*. (1998), when intake was not influenced but animal performance was improved, it is most likely because of increased intestinal amino acid absorption (Min *et al*., 2003) for tissue growth resulting from low to moderate CT binding of proteins. In another study, *A. nilotica* leaf meal supplementation with CT of 53 g kg^{-1} DM enhanced growth rate (Rubanza *et al*., 2007). This indicates that *A. nilotica* is a safe protein supplement provided it is supplied in moderate amounts. Feed conversion ratio increased linearly with increased *A. nilotica* leaf meal inclusion level. The results from the current study indicate that decreasing inclusion level of *Acacia* leaf meal resulted in better FCR values. These FCR results require further investigation.

Effect of *Acacia nilotica* leaf meal inclusion level on methane emission by male Boer goats

In the present study, *A. nilotica* leaf meal inclusion levels in Boer goat diets showed a tendency to produce similar methane as shown in Table 4.19. This result contradicts with the findings of Guglielmelli *et al.* (2011) who reported a negative correlation between CT level and amount of CH_4 produced. The same authors indicated that CH_4 production consistently declined as the level of CT increased. Similarly, Hariadi & Santosa (2010) reported a negative correlation between tannin level and CH_4 production. This suggests that the more tannins the diet contained the less CH_4 was produced. Animut *et al*. (2008), also, reported that energy lost as CH_4 by goats changed quadratically when the level of CT-containing *lespedeza* declined.

As expected, significantly less CH_4 (Table 4.21) was produced when the Boer goats were fed *A. nilotica* leaf meals compared to when on natural pasture (before the experiment). This could possibly be due to the tannin content found in *A. nilotica* leaf meals. The results are consistent with the findings of Puchala *et al*. (2005) who reported that CH_4 production was lower for goats fed CT-containing *Sericea lespedeza* than for the crabgrass/tall fescue forage diet. A similar reduction of 12 % in CH_4 emission was found by Carulla *et al*. (2005) when they supplemented sheep diets with high CT containing *Acacia mearnsii*. Hess *et al*. (2006), also, reported reductions in CH_4 emissions by feeding CT-rich *Calliandracalothyrsus* as compared to *Cratyliaargentea* having low CT contents. Reduced CH_4 emission might also be due the inhibiting ability of HT. Field & Lettinga (1987) reported that HT such as gallotanninc acid inhibited 50 % CH_4 production from non-rumen anaerobic environment at a concentration of 0.7 g/L. This study has shown that the use of *A. nilotica* leaf meal can reduce enteric CH_4 emissions even though inclusion levels of *A. nilotica* leaf meal used in this study did not exert variability in CH_4 emissions.

Effect of *Acacia nilotica* leaf meal inclusion level on blood profiles of male Boer goats

Changes in haematological and biochemical parameters of animals help in evaluation of stresses due to nutritional, environmental or pathological factors (Afolabi *et al*., 2010). *Acacia nilotica* leaf meal inclusion level had no influence on RBC, haemoglobin and haematocrit of the goats. Similar RBC, haemoglobin and haematocrit levels may be due to binding of tannins present in different *A. nilotica* leaf meals, especially, with iron (Olafadehan, 2011) and implies sufficient level of oxygen to be transported to the tissues as well as the level of carbon dioxide returned to the lungs (Soetan *et al*., 2013). Thus, goats used in the present study were not anaemic. This, also, suggests that tannins present in *A. nilotica* leaf meal did not have any adverse effects on general health of the goats. The results obtained in the present study are in line with the findings of Dey *et al*. (2008). The values of haemoglobin reported in this study were within the range of 7 - 15 and 8.15 - 10.75 g/dL reported for WAD goats and WAD sheep by Daramola *et al*. (2005) and Akinyemi *et al*. (2010), respectively. This is an indication that Boer goats on *A. nilotica* leaf meal inclusion level were not anaemic and transportation of oxygen in the blood was sufficiently maintained (Akinrinmade & Akinrinde, 2012).

Variation on the inclusion levels of *A. nilotica* leaf meal had an influence on WBC counts. Goats on diets having 10 or 20 % *A. nilotica* leaf meal inclusion level had higher WBC counts than those on a diet having a 15 % *A. nilotica* leaf meal inclusion level. According to Soetan *et al*. (2013), animals with low white blood cell counts are exposed to high risk of disease infection, while those with high counts are capable of generating antibodies in the process of phagocytosis and are highly resistant to diseases. Again, lower WBC count implies that the animals must have ingested a considerable amount of tannins in their diets, possibly reducing their resistance to diseases. Although variation on the inclusion levels of *A. nilotica* leaf meal caused significant differences, the concentrations of CT and HT in the diets were below the level that could cause any toxic effect in the animals (Olafadehan, 2011).

