QUANTIFICATION AND CHARACTERIZATION OF NUTRIENTS IN *SENEGALIA MELLIFERA* MILLED BIOMASS, FEED INTAKE AND NITROGEN BALANCE IN FEMALE BOER GOATS FED WITH *SENEGALIA MELLIFERA* BUSH-BASED FEEDS.

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DECLARATION

This is to declare that this mini thesis has been composed by myself and has not been submitted in any previous application for a degree. All sources of information are shown in the text and listed in references and all help by others have been duly acknowledged.

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You all won’t lose your reward in Jesus name. Amen

ABSTRACT

The objectives of this study were to quantify and characterize the nutritional content of milled *Senegalia mellifera* milled biomass obtained from nine blocks at Neudamm farm and to determine the dry matter intake (DMI), apparent digestibility and nitrogen retention in female Boer goats fed with *Senegalia mellifera* bush based feeds**.** Wood ash (WA), Polyethylene glycol (PEG, 6 000) and Biochar were evaluated as tannin deactivation methods**.** The milled biomass of *S. mellifera* was mixed using a clean concrete mixer with the following ingredients: yellow maize meal, liquid molasses; Marula oil press cake and coarse salt to formulate a complete diet with 14%CP and 11MJ ME/kg. Detannification treatments methods were added at a level of 5 g per day during feeding time. Eight (8) female Boer goats, with an average initial body mass of 31.5 kg (± 2.5 kg), were used in the feeding experiment. The goats were penned individually in metabolic cages measuring 120 cm long, 54 cm wide and 90 cm above the ground, allowing for the total collection of faeces and urine separately. Clean water was available *ad libitum* to the goats during the entire feeding experiment. The goats were fed in a 4x4 cross over Latin square design with four periods of experimental feeding. Each period lasted for 17 days, resulting in 68 days of experimental feeding. The goats were fed twice daily at 09:00h and 16:00h. The level of dry matter (DM) of feed offered was 4% of body weight.

The results obtained in this study showed that there was a significant difference ($p < 0.05$) in the chemical composition of *Senegalia mellifera* milled biomass harvested from the nine blocks at Neudamm farm. The CP content of *Senegalia mellifera* milled biomass ranged from 9.39 to 9.68 %DM while the NDF and ADF ranged from 59.17 to 64.33%DM and 43.77 to 48.01%DM, respectively. The condensed tannins (CT) content from all blocks did not differ ($p > 0.05$) and had a mean of 0.02 to 0.03%DM as leucocyanidin equivalent (LE $^{\text{Absorbance at 550 nm}}$).

The results obtained from the feeding trial showed that there was significant difference ($p < 0.05$) in the organic matter (OM) and ash content of different treatment diets. The apparent digestibility coefficient of DM, OM and NDF were not significantly different among treatments and the control diet ($p > 0.05$). Goats fed Biochar treated diet had the highest nitrogen intake (13.74g/d ($p < 0.05$), faecal nitrogen of 8.43g/d ($p < 0.05$) and nitrogen retention of 5.11g/d ($p < 0.05$), while goats fed the control feed (CNT), PEG and WA were similar ($p > 0.05$). All treatments resulted in a positive nitrogen retention ($p > 0.05$) with mean values ranging from 3.79 to 5.11 g/d.

The study concluded that, there was a significant difference ($p < 0.05$) in the chemical composition of *S. mellifera* milled biomass collected from nine blocks at Neudamm farm. Given the high CP content of the *S. mellifera*, this fodder resource can be considered a suitable supplement for poor quality (low N content) natural pastures and crop residues such as grass hay, straw and stover. The study also concluded that, there was a significant difference ($p < 0.05$) in the DMI, and nitrogen balance in Boer goats fed with *S. mellifera* feeds treated with Wood ash (WA), Polyethylene glycol (PEG, 6 000) and Biochar (BIO). The study therefore recommends that each detannification method should be tested at different rates of inclusion in *S. mellifera* bush based feed resources.

Keywords: Wood ash, Biochar, PEG, condensed tannins, DMI, apparent digestibility coefficient (DM, OM and NDF) and Nitrogen.

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LIST OF ABBREVIATIONS

ADF - Acid Detergent Fibre

ADG - Average Daily Gain

ADL - Acid detergent lignin

AM - *Acacia mellifera*

AOAC- Association of Official Analytical Chemists

BW - Body weight

Ca - **C**alcium

CO$_2$ - Carbon Dioxide

CP - Crude Protein

CPD - Crude protein digestibility

CT - Condensed Tannins

DE - Digestible energy

DM - Dry matter

DMD -Dry matter digestibility

DOM -Digestible organic matter

FAO Food and Agricultural Organization

GDP Gross domestic product

GPS- Global Positioning System

IAEA- International Atomic Energy Agency

L E- Leucocyanidin Equivalent

LWC -Live weight change

MAWF- Ministry of Agriculture Water and Forestry

ME - Metabolisable energy

N - Nitrogen

NDF - Neutral Detergent Fibre

NDP^4 -Fourth National Development Plan

OM - Organic Matter

OMD -Organic matter digestibility

P - Phosphorus

PEG - Polyethylene glycol

SAS - Statistical Analytical Software

SD - Standard deviation

SE - Standard Error

SPSS -Statistical Program for Social Sciences

SM – *Senegalia mellifera*

ST - Soluble Tannins

TP- Total Phenols

UNAM- University of Namibia

HC-Hemicellulose

DEDICATION

This mini thesis is dedicated to my Mother, Martha David for her endless support towards my studies. To my brothers and sisters, you are a source of inspiration. I extend this dedication to my late father Epafras Andreas Tuleni who passed away on the 3rd December 2017, father, we will always miss you.

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

In most southern African countries, livestock production systems are characterized by distinct wet and dry seasons. Namibia is one of the southern African countries rated (Mendelsohn, 2006) to have the driest climate with a wide regional variation in annual rainfall, from less than 20 mm in the Namib Desert and the coastal area to over 700 mm in the eastern strip of the Zambezi region. Although Namibia is associated with high temperatures and low rainfall in conjunction with frequent years of drought, livestock production remains the most contributor to the country's Gross Domestic Product (GDP) from the Agriculture sector (National Development Plan no 4 of Namibia, 2012).

According to the Namibian Livestock Census Report (NLCR, 2010), Namibia has an estimated 2.2. Million cattle, 1.8 million goats and about 2.5 million sheep that contribute about 76 % to the overall national agricultural output. Depending on the rainfall received per year, Namibia exports about 80% of beef and mutton to the European Union (EU), which accounts for about 15% to the national income (NMBAR, 2011).

Even though livestock contribute most to the agriculture sector, Namibian rangelands, where livestock are produced, is heavily encroached by invasive woody plants (Joubert, 2014). Bush encroachment is defined as the "the invasion and/or thickening of aggressive undesired woody species resulting in an imbalance of the grass: bush ratio, a decrease in biodiversity, and a decrease in carrying capacity", causing severe economic losses for Namibia – in both the commercial (freehold) and communal (non-freehold) farming areas (de Klerk, 2004).

Bush encroachment especially by *Senegalia mellifera* (Black thorn) subspecies *detinens* has long been considered an environmental and economic problem in the rangelands of Namibia and in other southern African countries (Skarpe, 1991; de Klerk, 2004; Ward, 2005). Bush encroachment has affected Namibia on a massive scale, with two-thirds of the country affected (Bester, 1996), disturbing multiple ecosystems and land uses. About N$1.5 million farming economic losses are due to bush encroachment from the commercial rangelands (Honsbein *et al*., 2009) on which over 65% of the national agriculture output is produced (Mendelssohn *et al*., 2003; Joubert, 2014). Bush encroachment has also negatively decreased the biodiversity and the carrying capacity of the rangeland (de Klerk, 2004), hence bush encroachment poses a major risk to animal feed security (de la Puerta, 2016).

With Namibia being committed to halt bush encroachment, reactive interventions such as chemical treatments are forbidden, while biological control using browsers and mechanical controls (cutting and felling and uprooting with bulldozers) are common in combating bush encroachment (de Klerk, 2004; Joubert, 2014). However, despite the afore mentioned interventions, bush thickening still remains a problem, partly caused by the fast regrowth of encroacher woody species (Lubbe, 2010; Natalia *et al*., 2010; Joubert, 2014).

Value chain addition to the harvested bush biomass has recently gained popularity (Honsbein *et al*., 2009; Joubert, 2014; de la Puerta, 2016), since it does not only aim to pay back the costly debushing, but also develops the local market and create high valuable products out of the harvested bush biomass. Among these value chains, bush-based feed or bush feed has gained special interest (Honsbein *et al*., 2009; de la Puerta, 2016) since it has a potential to enhance livestock feed and food security. Bush-based feed refers to the production of animal feed in which the encroacher bush biomass is the main ingredient.

The ability of encroacher woody plants to remain green even during dry season postulates their ability to retain their protein content, hence makes them a valuable protein-rich livestock feed sources. Bush based feed production intervention advocates that, reduction of bush encroachment into optimal levels through selective harvesting and utilization of the harvested biomass can restore rangelands, strengthening the draught resilience of farmers, recovery of the costs invested in debushing and enhances animal feed security. Bush feed production in Namibia has also demonstrated to be a viable possibility for farmers during drought periods as they are protein-rich feed sources; hence they can also be used as protein supplementary feeds throughout the year.

1.2. Statement of the problem

Even though bush feeds can be a viable protein rich livestock feed sources, it has to be stressed that forage feeds can also contain anti-nutritional factors or secondary plant metabolites such as tannins that can cause unpredictable effects on animals (Kumar and Vaithiyanathan, 1990; Dube *et al*., 2001; Makkar, 2003). Literature (Abdulrazak et al., 2001; Makkar, 2003a ; Osuga et al, 2008) have also highlighted the use of different treatments to avoid the negative effects of anti-nutritional factors especially tannins. Little information is available on the performance of animals fed with bush-based feeds in Namibia (Honsbein et al., 2009; de la Puerta, 2016). Regardless of notable findings of few farmers using bush-based feed in Namibia, enough scientific knowledge is still lacking on the use of bush-based feed such as the chemical or nutritional value of the bush feeds.

In addition, treatment of bush based feed to avoid detrimental effects of anti-nutritional have not receive any attention and there are no scientific proof of levels of treatment inclusion in bush feeds. Purely, there is economic uncertainty. Moreover, there is no scientific research in Namibia that has been conducted to explore the potential of local treatment methods that can deactivate anti-nutritional factors such as the tannins in bush based feeds.

1.3. Objectives of the study

1.3.1. General objective

The overall objective of the research study was to quantify and characterize the nutritional content of *S.mellifera* bush based feed and to determine the intake, digestibility and nitrogen balance of Boer goats fed with *S.mellifera* bush-based feeds.

1.3.2. Specific objectives

- To determine (Quantify and characterise) the chemical composition of *S. mellifera* bush based feed (leaves and twigs of less than 5cm) collected in nine blocks at Neudamm farm.
- To determine the feed intake, apparent digestibility and nitrogen balance in female Boer goats fed with *S. mellifera* supplementary feeds treated with or without different anti-nutritional deactivating ingredients.

1.3.3. Hypotheses of the study

Ho: There is no significant difference in the chemical composition of *S. mellifera* bush based feeds fractions (leaves and twigs (less than 5cm)) collected in nine blocks at Neudamm farm.

Ho: There is no significant difference in the feed intake, digestibility and nitrogen balance in goats fed with *S.mellifera* feeds treated with or without different anti-nutritional deactivating ingredients.

1.4. Significance of the study

The outcome of this study contributes to both Namibians communal and commercial farmers whose rangelands are affected by bush encroachment through effectively means of utilizing the encroacher bush to their full potential as animal feed/fodder and also processing the same woody plant into activated charcoal and wood ash as anti-nutritional treatments of tannins and other secondary metabolites. This study also indirectly provides means to develop the local feed market while restoring the rangeland through sustainable production of animal feed and also enhances animal feed security.

The determination of the nutritional composition of encroacher species is an imperative necessity in the formulation of bush based feeds. Employing appropriate and effective local processing techniques or combination of techniques could help reduce or neutralize the negative effect of anti-nutritive constituents in these protein rich bush feed for livestock nutrition. The in vivo experiment of this study will provide insight on the feed intake, digestion and the nitrogen balance of the bush feed. This research study is therefore encouraging, both in terms of value addition to the production of bush feeds and the prospect that, the targeted encroacher species can be utilized to the full and at improved extent.

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction

Livestock production covers approximately over 30% of global arable land (FAO, 2008a). Given the fast depletion of natural resources, exponential growing human population with its pressure and rising living standards, it has become extremely important to diversify the current animal agriculture to meet increasing demand for animal products (USDA, 2011). According to FAO, (2008a) the global meat and milk consumption is expected to rise from 568 to 700 million tonnes.

The area of livestock production that calls for critical examination is the availability of feed resources (FAO, 2008a). The interest in search for alternative/additional food and feed ingredients is of paramount importance mainly because of the global demand for grains that has exceeded the production and stiff competition between man and the livestock industry for existing food and feed materials (McClaran *et al.*, 2013).

In addition, the depletion of soil quality, lack of water and climate change continues to affect the productivity of crops and forage plants, impacting adversely the animal productivity (Pearson and Langridge, 2008). According to FAO (2008b), a quarter of the world’s population is sustained by production on degraded soils, given the fact that 20% of all cultivated areas, 30% of the forests and 10% of grasslands presently undergoing degradation. The biggest challenge therefore for animal nutrition scientists is to introduce and promote alternative feed resources that have high nutritive value and are adapted to harsh environmental conditions (USDA, 2011). Given the ongoing climate change, harsh conditions are also expected to occur: High temperature, droughts, flood and drastic climatic variations, with the greatest impact to be felt among subsistence or smallholder farmers in developing countries (Marton, 2007). According to Sansoucy (1994) wild under- utilized plant resources must therefore receive more attention as alternative livestock feed. Shelton and Brewbaker (1994) highlighted that the commonly grown trees and shrub legumes that have gained wide acceptance by farmers were lesser-known about 30-50 years ago. Such forage and shrub trees include: *Sesbania sesban, Gliricidia sepium, Calliandra calothyrsus and Leucaena species,* just to mention a few. According to Devendera (1993), *Leucaena* species has received the most attention as animal feed and has been cultivated over large areas of the tropics. This also applies to soybean meal, rapeseed meal and many other feed resources that were lesser known or unconventional some decades aback.

There are several other lesser-known and underutilized forage adapted to local, harsh conditions available today that have marvelous potential as livestock feed. The inattention of potentially excellent animal feed resources also results in loss of plant biodiversity. According to FAO (2010), over 75% of plants have become extinct in the last five decades largely because these were not being utilized. Thus, there is a need to identify such potential feed resources and use them to conserve biodiversity.

2.2. The concept of bush encroachment in Namibia

Bush encroachment is often seen as one of the most extensive forms of degradation in Southern African rangelands (de Klerk, 2004). This phenomenon is common in the arid and semi-arid biomes around the world (Skarpe, 1990; Eldridge *et al.,* 2011). The accepted definition for bush encroachment in Namibia by de Klerk (2004) is the following: “Bush encroachment is the invasion and/or thickening of aggressive undesired woody species resulting in an imbalance of the grass: bush ratio, a decrease in biodiversity, a decrease in carrying capacity and concomitant economic losses”. Other definitions of bush encroachment include: “Rangeland on which the density of bushequivalents (a 1.5 m high bush) per hectare exceeds twice the average annual rainfall" (Smit cited by de Klerk, 2004). "The invasion of woody species in areas that have always had either very low density of trees and shrubs or have been devoid of them" (Mannheimer and Curtis, 2009).

The primary causes of bush encroachment on savannahs include a reduction in the frequency of fires and overgrazing of livestock (Ward, 2005; Kgosikoma and Mogotsi, 2013). When the grass layer on savannahs loses its competitive advantage and its ability to utilize nutrients and water efficiently, higher infiltration of water and nutrients into the sub-soil results; a situation that benefits bush and tree species, allowing them to predominate (de Klerk, 2004). Bush encroachment is also accompanied by a change in the dominant grasses: perennial grasses are often lost, being replaced by annual species often of inferior quality for livestock (Scholes and Archer, 1997. Rothauge, 2007). Annual grasses are generally less productive than perennial grasses. Thus, animal production on an annual grass sward is very precarious and less sustainable.

In addition, an important theory is the State-and-Transition Model (Walter, 1971), which states that savanna ecosystems are event-driven, where rainfall and its variability play a more important role in vegetation growth (and composition) than the intensity of grazing. This model implies that bush encroachment is not a permanent phenomenon, and that a savanna can be changed to its grass-dominated state by favourable management or environmental conditions (Doughill *et al.*, 1999). Woody plants establish themselves after dry periods followed by a few wet years, and then maintain themselves by utilising most of the water. Rather than a steady annual increase in numbers, the general rule is that woody plants establish in large numbers during certain years and at varying intervals (Donaldson, 1968).

Bush encroachment therefore occurs rapidly and associated or triggered by management practices, natural events, or a combination of these factors. Increasing level of bush thickening have caused the demise of large trees (Mannheimer and Curtis, 2009). The smaller trees ‘suffocate’ the larger ones by using up much of the shallow soil moisture, depriving the large trees of water. Trees such as *Acacia erioloba* possess a long tap root that gives them access to deep groundwater but they also depend on moisture gathered from their other superficial roots.

Namibia’s bush encroached areas fall mainly within the semi-arid savannas, with rainfall varying from about 300 mm in the west to over 600 mm in the north-eastern parts (Mendelsohn *et al.*, 2003). It is typically reported “26 to 30 million hectares of Namibia are encroached”. This figure is based on the map compiled by Bester (1999) as shown in Figure 2.3, showing the density per hectare of dominant encroacher bushes in Namibia.

Namibia is affected by bush encroachment on a massive scale (SAEIA, 2016) as shown in Figure 2.1. The phenomenon affects an estimated 26 to 30 million hectares of farmland in 9 of the country’s 14 regions (Bester, 1999). That amounts to roughly 30 per cent of Namibia’s land area. Recent studies estimate an increase in bush encroachment up to 45 million hectares (SAEIA, 2016).

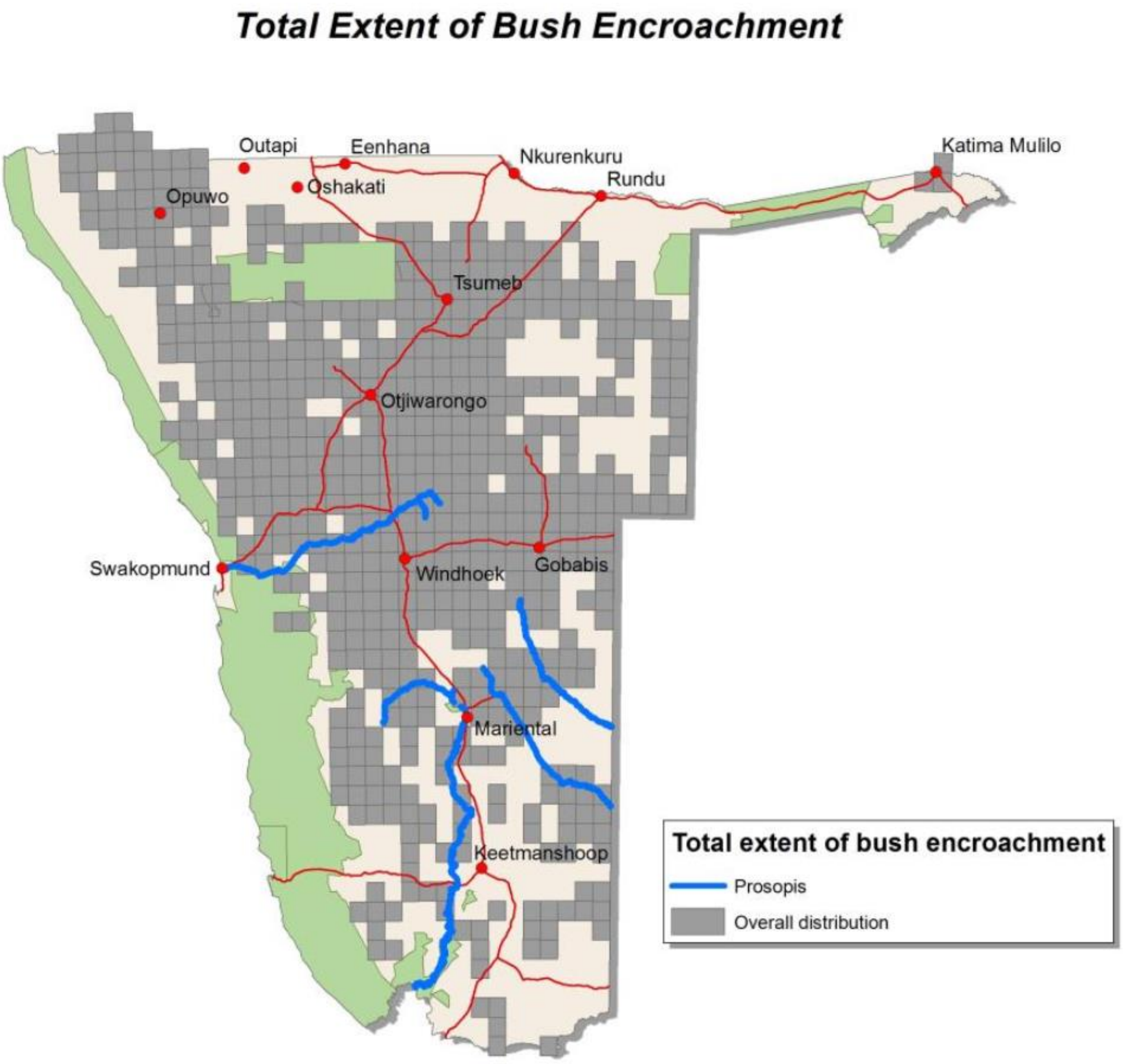

Figure 2. 1. The total extent of bush encroachment in Namibia (Source: SAEIA, 2016).

Namibia is affected by the invasion of alien invasive and indigenous encroacher species, of which some of these species covers hectares of land, stated to be encroached (SAEIA, 2016). Encroacher and invasive species are common terms used interchangeably although both contribute to bush encroachment they do not have the same meaning.

The term invasive is used to describe organisms that spread quickly and are considered as harmful species to the environment. Invader species are often considered a problem as they tend to alter ecological relationships among other species and can affect economic value of ecosystems.

Several plants have been categorized as indigenous encroacher species (SAEIA, 2016) Figure 2.2, with different densities in Namibia rangelands. These species include: *Acacia mellifera, Acacia reficiens, Colosphospermum mopane, Dichrostachys cinerea, Terminalia prunoides, Terminalia sericea, and Rhigozum trichotomum* and among others (Bester, 1999; De Klerk, 2004; Joubert *et al.,* 2013; SAEIA, 2016). On the other hand other indigenous woody species classified as of lesser importance include, *Combretum collinum* (mainly in Zambezi Region), *Acacia hebeclada, Acacia erubescens, Acacia fleckii, Acacia mearnsii* and *Acacia nilotica*. While the Invader species include: *Prosopis* species, *Leucaena* species and Lantana species.

The most widely spread and dangerous alien invasive in Namibia is *Prosopis glandulosa*. Prosopis is mainly confined to riverbeds and adjacent areas where they tend to outnumber and eliminate other indigenous species and reducing ephemeral flow in river beds through abstraction of ground water.

Bush encroachment by the above-mentioned species has lowered the productivity of land and its grazing capacity (Joubert *et al.*, 2013) by more than two-thirds and impacts negatively on groundwater recharge (Colin, 2010), biodiversity and other ecosystem services (SAEIA, 2016). At the same time, encroacher bush can deliver valuable biomass resource. Thus, bush control offers the potential to increase agricultural productivity, economic growth, employment energy supply and fodder for livestock. Furthermore, bush encroachment decreases the diversity of habitat structure (Cunningham, 1997) thereby influencing for example native savannah lizards (Meik *et al.,* 2002) and some bird species (Sirami and Monadjem, 2012).

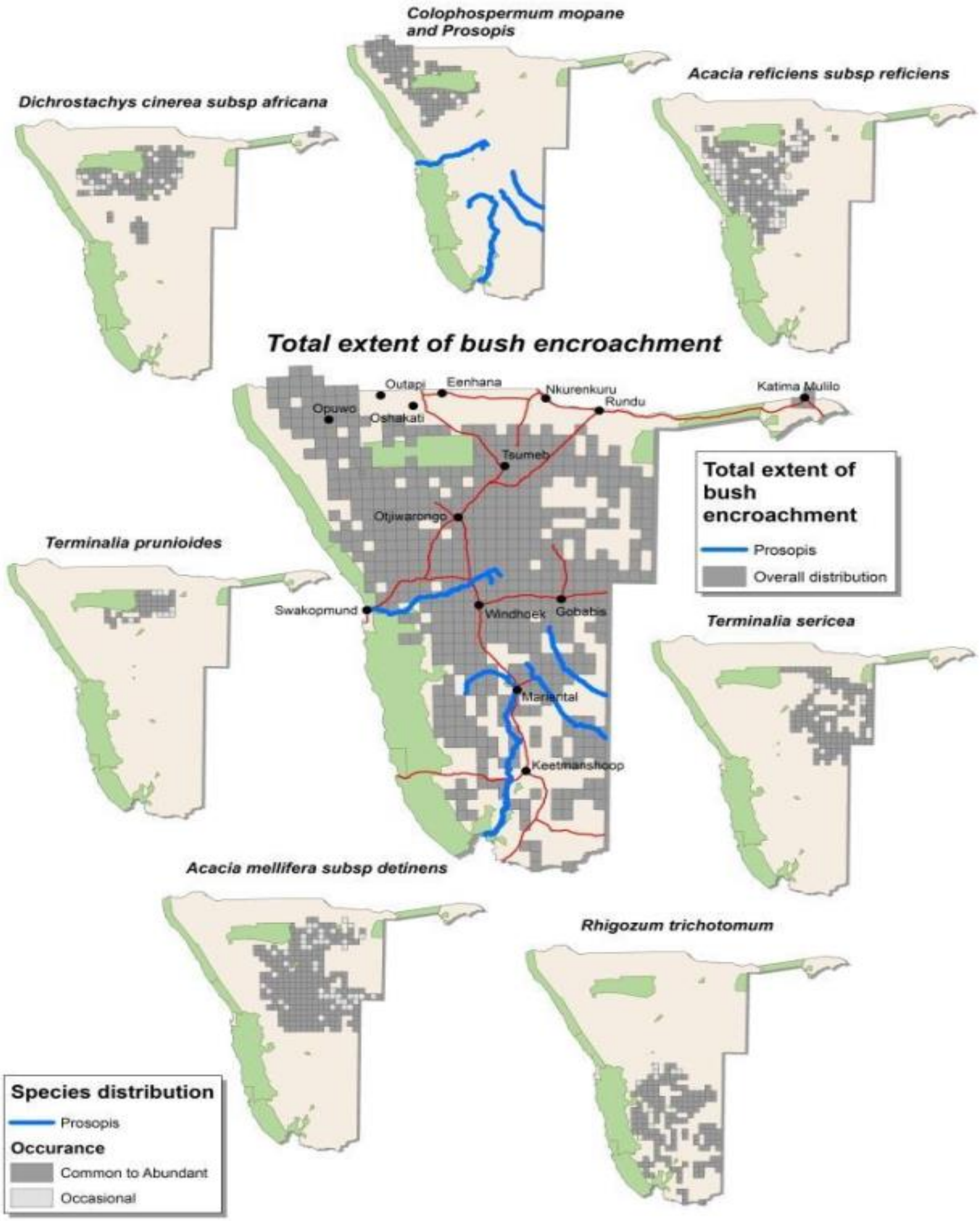

Figure 2. 2. The extent of bush encroachment in Namibia and the overall distribution of dominant encroacher species (Source: SAEIA, 2016).