Urea levels were within the established range of 3.5 - 10.7 mmol/L for healthy goats (Sirois, 1995). Serum urea decreased linearly with increased *A. nilotica* leaf meal inclusion level. The significantly lower urea level in the case of goats on a diet containing a 30 % *A. nilotica* leaf meal level might be due to reduced rumen protein breakdown and increased essential amino acid absorption in the small intestines (Waghorn *et al*., 1994). Lower serum urea concentration was reported in lambs fed *Ficus infectoria* leaf meal containing 1.5 - 2 % of CT (Dey *et al*., 2008). Similarly, lower serum urea concentration was reported in sheep grazing on *Lotus* pasture (Min *et al*., 2001) and in kids fed leaves of *Prosopis cineraria* (Bhatta *et al*., 2002). Thus, the low level of urea in goats on a diet having a 30 % *A. nilotica* leaf meal inclusion level indicated the poor utilisation of absorbed nitrogen. Serum glucose was affected by *A. nilotica* leaf meal inclusion level and optimised at 21.56 % level of *A. nilotica* leaf meal inclusion. Significant glucose level differences due to *A. nilotica* leaf meal inclusions observed in this study contradicts with the findings of Solaiman *et al*. (2010), who indicated that glucose was not affected by inclusion of tannin-rich *Sericea lespedeza* in the diet of male kids. However, glucose levels across dietary treatments in the present study were within normal physiological range of 1.1 - 3.0 mmol/L indicated for healthy goats by Žubčić (2001). Significant cholesterol level differences due to *A. nilotica* leaf meal inclusions contradicts with the findings reported by other authors (Olafadehan *et al.*, 2014; Brown *et al*., 2016) when goats were fed tannin-rich diet. However, cholesterol levels in the current study indicate absence of hypercholesterolemia.

The serum protein indices were similar and within the ranges of 56 - 96 g/L and 18.9 - 44.5 g/L for total protein and albumin, respectively, for healthy goats as indicated by Žubčić (2001). Similar total serum protein levels were observed in the goats, which may be an indication of underutilisation of the protein in the diets. This negative relationship between dietary CP and serum protein is in agreement with the findings of Yusuf *et al*. (2012) who reported the lowest serum protein of 4.7 ± 0.00

g/dL when WAD goats were fed *Panicum maximum* and *Newbouldia laevis* diets containing the highest protein of 16.86 %. Similarly, Brown *et al*. (2016) reported the lowest serum protein when the indigenous Pedi goats were fed *Vachellia karroo* leaf meal in *Setaria verticillata* hay-based treatment diets containing the highest protein content. These results may be due to the type, concentration and protein binding capacity of the tannins and concentration of dietary CP (Jayanegara *et al.*, 2009).

Acacia nilotica leaf meal inclusion level had an influence on serum ALP, ALT and AST. Blood ALP, ALT and AST were optimised at 17.58, 20.02 and 21.59 % levels of *A. nilotica* leaf meal inclusion, respectively. On the contrary, Dey *et al*. (2008) reported non-significant effect on serum enzymes (ALT and AST) in lambs fed *Ficus infectoria* leaves with 0 - 2 % of CT. Differences in serum enzyme values in the present study require further investigation. The ALT and AST in the current study fell within the normal physiological ranges of 7 - 24 IU/L and 43 - 132 IU/L, respectively (Daramola *et al*., 2005), except ALT values of goats on a diet having a 20 % *A. nilotica* leaf meal inclusion level were slightly higher than the normal physiological range. With ALP, goats on diets having 15 or 20 % *A. nilotica* leaf meal inclusion levels fell within the normal range of 30.73 - 79.18 IU/l reported for WAD goats by Ikhimioya & Imasuen (2007). However, goats on diets having 10 or 30 % *A. nilotica* leaf meal inclusion levels had higher ALP values than the normal range. Serum enzyme activities above the normal ranges are abnormal and are an indication that the animals might have suffered liver and/or kidney damages (Olafadehan *et al*., 2014). However, ruminants such as goats have the ability to develop defensive mechanisms that increase their tolerance to tannin toxicity (Lamy *et al*., 2011).

The levels of blood electrolytes and minerals of Boer goats on different *A. nilotica* leaf meal inclusion levels were comparable to normal physiological values obtained for WAD goats by other workers (Daramola *et al.*, 2005; Opara *et al.*, 2010), and showed no significant variation due to inclusion levels. This is similar to the findings of Olafadehan *et al*. (2014), who reported non-significant differences in blood electrolytes and mineral indices of goats when fed tannin-containing forage in varying proportions. The results obtained in this study indicate that *A. nilotica* leaf meal inclusion did not inhibit dietary mineral absorption.

Table 4.25 shows the major haematological indices and blood biochemical components of yearling Boer goats at the commencement of the experiment and during the experiment involving different *A. nilotica* leaf meal inclusion levels. *Acacia nilotica* leaf meal inclusion levels did not change red blood cell and haematocrit levels of Boer goats. However, significant changes in some white blood cell, urea, glucose and total serum protein were observed. Despite variability in some white blood cell, urea, glucose and total serum protein levels, the values were comparable to normal values obtained for healthy WAD goats (Daramola *et al.*, 2005; Opara *et al.*, 2010). This observation suggests that no serious condition arose which posed danger to the health of the experimental goats.