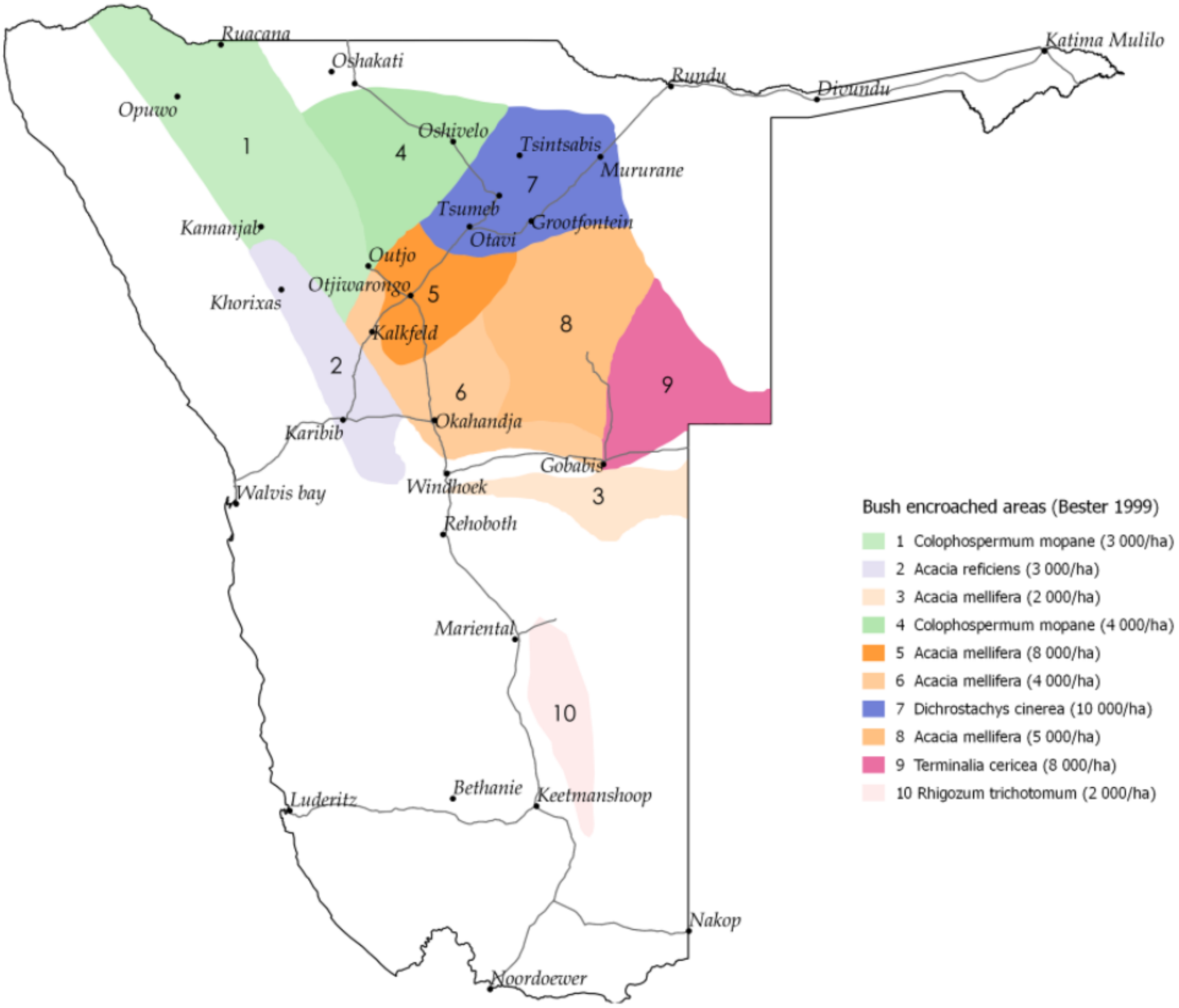

Figure 2. 3.The density dominant encroacher bushes in Namibia (Source: Bester, 1999).

Bush encroachment by *Acacia mellifera* (Vahl) Benth. *Subsp. detinens* (Burch.) Brenan and *Dichrostachys cinerea* (L.) Wight and Arn, has long been considered an ecological and economic problem in the rangelands of Namibia (Walter, 1971) as well as in other southern African countries (Skarpe, 1991; Roques *et al.*, 2001; Ward, 2005). The area affected by bush encroachment in Namibia is estimated to be about 260 000 km^2 (De Klerk, 2004).

This bush encroached area affects parts of at least seven vegetation types in Namibia, namely Mopane Savanna, Mountain Savanna and Thornveld, Thornbush Savanna, Highland Savanna, Camelthorn Savanna, Forest Savanna and Woodland (Giess, 1998). The bush encroached areas fall within the arid and semi-arid savannas with rainfall varying from about 300 mm in the west to about 500 mm in the north-eastern parts.

The prevailing perception in Namibia is that bush encroachment in arid savannas is largely a fairly recent phenomenon. Bester (1996) notes that, although it had already begun earlier, it was really since the late 1950s and early 1960s that the process dramatically accelerated. This was considered to be the consequence of a prolonged and severe drought in conjunction with an outbreak of foot-and-mouth disease which prevented farmers from destocking their already depleted rangelands.

The resultant overgrazing thus released the woody layer from much of the grass competition, allowing the shrubs to grow much quicker and thicken up. Yet, this perception has never really been tested, and most of the evidence for bush encroachment during the 20th century in Namibia is anecdotal. There is little or no scientific evidence available to prove or disprove the perception that the major problem has indeed occurred in the last 60 or so years.

Interestingly, anecdotal evidence from early explorers suggests that some landscape scale bush encroachment occurred as early as the 1850s (de klerk, 2004). Surprisingly little research, besides the occasional documentation of bush densities and cover (Bester, 1999), has been conducted in Namibia, and few studies aside from that of Wiegand *et al.* (2006) and Kambatuku *et al.* (2011) have attempted to understand the dynamics and processes in Namibian arid savannas. Instead, our received wisdom is drawn from other studies, mostly from South Africa and mostly from more mesic savannas. Despite this paucity of local research on bush thickening, much of the blame for the declines in rangeland and beef production has been placed with bush encroachment, and enormous amounts of money and effort have been put into treating the existing symptoms (De Klerk, 2004).

2.3. Woody plants as fodder for livestock

Woody plants (indigenous trees and shrubs) forms a major component of the diet of large and small livestock in Africa and Asia (Salem and Smith, 2008). The edible part of the woody plants such as the leaves, twigs, flowers, fruits and pods is referred to as the browse. Trees and shrubs provides protein, vitamins and relative mineral elements mostly during dry seasons as a result of poor rainfall and prolonged drought in arid and semi-arid areas (Salem and Smith, 2008).

A tree is defined as a woody plant with one stem or trunk branching well above the ground, while a shrub is defined as a bush with a number of stems or more or less equal size arising from near the ground and often branching low down (Mannheimer and Curtis, 2009).Woody plants especially those of the genus Acacia are reported to have adapted to semi-arid regions and have widely spread in most South African countries such as Namibia, South Africa, Botswana and Zimbabwe in particular. Woody plants such as the Acacia species and *Dichrostachys cinerea* have foliage that grows in the dry season and ruminant consumes them (Mlambo and Mapiye, 2015).

The use of tree pods as dry season protein supplement has been reported in literature (Sibanda and Ndlovu, 1993; Kindness *et al.,* 1999; Sikosana *et al.*, 2000b; Mlambo *et al.,* 2004; Smith *et al.*, 2005b). A study by Chepape *et al.* (2011) in South Africa reported that *Dichrostachys cinerea* was the most preferred species by both cattle’s and goats. Sanon *et al.* (2007), reported the importance of Sahelian Browse as feed for goats in Burkina Faso. Aganga and Tswenyane (2003) reviewed the nutritive value of various browse species in Botswana. Ansah and Nagbila (2011) reviewed the importance of local trees and shrubs as feed for livestock and medicinal purpose in Ghana.

Njarui and Mureithi (2004) reported that forage production systems such as *Leucaena leucocephala* and *Gliricidia sepium* cultivation were promoted in smallholder dairy farms in Kenya.

According to Sanon *et al.* (2007) the most important part of the edible woody plant biomass is not directly accessible to the animals due to the height of the trees and shrubs hence Njarui and Mureithi (2004) reported that trees and shrubs can be cut through a "cut and carry system" and fed to animals as supplements.

2.4. The Namibia livestock sector, challenges and opportunities

The livestock sector currently constitutes the world's largest user of natural resources (FAO, 2009), with 80% of all agricultural land used for grazing or animal feed production and 8% of the global water use, primarily for irrigation of feed crops (Steinfeld *et al.*, 2006). Livestock sector is also among the top significant contributors to local and global environmental problems (FAO, 2010). However, in a global circular bio-economy, livestock have many valuable roles (FAO, 2011) such as to provide sufficient protein-rich, safe and healthy food for humans; regulate the ecological cycles and close the nutrient loop; contribute to a more efficient agriculture by valorizing food-chain by-products ; to improve soil fertility by the use of grassland and proper spreading of manure; provide raw material for renewable energy and valuable by-products; provide ecosystem services linked to the vitality of diverse territories, employment in rural areas; landscape and biodiversity preservation and cultural heritage. Hence, it is essential to develop animal friendly production systems that meet the physiological and behavioural needs of farm animals.

In Namibia, livestock contribute 70% to the agricultural output (NPC, 2012), and serve various roles to communities including cash, wealth, sustenance and food security, draught power, manure, employment, skins, dowry, ecosystem health and exchange for other farm produce. Owing to climate, soil types and evapotranspiration rates, Namibia is better adapted to livestock-based as opposed to arable agriculture (NPC, 2012)

Livestock farmers in communal areas of Namibia hold approximately 62% of the total cattle population, 72% of the goats and 17% of the sheep, this being mainly confined to the northern part of the country (MAWF, 2014). Households herd sizes within communities vary considerably between and within regions, and livestock ownership is strongly skewed, with a small number of people owning large herds and a majority owning few animals or none at all (Sweet & Burke, 2000).

Livestock keeping in Namibia is known for its feed quantity and quality problems, especially during the dry seasons (NMBAR, 2011). Forages are normally dry and contain very little protein and minerals (NMBAR, 2011; MAWF, 2014). This leads to a deterioration of the animal body condition, a higher susceptibility to diseases and the death of large numbers of animals during extended dry seasons, when not providing supplement feeding or moving animals to areas with better grazing opportunities.

The reproductive performance becomes impaired because of an excessive loss of condition and weight (Masunda, 2002a). According to official figures the productivity in communal areas is indeed low, when measured against the marketed output (MAWF, 2014). While 42% of the national cattle herd is owned by communal farmers, their contribution to meat production is at only 4% (NMBAR, 2011).

Distant markets limit the development of farming in the communal areas and agricultural incomes are low and variable (NMBAR, 2011). Livestock supplies many non-marketed products and services, the value of which is not fully reflected in the national accounts (Jones, 2003). These include draught power, milk, hides, meat, manure and a traditional form of savings for rural communities.

The success of livestock farming on Namibian communal land has depended on mobility, as a strategy for ensuring access to water and pasture, in the past (Jones, 2003). However, the provision of permanent boreholes, an increase in the human population and the development of large permanent settlements have helped to reduce the possibility of maintaining mobility as a range management strategy (Blackie, 1999).

High variability of rainfall (inter-annual, intra-seasonal and spatial) (Mendelsohn *et al.,* 2002), and the distinct seasonal changes of the amount of rangeland fodder resources, as well as their quality, are typical characteristics of semi-arid and arid rangelands of Namibia, with which livestock farmers have to cope when applying farming strategies on which the success of the entire livestock production depends. The total annual rainfall varies greatly from year to year, with a coefficient of variation (CV) from 20% up to 80%, following the rainfall gradient from northeast to southwest (Mendelsohn *et al.*, 2002), and in the southwest is a higher risk of droughts than in the northeast.

Estimating the forage usage and requirement of livestock in semi-arid areas, and getting an idea of the carrying or grazing capacity is important, especially for the communal areas, in order to prevent the degradation and desertification of rangelands in the uncertain climate conditions of Namibia. A sustainable exploitation seems to be possible to a certain threshold, after that, the danger of irreversible degradation prevails. Rural people's livelihoods depend to a high degree of naturalresources (Flower & von Rooyen, 2001; Gundy, 2003).

Moreover, few studies have integrated browsing resources in their rangeland resource assessments in Southern Africa (du Toit, 1974; Walker, 1980; Huntley, 1982; Rutherford, 1982; Knemeyer, 1985; Dekker & Smit, 1996; Moleele, 1998; Mphinyane, 2001and 2003; Kamupingene and Abate, 2004; Dube *et al.*, 2006). Some were applied on communal grazing areas in Botswana (Moleele, 1998; Mphinyane, 2001) and in Namibia (Kamupingene and Abate, 2004; Dube *et al.*, 2006), making claim to be the classical papers.

Browse consists of leaves and twigs from shrubs and trees available to ruminants as feed and in a broader sense including also flowers, fruits or pods (Kamupingene and Abate, 2004). The notion of browse is a complex issue, depending on plant species, animal species, forage availability and accessibility and the nutritional state of the animals (Mphinyane, 2003).

Browse is of high importance as fodder resources during dry seasons and droughts, especially for communally managed, mainly free roaming mixed livestock herds, and it is often not integrated in carrying capacity calculations (Dube *et al.*, 2006). Multiple uses of woody plants include soil maintenance and protection against erosion, it is a source of energy (fire wood), people use it as construction material and with the shade trees and bushes reduce water loss from the soil (Gundy, 2003).

2.5. Description of black thorn (*S.mellifera)*, a dominant encroacher species in Namibia and a potential fodder tree for livestock.

Acacia mellifera (M. Vahl) Benth, *subsp. detinens*, was renamed *Senegalia mellifera* (Vahl) Seigler and Ebinger in 2010 (USDA, 2014). Nevertheless, since most papers refer to *Acacia mellifera*, it was decided to use this taxon in datasheets until *Senegalia mellifera* gains more widespread recognition (USDA, 2014). Its common name are: Black thorn, wait-a-bit, hook thorn

[English]; Swaarthaak, blouhaak, hakiesdoring, wynruit [Afrikaans];Katogwa, muguhungu, mukotokwa, umngaga [Ndebele]; Monga, mongana [Tswana]; Mongangatau [Northern Sotho]; Munembedzi [Tshivenda]; Monkana [Siswati]; Oiti, eiti [Arusha, Masa]; Mkambala, mvugala [Gogo]; Ghaland [Gorowa]; Yudegi, yudek [Iraqw]; Mangerada [Mbugwe]; Mujujumi [Nyaturu]; Kitr [Sudan]; Bilel, laner, lanen [Somali]; Kikwata [Swahili]; Tselim kenteb [Tigrigna]; Mupandabutolo [Tongan].

Figure 2. 4. *Senegalia mellifera* subsp *detinens* (Source: Kruger, 2016).

The black thorn (*Senegalia mellifera* (M. Vahl) Benth.) is an African shrub or tree growing to a height of up to 9 m. It has an extensive root system that explores large volumes of soils, allowing survival in dry areas (Hines *et al.*, 1993). It has a tangled, flat-topped canopy that may reach down to ground level, with branches that bear pairs of black hooked thorns (Figure 2.4) every 5 to 15 mm. The leaves are bipinnate with only 1-2 pairs of pinnae each bearing 1-2 pairs of ovate or obovate leaflets. Leaflets are 3.5-15 mm long x 2-12 mm broad. Initially green, black thorn leaves become glaucous with maturity. The flowers are fragrant, sweetly scented, 3-5 cm long and creamy white in colour, borne in dense hanging spikes. The fruits are straw coloured flat pods, 3-8 cm long x 1.5-2.5 cm wide that contain three seeds. The tree lives less than 10 years (Hines *et al.*, 1993; Orwa *et al.*, 2009; Nonyane, 2013; FAO, 2014).

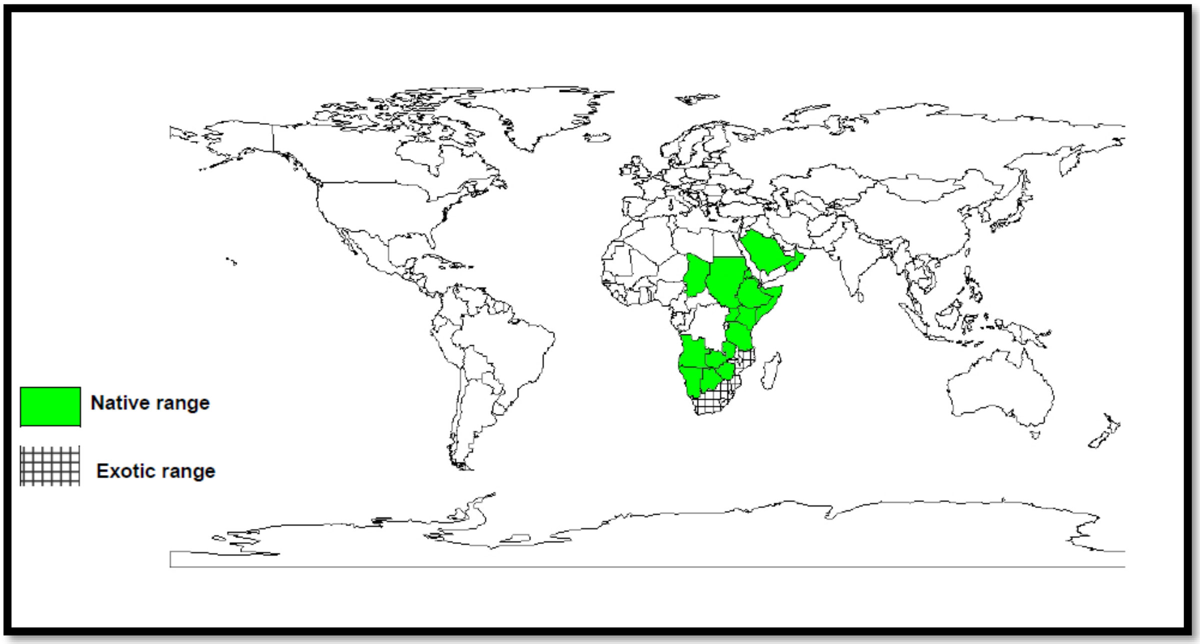

Figure 2. 5. The distribution of Black thorn (*Senegalia mellifera*) worldwide (Source: Orwa *et al.*, 2009).

The tree is a drought-resistant species widely spread in arid and semi-arid areas of Africa and the Arabian Peninsula. According to Stuth *et al.* (1990) it can be found from 1000 to 1400 (-1500) m above sea level in Kenya. This plan specie is found in regions with 400-800 mm annual rainfall and also in regions with a minimum of 100 mm rainfall (Stuth *et al.*, 1990).

S. mellifera trees grows in groups of pure, dense, impenetrable and even-aged thickets (Orwa *et al.*, 2009; Nonyane, 2013; FAO, 2014). The tree can be vegetatively propagated or sown (Stuth *et al.*, 1990). It is a slow-growing tree that is sensitive to cold and frost in the early stages of development (CIRAD, 1991). Fadel *et al.* (2002) recommended that *S. mellifera* seedlings are very palatable to livestock and should be protected during the first two years.

However, bush encroachment can occur, when left unattended, the trees form dense and impenetrable thickets, (Orwa *et al.,* 2009; Nonyane, 2013; de Klerk, 2004). This phenomenon can be controlled with fire, chemicals and mechanical harvest (Orwa *et al.,* 2009; FAO, 2014). Because they can form dense impenetrable thickets, *S. mellifera* often outcompete grasses in dry areas and become the only remaining species, causing a considerable reduction in seasonal grass yields (32-40% in Zimbabwe and 41% in the Eastern Cape) (Kraaij *et al.,* 2006).

2.5.1. Chemical composition of S.mellifera and other common browse trees in Southern Africa.

Fadel *et al.* (2002) reported that *S. mellifera* foliage has a high crude protein (CP) content that ranges from 15 to 17% CP, while Honsbein *et al.* (2017) (Table:2.1) reported CP content of 8.5%DM and a low organic matter digestibility of 46-48%.The variable amounts of acid detergent fibre (ADF) ranges from 17-34% according to Fadel *et al.* (2002) whilst Honsbein *et al.* (2017) reported ADF values of 46-57%. As in other browse species, the composition is extremely variable (Osuga *et al.,* 2007) due to the different proportion of leaves, petioles and twigs collected by researchers (Fade *et al.,* 2002; Osuga *et al.,* 2007, Heuze and Tran , 2015).

Like other Acacia species, *S. mellifera* foliage contains tannins, however the reported tannin content is extremely variable (Fade *et al.*, 2002; Osuga *et al.*, 2007). Condensed tannins have been found to be present either in low amounts of 0.2% DM (Osuga *et al.,* 2007), or in much larger quantities: in Sudan, from 1.4% DM in the early dry season (late October) to 5.7% DM in the late dry season (early June) (Fadel Elseed *et al.,* 2002). Honsbein *et al.* (2017) reported the NDF content of 57.92% in *S.mellifera* fractions in Namibia while Heuze and Tran (2015) (Table: 2.1) reported the NDF content of 33.35.

Table 2. 1. The chemical composition and nutritive value of *S.mellifera*

MAIN ANALYSIS	**UNIT**	**Heuze and Tran (2015) (Leaves)**	**Honsbein *et al.* (2017) (Leaves & twigs)**
Dry matter	% as fed	34.1	94.92
Crude protein	%DM	20.5	8.51
Crude fiber	% DM	18.1	-
NDF	% DM	33.3	57.91
ADF	% DM	23.1	46.57
LIGNIN	% DM	7.0	-
Ether extract	% DM	3.5	1.50
Ash	% DM	9.6	-
Gross energy	MJ/kg DM	18.3	-
Calcium	g/kg DM	19.3	-
Phosphorus	g/kg DM	1.2	-
Tannins	g/kg DM	47.0	-
ME ruminants (gas production)	MJ/kg DM	8.2	-
OM digestibility	%	55	46.48

Osuga *et al*, (2008) reported in Kenya that black thorn was ranked 4th and 3rd , in a comparison study with *Acacia brevispica*, *Ziziphus mucronata*, *Berchemia discolor* and *Maerua angolensis*, in the palatability of goats and had a better palatability index than *Leucaena leucocephala* for sheep (Abdulrazak *et al.,* 2001). Black thorn is a multipurpose tree (FAO, 2014) and according to Orwa *et al.* (2009), the leaves, pods and young shoots are nutritious and make fodder for livestock and wild animals. Black thorn is readily browsed by sheep and goats. The plant is also often browsed by camels, and wild animals such as black rhinos, kudus, elands and giraffes (Orwa *et al.,* 2009).

Goats are particularly fond of the leaves, which constitute a considerable part of their diet (Nonyane, 2013). Fallen browse (dry leaves and pods) are eaten on the ground by cattle and sheep who, unlike camels and goats, are less likely to browse (Orwa *et al.,* 2009). According to Abdulrazak *et al.* (2000), *S. mellifera* is a good browse species for all classes of domestic and wild ruminants in arid and semi-arid regions. Predominantly, it provides valuable protein supplementation to livestock (Osuga *et al.,* 2007).This is in support by Stuth *et al.,* (1990) who sated that the overuse of *S. mellifera* for firewood is of concern for goat production in Kenya. The flowers of *S. mellifera* are attractive to bees, which produce a high quality honey, hence the name mellifera (Hines *et al.,* 1993; Orwa *et al.,* 2009; Nonyane, 2013; FAO, 2014).The bark is used in ethnomedicine to treat stomach problems, sterility, pneumonia, malaria and syphilis (Rulangaranga, 1989 cited by Hines *et al.,* 1993).

According to Crowder and Cheddah (1982), the nutritive value of browse refers the chemical composition, intake, digestibility and the exploitation of absorbed food and nature of the digested products. The scholars reported that, the quality of forages is determined in terms of chemical composition, digestibility of plant constituents and amount of feeds consumed by ruminants. Conversely, the total amount of the forage materials eaten by animal is an important factor upon animal response as it affects total intake of nutrients and consequently influences animal production. Outcomes validated in different literature shows variable chemical composition among various browse fodder species ranging from 35-60, 107-300, 154-511, 14-396 and 51-206 g/kg DM, for ash, crude protein(CP), neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin(ADL), respectively (Sawe *et al.*,1998; Abdulrazak *et al.,* 2000 (Table:2.2); Rubanza *et al.,* 2003a,b).

Dominant browse foliage species in the literature contain intermediate to extraordinary concentrations of crude protein ranging from 120 to 292 g/kg DM (Reed *et al.,* 1990; Abdulrazak *et al.,* 2000a, b; Mokoboki *et al.,* 2006).The high CP values of browse tree and shrub legumes put forward their potential as CP supplements to ruminants fed low quality roughages. In contrast, palatable grasses especially during dry season or at maturity contain low CP which is lower than the minimum CP requirements of 80 g/kg DM (Annison and Bryden, 1998). Neutral detergent fiber (NDF) is considered to be a standard measure of the incompletely digestible cell wall contents, but this also varies in the amounts between species and ranges from 154 to 619 g/kg DM (Topps, 1992; Mtengeti *et al.,* 2006). Van Soest (1994) reported that NDF for forage species ranges from 540 to 770 g/kg DM. Honsbein *et al.* (2017) reported CP content of 8.5%DM and a low organic matter digestibility of (46-48%).Increasing levels of NDF limits dry matter intake (Van Soest, 1994). Most browse tree foliage species have adequate to low contents of fibers. Mokoboki *et al.* (2011) reported low ADF for *Acacia hebeclada* (145 g/kg DM) and *Acacia siberiana* (165 g/kg DM) which could be associated with high digestibility. Mtui *et al.* (2009) reported low ADL which ranged from 33 g/kg DM in *Morus alba* to 110g/kg DM (*Gliricidia sepium*).

2.5.3. Digestibility of S. mellifera

In a comparison of 15 indigenous browse species in Kenya, Ondiek *et al.* (2010) noted that *S. mellifera* was in the middle of the range for *in vitro* DM degradability (56%) and *in vitro* (gas production) OM digestibility (54%), with lower values than those of *Maerua angolensis* and *Ziziphus mucronata.* Honsbein *et al.* (2017) (Table: 2.2) reported a low organic matter digestibility of 46-48%. In another experiments aimed at alleviating the effect of acacia tannins on protein digestibility, the addition of PEG (polyethylene glycol) to black thorn foliage did not increase gas production, probably because the black thorn does not contain large amounts of tannins (Osuga *et al.*, 2007; Wambui *et al.*, 2012).

According to Wambui *et al.* (2012), the addition of brewer's yeast increased gas production in a browse mixture containing *Berchemia discolor* and black thorn in a 1:1 ratio. Moreover, Osuga *et al.*, (2007) and Wambui *et al.*, (2012) reported that probably because the black thorn does not contain large amounts of tannins, the addition of PEG (polyethylene glycol) to black thorn foliage did not increase gas production, in an experiment aimed at alleviating the effect of tannins on protein digestibility.

Table 2. 2. Chemical composition (g/kg DM) of common browse trees in Southern Africa.

BROWSE SPECIES	**CP**	**NDF**	**ADF**	**ADL**	**ASH**	**Source**
Acacia tortilis	141	195	169	42	41	Abdulrazak *et al* (2000)
Acacia mellifera	194	269	192	77	n.a	Abdulrazak *et al* (2000)
Melia azedarach	141	n.a	n.a	n.a	53	Mtui *et al* (2009)
Acacia senegal	238	245	141	52	77	Ndlovu *et al* (2000)
Salvadora persica	184	333	213	71	171	Rubanza *et al* (2006)
Boscia spp	231	370	257	81	143	Rubanza *et al* (2006)
Morus alba	186	246	208	81	143	Shayo (1997)
Acacia hebeclada	226	379	145	n.a	n.a	Mokoboki *et al* (2011)

2.7. Mineral content of browse tree

Minerals are essential for normal growth, reproduction, health and proper functioning of the animal's body (McDowell, 1992). Minerals safeguard and maintain the structural constituents of the body, organs and tissues, and are ingredients of body fluids and tissues as electrolytes (Rubanza *et al.* 2006). Minerals have catalytic functions in the cells as well as maintaining acid-base balance and osmotic control of water circulation within the body (McDonald *et al.,* 1995; Mtui *et al.*, 2008). Minerals are divided into macro and micro minerals based on their requirements in the animal body (McDowell, 1992).