5.2 CONCLUSIONS AND RECOMMENDATIONS

Nutrient composition of *Acacia* (*A.*) *karroo*, *A. tortilis* and *A. nilotica* leaf meals and *Avena sativa* hay obtained in this study supports the hypothesis that *Acacia* species have high crude protein contents. All the three *Acacia* species and *Avena sativa* hay had different nutrient compositions, except for dry matter, potassium, zinc and phosphorus contents. With respect to protein content, all the three *Acacia* species contained high crude protein contents above 12 %. This is ideal for protein supplementation for goats feeding on poor quality roughages like *Avena sativa* hay. *Acacia tortilis* leaves contained a higher crude protein (14.49 %) level than *A. karroo* (13.08 %) and *A. nilotica* (12.42 %) leaves. This could mean that *A. tortilis* leaves may have a better impact on animal productivity and performance as compared to *A. karroo* and *A. nilotica* leaves. With respect to tannins, only *A. nilotica* leaves contained hydrolysable tannins. *Acacia karroo, A. tortilis* and *A. nilotica* leaves contained low condensed tannin contents of 1.61, 1.76 and 1.49 %, respectively. These values were below the levels that could possibly cause toxic effects to animals. It is concluded that nutrient composition of *A. karroo, A. tortilis* and *A. nilotica* leaves in this study appeared adequate for ruminants and these *Acacia* species can be safe to use as protein supplements when provided sparingly.

Consumption of tannins has been believed to have toxic effects on animal productivity and performance. However, we now have some knowledge and evidence about tannins, their doses and their effects on animals that consume them. Results of the present study revealed that tannin contents in *A. karroo*, *A. tortilis* and

A. nilotica leaf meals used are lower than the toxic levels reported in many other plants by other authors and hence they are good enough for beneficial activities. These results suggest the potential for tannins in *A. karroo*, *A. tortilis* and *A. nilotica* leaf meals and that when included in small amounts in the diets cause no negative effects on the productivity of the goats. Although some of the nutrient intakes and digestibility values differed significantly in *A. karroo*, *A. tortilis* and *A. nilotica* leaf meal inclusion levels, the goats attained desired live weight gains that remained similar throughout the experiments. Therefore, it can be concluded that all the inclusion levels of *A. karroo*, *A. tortilis* and *A. nilotica* leaf meal in the diets provided adequate protein and other nutrients for normal growth of the goats. However, goats on 20 % *A. karroo* leaf meal inclusion level had better digestible nutrients and feed conversion ratio. Therefore, 20 % *A. karroo* leaf meal inclusion level is recommended. A positive relationship was observed between *A. tortilis* leaf meal inclusion level and diet intake. Therefore, 30 % *A. tortilis* leaf meal inclusion level is recommended. Positive relationship was observed between *A. nilotica* leaf meal inclusion level and feed conversion ratio in male Boer goats. Therefore, 30 % *A. tortilis* leaf meal inclusion level is recommended. It was noted that nutrient intake, digestibility and feed conversion ratio of Boer goats in the present study were optimised at different inclusion levels for all the three *Acacia* species. This may imply that inclusion levels of *A. karroo*, *A. tortilis* and *A. nilotica* leaf meals for optimal productivity will depend on the *Acacia* species used and, also, on the particular productivity parameter in question. However, further research is needed to expand our understanding on the relationships between inclusion levels of these three *Acacia* species and nutrient intake, digestibility and feed conversion ratio.

There is some excitement about useful tannin-containing plants that could be used to reduce methane emission by animals. This study covered the current state of knowledge on methane production and emission by goats relevant to productivity of the goats. *Acacia karroo, A. tortilis* and *A. nilotica* when mixed with *Avena sativa* were found to reduce methane emission by Boer goats. These results confirmed that *A. karroo, A. tortilis* and *A. nilotica* leaf meal inclusions in the diets provide suitable alternative to mitigate methane emission and possibly production. Reduction in methane emission is associated with reduced green-house gas contribution to global warming and increased efficiency of energy utilisation which could be used for body maintenance and productivity. However, goats on different inclusion levels within *A. karroo, A. tortilis* or *A. nilotica* leaf meals had similar enteric methane emissions. Thus, although *A. karroo, A. tortilis* and *A. nilotica* leaf meals reduced methane emission, levels of leaf meal inclusions for optimal reduction in methane emission were not determined. More studies are required to determine *Acacia* inclusion levels for optimal methane production and emission by goats.

Findings from this study may, also, serve as references for diagnostic purposes in goats. The present study revealed that despite the mild variations in some blood parameter values obtained in goats on *A. karroo, A. tortilis* and *A. nilotica* leaf meal diets with different inclusion levels, the values were within the normal range for normal healthy goats reported in the literature. It was, thus, concluded that inclusion levels of *A. karroo, A. tortilis* and *A. nilotica* leaf meals used did not cause any major health disorders. Tannin contents of *A. karroo, A. tortilis* and *A. nilotica* leaf meal inclusion levels used in this study were well tolerated by the goats. It, thus, suggests that *A. karroo, A. tortilis* and *A. nilotica* leaf meal inclusion levels used will not cause any adverse effects on the blood profiles of the experimental goats.

CHAPTER 6

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6.1 REFERENCES

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