Macro minerals are present at larger levels in the animal body or required in larger amounts in the diet (Mtui *et al.,* 2008). Macro minerals include calcium, chlorine, magnesium, phosphorus, potassium, sodium, and sulfur. Most of tropical forages are documented to have calcium (Ca) levels ranging from 8.6-10.2 g/kg DM (Minson, 1990; Rubanza. 2005). Rubanza *et al.* (2006) and Mtui *et al.* (2008) reported a high range of Ca (6.6-35.6) g/kg DM. Calcium and Phosphorus ratio acclaimed for normal physiological function of ruminants is 2:1 (McDonald *et al.,* 1995).

Browse species in most cases have much higher Ca: P than the requirements of the animal such as that described by Rubanza (2005) of (6.6:1-31.5:1) and Rubanza *et al*. (2006) of 13.8:1-55.1:1. Phosphorus levels for most browse species range from 1-5 g/kg DM as noted by Rubanza *et al.* (2006), Mtengeti *et al.* (2006) and Mtui *et al.,* 2008). However, Abdulrazak *et al*. (2000) noted low P concentrations in Acacia species ranging from 0.7-1.6 g/kg DM. Magnesium concentrations in browse species in most legumes have range from 1.3-6.6 g/kg DM (Abdulrazak *et al.,* 2000; Rubanza *et al.,* 2006; Mtengeti *et al.,* 2006 and Mtui *et al.,* 2008). Sulfur contents in Acacia species were reported to range from *Acacia brevispica* (0.7 g/kg DM) to *Acacia nubica* (6.6 g/kg DM) (Mtui *et al.,* 2008).

In contrast, micro minerals are often referred to as trace minerals, meaning they are present at low levels in the body or required in smaller amounts in the animal's diet (Abdulrazak *et al.* 2000; McDowell, 1992). Micro minerals include chromium, cobalt, copper, fluorine, iodine, iron, manganese, molybdenum, selenium, and zinc (McDowell, 1992).

Then concentrations of sulfur in most tropical legumes range from 15-35 mg/kg DM (Minson, 1990). Concentrations of Cu reported by Kakengi *et al.* (2007) and Rubanza *et al.* (2006) ranged from 5.1-9.9 mg/kg DM. However, Abdulrazak *et al.* (2000) noted high concentration of Cu in *Acacia Senegal*. Rubanza. (2005) reported high contents Fe for tropical browse species that ranged from 146.2-432 mg/kg DM. However, the minimum Fe requirement for ruminants is 30-60 mg/kg DM and17 the Fe contents for most tropical forages and legumes range from 100-700 mg/kg DM (McDowell, 1992).

Manganese contents for browse species as reported by Rubanza. (2006) ranged from 44.6-306 mg/kg DM. However, Abdulrazak *et al.* (2000) and Kakengi *et al.* (2007) reported a different range (9.4-67.8) mg/kg DM for other browse species. The levels of Zinc in most browse species range from 10.2-34.7 mg/kg DM (Abdulrazak *et al.*, 2000, Rubanza *et al.*, 2006 and Kakengi *et al.*, 2007). Minson (1990) reported mean Zn concentration of most forages ranging from 36-47 mg/kg DM.

Distinctions in the concentrations of macro and micro minerals among species is attributed to the difference in nature of soils, fertility of the soils and rainfall patterns of the soil (McDowell, 1992 ;Abdulrazak *et al.,* 2000). Furthermore genotypes, variation of mineral uptake among the species, stage of maturity and proportion of leaf samples taken for analysis are the cause of variations (Minson, 1990).

2.8. Factors affecting the chemical composition of tree browse.

The chemical composition of browse tree foliages is a function of plant species (Crowder and Cheddah, 1982) and environmental factors (Singh *et al.*, 2010). Main factors include genotype, stage of growth, edaphic factors, climatic condition, topography and presence of toxic substance.

2.8.1. The effect of plant genotype.

Woody plants can maintain sufficient nutritional levels during critical period of the year such as in summer, when grasses have been depleted (Luginbuhl and Poore, 1998). Studies have confirmed that woody plants generally have high protein content, high lignin and tannin content when compared to grasses (International Atomic Energy Agency (IAEA), 2006).

However, the amounts vary greatly from one species to another and phenological stage of the plant (Luginbuhl and Poore, 1998). Genotypic dissimilarities among browse tree species affects the chemical composition of the tree forages in relation to nutritional value (Upreti and Shrestha, 2006). Erickson *et al.,* (1982) noted variability in the chemical constituents among barley straw of different cultivars.

The latter authors noted that, six-rowed barley straw had low CP, P and hemicelluloses while higher in neutral detergent fiber (NDF), acid detergent fiber (ADF) and ash compared to two-rowed barley straw. Genotypic variations were also observed between Karl barley straw and six-rowed barley straw genotypes whereby the Karl barley straw had higher nutritive value compared to six –rowed and two-rowed barley straws (Erickson *et al,* 1982). Furthermore, the palatability and abundance of the various species determine the botanical composition of the animals diet (Rothauge, 2006).

2.8.2. The effect of plant growth stage

The stage of growth is the most paramount factor affecting the chemical composition and digestibility of range tree browse (Ndlovu *et al.,* 1995). Chemical compositions of tree foliages are greatly affected by plant maturity (Upreti and Shrestha, 2006). Plant growth from seedling to maturity consist of different stages including vegetative phase, stem (seedling) and finally reproductive stage (Singh *et al.,* 2010).

Furthermore, there is endless change in plant chemical composition as it grows from one stage to another (Ndlovu *et al.,* 1995; Singh *et al.,* 2010). Younger plants tend to have higher CP contents than matured plants, for instance Singh *et al.,* (2010) noted higher levels of crude protein in young leaves of *Celtis australis* which decreased with leaf maturation.

Most plants decline in nutrient composition with advanced maturity (Topps, 1992). Ndlovu *et al.*, (1995) reported a decline in crude protein while NDF and ADF increased with leaf maturity of tree browse. According to Topps (1992) total dry matter yield is linearly related to the plant maturity and inversely related to digestibility. Shayo (1997) noted lower concentrations of crude protein in older leaves (140 g/kg DM) than younger leaves (186 g/kg) DM of *Morus alba*. As the season advances and plant mature, the protein content also decreases hence anti-nutritional such as the phenolic-tannin level increases (IAEA, 2006).

The variation in chemical composition could also be due to differences in time of samples of collection of trees materials (Singh *et al.,* 2010; Ndlovu *et al.,* 1995). Different seasons showed significant effects on the chemical composition of the trees as leaves became more fibrous and lignified during winter months (IAEA, 2006).

2.8.3. The effect of soil (edaphic factors)

Soils with a particular nutrient have negative impact on plant productivity (Aikpokpodion, 2010). The main effect of soil on plants nutritive value is related to soil's nutrient status and availability (IAEA, 2006). Soil texture has a significant effect on fresh biomass yields, dry matter, crude cellulose and crude ash content formation mainly due to its influence on nutrient supply to the plants (Aikpokpodion, 2010). According to Geren *et al.* (2009) trees grown on light soil texture tend to have high fresh biomass yield, dry matter, crude protein, and cellulose and crude ash content formation than those grown on heavy textured soil.

2.8.4. The effect of climate

Climatic factors such as: temperature, humidity, precipitation, light intensity and altitude effect the nutritive value of woody plants (Singh *et al.,* 2010). Granting that plants are reliant upon the soil for their mineral nutrients, climatic factors affect respiration, assimilation, photosynthesis and metabolism to an extent that the mineral and organic matter content of plants may be strongly modified by climatic factors even though grown on the same soil (Mountousis *et al.,* 2006). Rainfall may have direct and indirect influences upon the quality of browse (Aganga *et al.,* 1998; Mountousis *et al.,* 2006). Rainfall, in general, tends to increase nitrogen; phosphorus and ether extract (the soluble fat constituent) (Singh *et al.,* 2010). Even if browse species are less affected by summer droughts than grasses and forbs because of their deeper root systems, they are able to thrive and remain the option during the dry period (Aganga *et al.,* 1998).

Altitude dissimilarities influence nutritive variation of tree foliages (Mountousis *et al.,* 2006; Singh *et al.,* 2010). Variation in *in vitro* dry matter digestibility was observed in the study of *Albizia gummifera* due to altitude differences (Kechero and Duguma, 2011). The latter author also added that ash, crude fiber (CF) and crude protein content of the browseable materials are much influenced by altitude variations as it showed positive correlation to EE and CF content. The results from the study of *Celtis australis* by Singh *et al.* (2010) indicated that, high altitudinal populations exhibited comparatively higher nutritive values than those from low altitude. Crude protein in adult foliage also showed strong positive correlation with altitude. However, ash content did not exhibit any established trend with an altitude either in case of mature or juvenile foliages (Singh *et al.,* 2010).

2.8.5. The effect of anti-nutritional factors

Woody plants have evolved survival strategies either as a way of storing their nutrients or as a means of defending their structure and reproductive elements from herbivores or in some instance to make use of the animals to spread their seeds (Silanikove *et al.,* 2001; Makkar, 2003). Tannins are chemical or secondary compounds found in plants not directly involved in the process of plant growth but act as deterrents to insects and fungal attack or being eaten by animals (Makkar, 2003). During some plant growth stage, the animals are discouraged from eating the plants while during other stages the consumption of such plants is encouraged (Makkar, 2003).

Tannins are plant secondary compounds acting as anti-nutritional factors affecting rumen function by reducing rumen ammonia level, decrease protein degradation, depressing fiber digestibility (Mangan, 1988; Silanikove *et al.,* 2001; Makkar, 2003). At low concentration of tannins in the diets of ruminants (less than 5%), tannins play beneficial roles by increasing by-pass protein or by decreasing ammonia loss (Gutteridge and Shelton, 1998; Aerts *et al.,* 1999). At higher concentration of tannins (>50 g/kg DM) tannins cause detrimental effects by depressing palatability, decreasing rumen ammonia and post-ruminal protein absorption and thus lowered protein availability (Silanikove *et al.,* 2001). Silanikove *et al.* (2001) also reported that, some herbivores have also developed survival strategies e.g. the ability to select certain parts of the plants or to develop microbial populations capable of minimizing anti-nutritive factors such as the destruction of limousine and some tannin from tanniferous plants. Anti-nutritive factors are often associated with woody plants rather than grasses (Scalbert, 1991). Many woody plant leaves contain various levels of anti-nutritional factors that have an affinity for carbohydrates, amino acids and minerals rendering them unavailable for rumen micro-flora and the animal (Silanikove *et al*., 2001; Makkar, 2003). Tannin could exhibit both negative and positive effects on nutritive value depending on the amount in the browse (Scalbert, 1991).

2.9. Major anti-nutritional factors in browse trees

Anti-nutritional factors are a chemical compounds synthesized in natural food and / or feedstuffs by the normal metabolism of species (Makkar, 2003). These anti-nutritional factors are also known as ‘secondary metabolites’ in plants and they have been shown to be highly biologically active (Habtamu and Nigussie, 2014). According to Smitha *et al.* (2013) Anti-nutritional factors (ANF) are compounds which reduce the nutrient utilization and/or food intake of plants or plant products used as human foods or animal feeds and they play a vital role in determining the use of plants for humans and animals

The toxicity due to the consumption of various forages is very common among the farm animals (Soetan and Oyewole, 2009). Anti-nutritional factors may be divided into two major categories. They are: (1). Proteins (such as lectins and protease inhibitors) which are sensitive to normal processing temperatures (Makkar, 2003). (2). Other substances which are stable or resistant to these temperatures and which include, among many others, polyphenolic compounds (mainly condensed tannins), non-protein amino acids and galactomannan gums (Osagie,1998). The major ones includes: toxic amino acids, saponins, cyanogenic glycosides, tannins, phytic acid, gossypol, oxalates, goitrogens, lectins (phytohaemagglutinins), protease inhibitors, chlorogenic acid and amylase inhibitors (Akande *et al.,* 2010). More often than not, a single plant may contain two or more toxic compounds, generally drawn from the two categories, which add to the difficulties of detoxification. According to Aletor (1993), there are several anti-nutritional factors that are very significant in plants used as animal feeds and some most common ones with their mechanism of toxicity and impact on animal health and productivity.

2.9.1. Tannins

Tannins are defined as water soluble phenolic compounds of plants with molecular weight between 500 and 3000 Daltons (Akande *et al.,* 2010). All tannins are phenolics but not all phenolics are tannins (Makkar, 2003). Tannins can be distinguished from other polyphenolic compounds by their ability to precipitate gelatine and other proteins from aqueous solution (Silanikove *et al*., 2001; Makkar, 2003). Tannins have a property of binding to protein to form reversible and irreversible complexes due to the existence of a number of phenolic hydroxyl groups (Patra and Saxena, 2010).

Tannins have negative effect on protein metabolism and decrease palatability of feeds at high levels (Barry and Manley, 1986; Bryant *et al*., 1992) but at very low levels, most are beneficial (Foo *et al*., 1996; Makkar, 2003). High levels of tannins are common in some woody plants such as *Acacia* species and *Dichrostachys* species (Mlambo and Mapiye, 2015). Condensed tannins and hydrolysable tannins are the two major classes of tannins (Barry and Manley, 1986). Condensed tannins are made up of flavan-3-ols linked via carbon-carbon bonds (Patra and Saxena, 2010; Makkar, 2003). They are also called proanthocyanidins because if treatment with acidic alcohol produces coloured anthocyanidin (Makkar, 2003).

Hydrolysable tannins are polyesters of phenolic acids (gallic acids, hexahydroxydiphonic acid and their derivatives) and d-glucose or quinic acid (Patra and Saxena, 2010; Makkar, 2003). Proanthocyanidins are the most common type of tannin found in forage legumes (Reed, 1995). The two types differ in their nutritional and toxic effects (Makkar, 2003). The condensed tannins have more profound digestibility-reducing effect than hydrolysable tannins, whereas, the latter may cause varied toxic manifestations due to hydrolysis in rumen (Akande *et al.,* 2010). According to Mueller-Harvey and McAllan (1992), tannins are heat stable and they decreased protein digestibility in animals and humans, probably either making protein partially unavailable or inhibiting digestive enzymes and increasing fecal nitrogen. Woody plants often have thorns, fibrous foliage and growth habits which protect the crown of the tree from defoliation (Patra and Saxena, 2010).

Plants synthesize tannins in order to defend themselves against insect, fungal and herbivores, also known as ‘defence’ theory (Patra and Saxena, 2010). The proposed mechanism of defence is their astringent taste and their ability to interfere with digestive enzymes of predators (Mueller-Harvey and McAllan, 1992; Makkar, 2003). Tannin synthesis depends on plant cell vacuole differentiation and exogenous factors (Mueller and McAllan, 1992).

In addition seasonal effects, light intensity, temperature and soil fertility has been concerned in tannin synthesis (Mueller and McAllan, 1992). Anti-nutritional factors act within the animal’s digestive system by binding to substrate which can be protein, carbohydrates, lipids, minerals and vitamins (Haslam, 1993 and Norton, 1994). Anti-nutrients can also prevent digestive enzymes or can be antimicrobial (Scalbert, 1991, Asfari *et al.*, 1993). Goats are capable of selecting low tannin containing older growth on browse and leave out current’s season growth which has higher tannin content (Mueller-Harvey and McAllan, 1992). Sikosana *et al.* (2002b) reported that high levels of tannins in *Acacia nilotica* reduced growth rates of animals due to lower feed intake and protein digestibility. The effect of tanniferous feeds on milk fat and protein composition varies markedly depending on the concentration of tannins present in the feeds (Vasta *et al.*, 2008; Mlambo and Mapiye, 2015). These compounds are present in numerous tree and shrub foliages, seeds and agro-industrial by-products (Dube *et al.*, 2004).

2.9.2. Saponins

Saponins are secondary compounds that are generally known as non-volatile, surface active which are widely distributed in nature, occurring primarily in the plant kingdom (Avato *et al.,* 2006; Umaru *et al.,* 2007**)**. They are structurally diverse molecules and consist of non-polar aglycones coupled with one or more monosaccharide moieties (Jenkins and Atwal, 1994; Habtamu and Ngusse, 2014). This combination of polar and non-polar structural elements in their molecules enlightens their soap-like behavior in aqueous solutions (Jenkins and Atwal, 1994).

The structural complexity of saponins results in a number of physical, chemical, and biological properties, which include sweetness and bitterness, foaming and emulsifying , pharmacological and medicinal, haemolytic properties, as well as antimicrobial, insecticidal activities (Habtamu and Ngusse, 2014).

Saponins reduce the uptake of certain nutrients including glucose and cholesterol at the gut through intra-luminal physicochemical interaction. Hence, it has been reported to have hypo cholesterol emic effects (Umaru *et al.*, 2007). In chickens saponins have been reported to reduce growth, feed efficiency and interfere the absorption of dietary lipids and vitamins (A & E) (Jenkins and Atwal, 1994). Saponins are among several plant compounds which have beneficial effects and among the various biological effects of saponins are antibacterial and antiprotozoal (Avato *et al.,* 2006**).**

2.9.3. Cyanogens

Cyanogens are glycosides of a sugar or sugars and cyanide containing aglycone (Sarah, 2007). It can be hydrolysed to release HCN (hydrogen isocyanide/ hydrocyanic acid) by enzymes that are found in the cytosol (Smitha *et al., 2013*). Damage to the plant occurs when the enzymes and glycoside form HCN. The hydrolytic reaction can take place in the rumen by microbial activity. Hence, ruminants are susceptible to CN (Cynodine) toxicity than non- ruminants (Smitha *et al., 2013*). The HCN is absorbed and is rapidly detoxified in the liver by the enzyme rhodanese which converts CN to thiocyanate (SCN).Excess cyanide ion inhibits the cytochrome oxidase. This stops ATP formation, tissues suffer energy deprivation and death follows rapidly. The lethal dose of HCN for cattle and sheep is 2.0-4.0 mg per kg body weight (Sarah, 2007).

2.9.4. Alkaloids

Alkaloids are one of the largest groups of chemical compounds synthesised by plants and generally found as salts of plant acids such as oxalic, malic, tartaric or citric acid (Habtamu and Nigussie, 2014). Alkaloids are small organic molecules, common to about 15 to 20 per cent of all vascular plants, usually comprising several carbon rings with side chains, one or more of the carbon atoms being replaced by a nitrogen (Smitha *et al., 2013*). They are synthesized by plants from amino acids (Umaru *et al.,* 2007). Decarboxylation of amino acids produces amines which react with amine oxides to form ldehydes (Habtamu and Nigussie, 2014). The characteristic heterocyclic ring in alkaloids is formed from Mannich-type condensation from aldehyde and amine groups (Smitha *et al., 2013*).

The chemical type of their nitrogen ring offers the means by which alkaloids are sub classified: for example, glycoalkaloids (the aglycone portion) glycosylated with a carbohydrate moiety (Habtamu and Nigussie, 2014). They are formed as metabolic by products. Insects and herbivores are usual1y repulsed by the potential toxicity and bitter taste of alkaloids (Umaru *et al.,* 2007). Alkaloids are considered to be anti-nutrients because of their action on the nervous system, disrupting or inappropriately augmenting electrochemical transmission (Smitha *et al., 2013*). For instance, consumption of high tropane alkaloids will cause rapid heartbeat, paralysis and in fatal case, lead to death. Uptake of high dose of tryptamine alkaloids will lead to staggering gate and death (Smitha *et al., 2013*). Indeed, the physiological effects of alkaloids have on humans are very evident (Habtamu and Nigussie, 2014).

2.9.5. Protease inhibitors

Protease inhibitors are widely distributed within the plant kingdom, including the seeds of most cultivated legumes and cereals (Chunmei *et al.,* 2010). Protease inhibitors are the most commonly encountered class of antinutritional factors of plant origin. Protease inhibitors have the ability to inhibit the activity of proteolytic enzymes within the gastrointestinal tract of animals (Habtamu and Nigussie, 2014). Due to their particular protein nature, protease inhibitors may be easily denatured by heat processing although some residual activity may still remain in the commercially produced products (Smitha *et al., 2013*). The antinutrient activity of protease inhibitors is associated with growth inhibition and pancreatic hypertrophy (Chunmei *et al.,* 2010).

2.9.6. Nitrates

Nitrate toxicity of cattle was noted as early as 1895 with corn-stalk poisoning (Singh *et al.,* 2000). However, nitrate was not recognized as the principle toxicant during that period. In the late 1930s, after an outbreak of oat-hay poisoning in the high plains region, an indictment of nitrate was finally made (Launch Baugh, 2001). Some of the fodder crops such as Sudan grass, pearl millet (Andrews and Kumar, 1992) and oats (Singh *et al.,* 2000) can accumulate nitrate at potentially toxic levels. Nitrate poisoning is better described as nitrite poisoning.

When livestock consume forages, nitrate is normally converted in the rumen from nitrate to nitrite to ammonia to amino acid to protein (Singh *et al.*, 2000). When forages have an unusually high concentration of nitrate, the animal cannot complete the conversion and nitrite accumulates. Nitrite is absorbed into the bloodstream directly through the rumen wall and converts hemoglobin (the oxygen carrying molecule) in the blood to methaemoglobin, which cannot carry oxygen.

The blood turns to a chocolate brown color rather than the usual bright red (Benjamin, 2006). An animal dying from nitrate (nitrite) poisoning actually dies from asphyxiation, or lack of oxygen (Benjamin, 2006). Factors affecting the severity of nitrate poisoning are the rate and quantity of consumption, type of forage, energy level or adequacy of the diet. Benjamin (2006) reported that sheep and cattle fed poor diets seem to be more susceptible to nitrate poisoning.

2.9.7. Oxalate

Strong bonds are formed between oxalic acid, and various other minerals, such as Calcium, Magnesium, Sodium, and Potassium. This chemical combination results in the formation of oxalate salts (Habtamu and Nigussie, 2014). Oxalate is an anti-nutrient which under normal conditions is confined to separate compartments (Cheeke, 1995). However, when it is processed and/or digested, it comes into contact with the nutrients in the gastrointestinal tract (Cheeke, 1995). When released, oxalic acid binds with nutrients, rendering them inaccessible to the body (Rahman and Kawamura, 2011). If feed with excessive amounts of oxalic acid is consumed regularly, nutritional deficiencies are likely to occur, as well as severe irritation to the lining of the gut (Habtamu and Nigussie, 2014).

In ruminants oxalic acid is of only minor significance as an anti-nutritive factor since ruminal microflora can readily metabolize soluble oxalates (Habtamu and Nigussie, 2014). Various tropical grasses contain soluble oxalates in sufficient concentration to induce calcium deficiency in grazing animals. These include buffel grass (*Cenchrus ciliaris*), pangola grass (*Digitaria decumbens*), setaria (*Setaria sphacelata*) and kikuyugrass (*Pennisetum clandestinum*). Oxalates react with calcium to produce insoluble calcium oxalate, reducing calcium absorption. This leads to a disturbance in the absorbed calcium: phosphorus ratio, resulting in mobilization of bone mineral to alleviate the hypocalcemia.

Prolonged mobilization of bone mineral results in nutritional secondary hyperparathyroidism or osteodystrophy fibrosa (Rahman and Kawamura, 2011). Cattle and sheep are less affected because of degradation of oxalate in the rumen. However, cattle mortalities from oxalate poisoning due to acute hypocalcemia have occurred on setaria pastures and sheep have been poisoned while grazing buffel grass (Rahman and Kawamura, 2011). Levels of 0.5 per cent or more soluble oxalate in forage grasses may induce nutritional hyperparathyroidism in horses (Rahman *et al.*, 2009).

The oxalate content of grasses is highest under conditions of rapid growth with concentrations as high as 6 per cent or more of dry weight (Cheeke, 1995).Young plants contain more oxalate than older plants (Jones and Ford, 1972). During early stages of growth, there is a rapid rise in oxalate content followed by a decline in oxalate levels as the plant matures (Davis, 1981). Rahman *et al.* (2009) observed that the oxalate content of Napier grass can be manipulated by varying the harvesting interval, and that oxalate content declined as the harvest interval increased (Smitha *et al.*, 2013).

2.9.8. Phytate

Phytate, which is also known as inositol hexakisphosphate, is a phosphorus containing compound that binds with minerals and inhibits mineral absorption (Thava and James, 2001). The cause of mineral efficiency is commonly due to its low bioavailability in the diet. The presence of phytate in feeds has been associated with reduced mineral absorption due to the structure of phyate which has high density of negatively charged phosphate groups which form very stable complexes with mineral ions causing non-availability for intestinal absorption (Walter *et al*., 2002). Phytates are generally found in feed high in fibre especially in wheat bran, whole grains and legumes (Thava & James, 2001).

2.10. Mechanism of toxicity by anti-nutritional factors in browse trees.

Tannins may form a less digestible complex with dietary proteins and may bind and inhibit the endogenous protein such as digestive enzymes (Akande *et al.,* 2010). The tannin-protein complexes are astringent and adversely affect feed intake and all plants contains phenolic compounds but their type and concentration may cause negative animal responses (Smitha *et al.*, 2013). The concentration of condensed tannins above 4 per cent has been reported to be toxic for ruminants as they are more resistant to microbial attack and are harmful to a variety of microorganisms (Waghorn, 2008). It has been reported that saponins can affect animal performance and metabolism in a number of ways as follows: erythrocyte hemolysis, reduction of blood and liver cholesterol, depression of growth rate, bloat (ruminants), inhibition of smooth muscle activity, enzyme inhibition and reduction in nutrient absorption (Akande *et al.,* 2010).

Phytic acid acts as a strong chelator, forming protein and mineral-phytic acid complexes; the net result being reduced protein and mineral bioavailability (Khare, 2000). Phytic acid is reported to chelate metal ions such as calcium, magnesium, zinc, copper, iron and molybdenum to form insoluble complexes that are not readily absorbed from gastrointestinal tract (Waghorn, 2008). Phytic acid also inhibits the action of gastrointestinal tyrosinase, trypsin, pepsin, lipase and amylase (Khare, 2000). Similarly Oxalic acid binds calcium and forms calcium oxalate which is insoluble while trypsin inhibitors have been implicated in reducing protein digestibility and in pancreatic hypertrophy (Akande *et al.,* 2010).

2.11. Beneficial effect of anti-nutritional factors in browse trees foliage to livestock.

Tannins, protect proteins against excessive degradation in the rumen by forming reversible complexes with proteins (Makkar, 2003). These complexes are not degraded at pH values present in rumen (Butter *et al.,* 2000), but they disintegrate at pH values of the abomasum and small intestine (Jones and Mangan, 2003). The positive of tannin in animal feeing includes; increased efficiency of protein utilization, reduction of parasite burden, reduction of proteolysis during ensilage, bloat prevention, increase quality of animal products, reduction of nitrogen emission into the environment and defaunate rumen (Adesogan *et al.*, 2004). Condensed tannins (CT) have improved live weight gain, wool production and reproductive efficiency in sheep fed temperate forages and reduced the impact of gastro-intestinal parasitism (Makkar, 2003). However, their value is also linked to environmental issues, such as reducing nitrogen pollution from animals grazing lush pastures with a high nitrogen content and lessening methane emissions from rumen fermentation (Waghorn, 2008).

Saponins have shown a variety activities such antitumor, cholesterol lowering, immune potentiating, anticancer, antioxidants (Blumert and Liu, 2003) and to presser lower risk of implicated in coronary heart diseases (Ferri, 2009), and saponins potential as ointment hydrocarbon to shape of first collagen, as the protein have a role in recovery process of wound healing.

Potential beneficial effects of protease inhibitors remain unclear, although lower incidences of pancreatic cancer have been observed in populations where the intake of soybean and its products is high (Blumert and Liu, 2003). While protease inhibitors have been linked with pancreatic cancer in animal studies, they may also act as anti-carcinogenic agents (Chunmei *et al.,* 2010).

2.12. Methods to counteract the effect of tannins and other anti-nutritional factors in browse trees foliages.

Most tropical browse species used as animal feed contain substantial amounts of phenolic compounds, mainly tannins, as well as other secondary compounds (Makkar, 2003; Ben Salem *et al.*, 2005). The existence of tannins in the feeds could reduce their nutritional value, as tannins bind to feed proteins thereby making them unavailable to ruminal micro-organisms, but this negative effect depends on the kind of tannins (Makkar, 2003).

Mueller-Harvey (2005) concluded that hydrolysable tannins are harmful, but condensed tannins (CT) are safe as long as they account for less than 5% of the DM in feed. There is an inverse relationship between high CT level in forages (more than 50 g CT/kg DM) and their palatability, voluntary intake, digestibility and N retention in ruminants (Silanikove *et al.*, 1996).

However, a low level of tannin will improve nitrogen utilization by ruminants since many tannins can alter the site of protein digestion and thereby improve amino acid absorption (Jones & Mangan, 2003; Perez and Norton, 1996). This has been referred to as rumen escape protein and leads to higher growth rates, milk yield and fertility (Mueller -Harvey, 2005) since tannins form stable and insoluble complexes with proteins at pH 3.5-7.0, but these complexes dissociate at pH 7.5.

Russel and Lolley (1989) observed that treatment of tanniferous feed sources with alkalis (urea, sodium hydroxide, potassium hydroxide, etc.) and oxidizing agents (potassium dichromate, potassium permanganate, etc.) decreased their total extractable phenols contents. However, the main disadvantage of these chemical treatments is the loss of soluble nutrients (Makkar and Singh 1993) .Therefore, ways and means of eliminating or reducing their levels to the barest minimum should be discovered (Soetan and Oyewole, 2009**)**.

The use of polyethylene glycol (PEG)for which tannins have higher affinity than for proteins, is by far the most used reagent to neutralize these secondary compounds (Muller-Harvey, 2001). Most tannins are located in seed coats (skin) and hulls while fruit (meat nut) are practically tannin free (Shahidi and Nazck, 2004). Reductions in tannins contents of cow pea ranged from 6.7% to 68.5% in boiled, microwave cooked and autoclaved peanut seeds (Embaby, 2011). Soaking at ambient temperature had the least reduction (15%) while soaking at 60°C for 7h had the highest reduction (61%) of tannin contents in Tigernut (Adekanmi *et al.*, 2009*).*

The phytate molecule is negatively charged at the physiological pH and is reported to bind essential, nutritionally important divalent cations, such as iron, zinc, magnesium and calcium. This forms insoluble complexes, thereby making minerals unavailable for absorption (Frontela *et al.*, 2008). Longer time of boiling, microwave and autoclaving resulted in lower levels of phytic acid. Thus, autoclaving for 20 min was the most effective for phytic acid reduction (24.7% loss). Roasting of sesame is more effective (the reduction ranged from 15.6% to 22%) than boiling and microwave (the reduction ranged from 3.8% to 11.8%) for phytic acid.

Roasting can cause a significant reduction (the reductions up to 23.1 – 28.6 %,) in phytic acid contents of other seeds (Embaby, 2011). Similarly longer time of both boiling (for 40 min) and autoclaving (for 20 min) caused a complete inactivation of trypsin inhibitor activities, but the longer time of microwave (12 min) reduced trypsin inhibitor activities by 61.5% Boiling, simmering and blanching caused significant reduction in the level of cyanide content of *Moringa oleifera* leaves by 88.10%, 80.95% and 61.90% respectively (Sallau *et al.*, 2012). Boiling also reduces oxalate content *Arachis hypogaea* L (Groundnut) from 3.04 mg/g 2.62 mg/g, trypsin inhibitor from 0.12 TUI/g to 0.09 TUI/g (Mada *et al.*, 2012).

Sarangthem and Singh (2013) reported that phytate content of 35.95mg/100g and30.67mg/100g in fresh bamboo shoots of *Dendrocalamus hamiltonii* and *Bambusa balcooa* reduce to 22.46mg/100g and 24.12 mg/100g in the traditional fermented and laboratory fermented samples respectively. However, in the same report tannin content of 31.49mg/100g and 45.49mg/100g in fresh bamboo shoots of *Dendrocalamus hamiltonii* and *Bambus abalcooa* respectively increases to 68.21mg/100g and 52.00mg/100g fresh within the traditional and laboratory fermented samples.

Moreover, according to Bhat (2013), none of the methods have found to be successful in total alleviation/inactivation of tannins without the loss of nutritive values, hence this limits the utilisation of the vast amount of tanniferous plant materials as animal feeds. Polyethylene glycol (PEG) a tannin-neutralizing agent have long been used to improve the nutritive value of tanniferous feeds (Makkar, 2003a; Silanikove *et al*., 2001).PEG is a synthetic polymer over which tannins have higher affinity than for proteins, it dislocates tannin protein complexes and increases protein availability to microflora in the rumen of host animals (Makkar and Singh, 1992; Mlambo *et al*., 2015).

Decandia *et al.* (2000) found that PEG did not affect the diet intake but the CP digestibility of the diet increased from 37% without PEG to 71% with 50 g of PEG/day in goats fed *ad libitum* with foliage of *Pistacia lentiscu.* However, the high cost of this reagent limits its use in practice and in some cases utilization of alkalis, oxidizing agents and PEG could contribute to environmental pollution.

The benefits from the use of polyethylene glycol (PEG) as tannin inactivating agent are well documented (Table 2.3). PEG is an inert and unabsorbed molecule that can form a stable complex with tannins, preventing the binding between tannins and protein (Decandia *et al.,* 2000). Therefore, PEG releases forage proteins from tannin-protein complexes and improves their nutritional value leading to improved performance of sheep and goats. According to Ben Salem *et al.* (1999) the intake of *Acacia cyanophylla* by sheep increased as the level of PEG increased and PEG inactivated the condensed tannins in *Acacia cyanophylla*, thus improving microbial organism synthesis and growth of sheep.

Ben Salem *et al.* (2005) found that soaking Acacia in Acacia wood ash solution (120 g of wood ash DM/L of water, pH=12.4) decreased total extractable phenols, total extractable tannins and extractable condensed tannins, but also reduced OM and CP content. Feeding Acacia treated with wood ash solution did not affect intake and OM digestibility of the diet, but increased CP and NDF digestibility of Barbarine rams.

Table 2. 3. The use of polyethylene glycol (PEG) as tannin binder in goats.

Diet offered	**Inclusion rate of PEG**	**Findings**	**References**
***Acacia karroo*, *Acacia tortilis* and Ziziphus *mucronata*.**	20 g/animal/day	PEG increased use of tannin-containing woody plants. Unsupplemented goats spent more time grazing than browsing	Mkhize *et al*., 2015
Tifton 85 hay, which was replaced by *flemingia* leaf hay at 0%, 12.5% and 25% rates	60 g/animal/day	PEG increased intake and digestion of tannin-rich Flemingia leaf hay. No effect was observed on milk yield	Fagundes *et al*.,2014
Fresh evergreen branches (leaves and stems) of condensed tannin-rich *Arctostaphylos canescens*	5% - 3% body weight/day	Dosing with PEG increased feed intake, nutrient digestibility and weight gain	Narvaez *et al*.,2011
Mature and ripe *Dichrostachys cinerea* fruits (200 g/animal/day) milled through a 4-mm screen. 600 g/day grass hay	20 g PEG/100 g *Dichrostachys cinerea* fruit	Excessive protein degradation in the rumen leading to high urine N loss and low N retention values. Untreated fruits promoted higher N retention values	Mlambo *et al*.,2004
Air-dried tree fodder of *Acacia boliviana*,	5 g of PEG/1.5 Kg of each diet	Anti-nutritional factors were still operative	Maasdorp *et al.*,1999

In addition, wood ash has also been used in treating tannin rich feeds (Table 2.4) as it decreases the concentration of condensed tannins (Makkar and Singh, 1992).The alkaline pH of wood ash is said to overcoming the acute toxic effects of tannins or phenolic compounds (Muller-Harvey, 2006). The study of Muller-Harvey (2006) have also highlighted that wood ash have no effect on the nutritive value of the feed.

More importantly, activated charcoal has also been long used as an adsorbent to reduce various intoxications hence the study of Ben Salem (2005) suggested that activated charcoal could be a priori to deactivate tannins in tanniferous feeds. In addition the effect of activated charcoal on the nutritive value has not been studied. Hence, Bhat (2013) proposed that, a more cohesive and integrated detannification strategy is required for alleviating tannins for enhancement of the feeding value of tannin rich biomass. Likewise, Makkar (2003) suggested the need to investigate further effectiveness of the promising techniques through research studies.

Table 2. 4. The use of wood ash (WA) as a tannin binder in goats.

Diet offered	**Inclusion rate**	**Findings**	**References**
***Acacia nilotica* and *Dichrostachys cinerea* fruits**	10g Wood Ash 10g Wood Ash	- Reduced tannins by 75 and 96 % in *A. nilotica* and *D. cinerea* - Achieved 61 to 73 % inactivation of *D. cinerea* tannins, but only 3 to 28 % of *A. nilotica* tannins.	Makkar and Singh (1992)
***Acacia nilotica* and *Dichrostachys cinerea* fruits**	9 g Wood Ash 10g Wood Ash		Makkar and Singh (1992)
***Quercus incana* (oak) leaves**	10g Wood Ash 9 g Wood Ash	- 80 % decrease in the protein precipitating capacity of tannins	Price *et al*., (1979)
Oak and pine leaves		- Wood ash from oak and pine differed slightly in their potency.	

On the other hand, activated charcoal as a powder or as tablets has been widely used among humans for centuries to cure indigestion and, more importantly, as an antidote to detoxify poisons (Banner *et al.,* 2000). It is also used as an antidote in veterinary medicine (Cooney, 1995). Mturi (1991, 1993) suggested that the habit of eating wood charcoal by the Zanzibar red colobus monkey (*Procolobus kirkii*), which consumes a diet of foliages containing high levels of phenolic material, is known to reduce or eliminate such toxicity by binding part of the phenolic compounds to the charcoal, thus preventing their gastrointestinal absorption.

Charcoal has also been used in the diets for livestock to reduce anti-nutritional effects of secondary compounds in feeds (Poage *et al.,* 2000). According to Poage *et al.* (2000) lambs fed bitterweed (*Hymenoxys odorata*) alone consumed considerably less than lambs that received bitterweed with activated charcoal and higher doses of activated charcoal resulted in higher consumption of bitterweed. The effects of charcoal on elimination of harmful substances are reported to be due to the adsorption of a wide range of compounds such as phenols, alkaloids and salicylates (Banner *et al.,* 2000; Poage *et al.,* 2000; Struhsaker *et al.,* 1997).

2.13. The effect of supplementing trees browse to small ruminants.

The goat (*Capra hircus*) is shown to have been one of the first animals to be domesticated by humans, about 7000 BC in South West Asia (Peacock, 1996) then spreading into all the tropical zones and most temperate areas. The world goat population is estimated at 790 M and most (96%) are found in developing countries (FAO, 2006) where they are of great importance. Goats are usually kept by poor people (often women in some areas) to whom they provide useful products and services. Goat milk is highly nutritious and has a similar nutritional profile to human milk (Peacock, 1996). All these attributes lead to the connotation that the goat is “a poor man’s cow” (Mahatma Gandi, great Indian Leader) quotation taken up by Peacock (1996) who qualified it as “a poor person’s bank.

Goats are natural browser, feeding by preference on tree leaves, flowers, fruits/pods and even the woody stem of trees. Their small mouth and mobile upper lip and tongue enable them to pick small leaves between thorns, flowers, fruits and others plants parts, thus choosing only the most nutritious available feed. Goats are shown to eat preferentially at heights between 20 and 120 cm above ground and can stand on their hind legs or even climb trees to reach the best forage. They are known to feed on a wide variety of forages, and the choice is influenced by the diversity of feeds available. This attitude seems to be related to the need to maintain the rumen environment within a certain physiological and microbiological range (Morand-Fehr, 2005).

However, they seem to not thrive well when kept on a single type of feed for any length of time (Devendra and McLeroy, 1982). The feeding strategies of goats, reported by Luginbuhl and Poore (1998), consist of selecting grasses when the protein content and the digestibility are high, but switching to browse when their nutritive value may be higher. However, where browse is not available, goats can feed on grasses and crop residues such as cereal straws, but tend to prefer less coarse grasses (Devendra and McLeroy, 1982). According to Luginbuhl and Poore (1998) goats are not able to digest cell walls as well as cattle because the feed stays in their rumen for a shorter period of time. On the other hand, Morand-Fehr (2005) reported similar retention time of feed particles in the digestive tract of sheep and goats eating the same quantity of good quality forage, but the retention time of goats receiving poor quality forage was longer. Hence sheep and goats have similar patterns of digestion of moderate to high quality forages, but goats are better in digesting forages rich in cell walls and poor in nitrogen. This is attributed to their ability to recycle urea nitrogen (Silanikove, 2000). In addition, goats are efficient in the use of water and have a low rate of water turnover per unit of body weight (Devendra and McLeroy, 1982). The adaptation of goats to water shortage in hot environments in the tropics has been explained by low water turnover and the ability to resist desiccation (they do not sweat, and lose less water in faeces and urine).

The DM intake of goats, indicating the capacity to utilise feed voluntarily, depends on the breed (meat or milk) and the environment. Thus in the tropics, intake of 4 to 5% of live weight has been reported for dairy goats and 3% for meat goats (Devendra and McLeroy, 1982). The growth rate and mature weight of goats vary widely in different parts of the world, due to differences in breeds and level of nutritional management. However, Luginbuhl and Poore (1998) noted that the goat has lower rate of weight gain and do not fatten like cattle and sheep; thus to achieve maximum potential, goats need high quality feed and require optimum balance of many different nutrients.

Goats, with their habits of browsing, were able to collect more nutrients from the environment. They are also shown to adapt much faster than cattle or sheep to seasonal and geographic variations, which has resulted in them being termed as mixed feeding 'opportunists' (Lu, 1988). Silanikove *et al.* (1996) concluded that goats have the ability to consume large amounts of tannin rich plants without exhibiting toxic syndromes (due to a detoxifying enzyme in the saliva), which is not the case for other ruminant species.

Various studies have supplemented goats with browse feeds (see Table 2.5.). According to Yayneshet *et al.* (2008) Supplementation of *Dichrostachys cinerea* pods at different levels of 0.5 %, 1.0 % and 1.5 % to growing Abergelle goats browsing in the lowlands of Ethiopia, a highest DM intake of 84.6 g/day$^{-0.75}$ BW and gain of 21.7g/day was recorded for the group that received 1.5 % *D. cinerea* fruits than in other groups. In a different study by Sikosana *et al*. (2002a) various browse fruits that includes *Acacia erioloba, Acacia erubescens, Dichrostachys cinerea, Acacia nilotica and Acacia tortilis* fruits were fed to indigenous castrated males. Animals investigated were restricted to receive a maximum of 200 g pods per day per goat to determine their growth performance and carcass characteristics (Sikosana *et al*. 2002a). The results showed that goats offered *A. nilotica* and *D. cinerea* pods had higher growth rate of 13.3 and 4.8 g/day, respectively, than in other treatments. Goats offered with A. *nilotica* (-27 g/day), A. *erioloba* (-3.3g/day) and A. *erubescens* (-1.9g/day) had significantly lower weights. According to Sikosana *et al*. (2002a) the reason for lower growth in *A. nilotica* group was due to high amount of anti-nutritional factors in the fruits.

According to Sikosana *et al*. (2002a) similar browse fruits were offered to determine the intake of indigenous castrated Matebele goats. The outcomes of the study showed that goats which received *D. cinerea* had higher intake of 844 g/day and *A. nilotica* with lowest of 491g/day than in other groups. Furthermore, the study by Maphosa *et al*. (2009), lactating Matebele does were supplemented with *Dichrostachys cinerea* pods containing 19 % CP. The result showed that kids from supplemented and not milked (SNM) group had higher ADG (103 g/day) than kids from not supplemented and milked (NSM) (85 g/day) and supplemented and milked (SM) (74 g/day) groups.

Maphosa *et al.* (2009) also concluded that the weaning weight of kids from SNM was higher (12.8 kg) than NSM (11.2 kg) and SM (10.2 kg) group. In comparison, does from SM group produced more milk yield of 308 ml/day than SNM (273 ml/day) group. In contrast, another study in Kenya by Lengarite *et al*. (2014) whole and milled *Acacia tortilis* pods were fed to lactating goats. The authors reported intake of 186 and 413 g/day and milk yield of 300 g/day and 349 g/day respectively. In addition, Ngambu *et al*. (2013) reported that, the supplementation of *Acacia karoo* fresh leaves on castrated kids had higher growth rate of 105 versus 43 g/day and meat quality than the non-supplemented goats.

Moreover, in a study by Krebs *et al.* (2007) to determine the effects of feeding *A. saligna*, treated with PEG, on feed intake, nitrogen balance and rumen metabolism in sheep, the result showed that for all dietary treatments ruminal ammonia levels were below the threshold for maximal microbial growth. Feeding *A. saligna*, without PEG, had a definite defaunating effect on the rumen (Krebs *et al.*, 2007).

Table 2. 5. The effect of supplementing different tree browse foliages on goat's performance.

Goat type	**Browse foliage**	**Foliage offered**	**Intake(gDM/day)**	**Weight gain (g/day)**	**Milk yield (ml/day)**	**Reference**
Small east Africa goats	*A. tortilis*	200g/day pods	882-95	82-87	300.349	Lengarite *et al*.,2014)
Xhosa lop eared goats	*A. karoo*	200g/day leaves	n.a	105-43	N/A	Ngambu *et al*.,2013
Matebele does and kids	*D. cinerea*	299g/day pods	SM	74	308	Maphosa *et al*.,2009
			SNM	103	-	
			NSM	85	273	
Castrated Matebele goats	*A. tortilis*	200g/day pods	n.a	13.3	N/A	Sikosana *et al*.,2002a
	A. nilotica		491	-27		
	D. cinerea		844	4.8		
	A. erubescens		669	-1.9		
	A. erioloba		731	-3.3		
Abergelle growing male goats	*D. cinerea*	0.5% pods	84.6	10.0	N/A	Yayneshet *et al*.2008
	D. cinerea	0.1% pods	83.8	15.8		
	D. cinerea	1.5% pods	94.3	21.7		

According to Krebs *et al.* (2007) it was therefore concluded that *A. saligna* was inadequate as the sole source of nutrients for sheep, even with the addition of PEG 4,000 or PEG 6,000. The anti-nutritional effects on the animals were largely attributed to the excessive biological activity of the phenolics in the *A. saligna* leaves. The study concluded that there is a need to determine other supplements that may be complimentary with PEG to enhance the nutritive value of *A. saligna* to maintain a minimum of animal maintenance.

Most outstandingly Mui *et al. (*2002), conducted a study in which diets with foliage of Flemingia (*Flemingia macrophylla*) or Jackfruit (*Artocapus heterophyllus)* were fed to goats with the objective to study nitrogen (N) balance and effect of a daily supplementation of polyethylene glycol (PEG) on intake and digestion. The study results of Mui *et al. (*2002) showed that the DM digestibility was highest (65.9-74.3%) for goats fed the SBM (Soybean meal) diet in both the dry and wet season. The DM digestibility of goats fed the Jackfruit and the Flemingia diets was similar in both the dry (58.6- 59.2% respectively) and the wet season (53.9-56.1% respectively). The CP digestibility was highest (73.0-73.6%) for the SBM diet followed by the Jackfruit diet (47.0-38.5%) and was lowest (36.8-30.0%) for the Flemingia diet in both dry and wet seasons, respectively.

The NDF digestibility was low for both the Jackfruit (36.4%) and Flemingia (38.0%) diets in the wet season. All diets resulted in a positive N balance. The N retention was highest (0.465-0.604 g/kg $W^{0.75}$) in the SBM diets and lowest (0.012-0.250 g/kg W0.75) in the Flemingia diet. Addition of PEG had no effect on feed intake for any of the diets. Mui *et al. (*2002) noted that PEG added in the Flemingia diet had a positive effect only on NDF digestibility, but the digestibility of the Jackfruit diet was significantly increased. According to Mui et al. (2002) Supplementation with PEG reduced digestibility and N retention of Flemingia, possibly because of the low tannin level, but increased digestibility and N retention for Jackfruit foliage. In addition the study of Ansah *et al*. (2016) conducted two separate experiments to investigate the effect of tanniferous (CT) browse plant supplementation on the growth, nutrient digestibility and blood biochemical properties of Djallonké sheep.

The study results disclosed that In experiment I, whereas lambs supplemented with the highest condensed tannin (CT) browse plant (*C. Pentandra*) had improved ($P<0.05$) ADWG (Average

Daily Weight Gain) compared to the control, it did not differ from the ADWG reported in lambs that were supplemented with A. *lebbeck* even though it did not contain measurable levels of Condensed Tannins (CT). The blood metabolites did not differ among treatments.

Ansah *et al*. (2016) noted that lambs fed with *S. siamea* ration had the lowest DMI (Dry Matter Intake) with the highest reported in *G. arborea*. Lambs fed with *A. lebbeck* had the highest (P<0.05) CP digestibility and nitrogen balance. The lowest NDF and ADF digestibility were obtained in animals fed the *G. arborea* diet. The author described that the tanniferous browse plants used in this experiment were high in nutritive value and resulted in improved live weight of lambs hence recommended that such diets could be fed as supplement to lambs grazing natural pasture during periods of feeds scarcity.

2.14. Digestibility of browse forages

Studies on the digestibility of browse fodders are very significant as they allow the estimation of nutrients really available for animal nutrition. Oba and Allen (2005) noted that, digestibility of the feeds can be measured in terms of digestible energy (DE), digestible organic matter (DOM) and digestible dry matter (DDM). Digestibility can also be measured through total digestible nutrients (TDN) as an indirect way for estimation of feed digestibility (Dynes and Schlink, 2002).The *in vivo* technique is the classical and direct method for estimating feed digestion by animals (Reed, 1995; Dynes and Shrink, 2002). However, due to difficulties (time consuming, tedious, and costly) in its application, indirect methods are frequently used. Most of the studies on digestibility of browse fodders used the *in vitro* technique, which provides a comparative estimate of DMD and can be used to rank the quality of the feed.

The *in vitro* gas production (Menke and Steingass, 1988) method has been used by a number of scholars as it is considered quick and less expensive compared to *in vivo* studies (Babayemi *et al.*, 2009). However, *in vitro* method is limited as it does not take into account the intake of forage by the animal. The *in Sacco* method (López *et al*. (1991, 1999)) has the advantage of measuring the rate of digestion of different feed components (protein and starch) through nylon bags suspended in the rumen, and can also be used to rank feeds (Gutteridge and Shelton, 1998). However *in Sacco* method is known to usually overestimate *in vivo* digestibility (Gutteridge and Shelton, 1998). Scholars have also advanced cheaper and faster techniques for measuring neutral detergent fiber digestibility (NDFD) such as using Near Infrared Reflectance Spectroscopy (NIRS).

The factors involved in the variation in digestibility among browse fodders include the concentration of N, cell wall content, especially lignin, and tannins (Moore and Jung, 2001). A low level of CP (less than 80 g/kg DM) is shown to depress digestibility, as it is not sufficient to meet the needs of the rumen bacteria (Norton, 1998).On the other hand, low NDF content (20 to 35%) has been shown to result in high digestibility, while lignification of the plant cell wall decreases the digestibility of plant material in the rumen (Moore and Jung, 2001).

The unprocessed woody materials were considered indigestible by ruminants (Millet *et al,* .1970), but using various chemical or physical treatments, their digestibility were markedly increased. Saarinen *et al.* (1959) reported the *in vivo* digestibility of wood pulp, ranging from 0.27 to 0.90 depending on the lignin content. The *in vivo* digestibility of bleached (Lignin erased and the pulp whitened) chemical pulp fines from mixed wood was 0.78 for DM and 0.86 for carbohydrates (Millet *et al,* .1973) indicating that the material had high energy value for ruminants. Many studies (Buxton and Redfearn, 1997; Moore and Jung, 2001) have reported a negative correlation between lignin concentration and cell wall digestibility by its action as a physical barrier to microbial enzymes. Negative correlations between tannin and protein or DM digestibility have also been studied (McSweeney *et al.*, 1999; Balogun *et al.,* 1998). Hence information on the NDF, ADF, lignin and tannin content of tree foliage is essential for the assessment of their digestibility. A wide range of variation in digestibility is reported in tropical browse species. Breman and Kessler (1995) showed a mean OMD of 0.53 in Sahelian and Sudanian zones of West Africa. Le Houerou (1980) reported a mean DCP of 510 g/kg for West African browses, with 760 g/kg for legumes. Fall (1991) reported large variations in DMD, ranging from 0.26 to 0.88 between species and plant parts. Sanon (2007), reported high OMD (0.56 to 0.66 g/kg) and CPD (0.64 to 0.73 g/kg DM) compared to the mean values reported by other authors for West African browses. The digestibility values were somewhat higher for the pods than the leaves (except CPD of the leaves of *P. lucens*). Fall (1991) also found the pods of some Acacia species more digestible than the leaves (*A. albida* and *A. tortilis*).

Many studies focusing on woody plants nutritive value however have been limited to chemical composition regardless of past recommendations (Le Houerou, 1980) that priority research should be given to intake and digestibility studies. Result from *in vitro* studies such that of Lucia (2016) showed that 17 indigenous woody plants in Namibia have higher DM contents mostly in January (963±2.43 g/kg) and lower in September (929±2.30 g/kg), while high levels of NDF in this woody plant species were recorded at 410.4±15.18 in January and 406.3±14.35 in September respectively. According to Lucia, the leaves of *A. mellifera* were digested at lowest rate 0.068 /hour and *C. apiculatum* highest (0.236 /hour).

In another study, Boufennara *et al.* (2012) reported that monocot showed lower *in vitro* and *in Sacco* digestibilities, fermentation rate, cumulative gas production and extent of degradation than dicotyledonous species. Mui *et al. (*2002) reported similar DM digestibility of goats fed the

Jackfruit and the Flemingia diets in both the dry (58.6- 59.2% respectively) and the wet season (53.9-56.1% respectively) whereby, both the Jackfruit (36.4%) and Flemingia (38.0%) diets had low NDF digestibility in the wet season (Mui *et al.,* 2002).

2.17. Conceptual framework /inference from literature

Browse plant species quoted in the collected works are imperative fodder for livestock, they present a foreseen livestock feed industry since they are densely populated in the rangelands which resulted in a phenomenon called bush encroachment in Namibia. This includes species such as; *Senegalia mellifera, Dichrostachys cinerea, Terminalia sericea, Terminalia sericea, Colophospermum mopane* and *Rhigozum trichotomum* in the southern part of the country.

The above mentioned browse plant species contribute substantially to the nutrition of livestock, even though increasing number of bush densities resulted in loss of land productivity and reduced carrying capacity. However, animals heavily depend on these browses as source of fodder especially during the dry season; therefore, complete removal should not be considered. Past and current studies provided a lot of evidence on woody browse as an alternative feed resource for livestock, locally available and inexpensive and good source of protein that do not compete with human food.

Literature have revealed the nutritional value of woody species, been estimated from one browse to another, their leaves, fruits or pods using different method. Scholars have also highlighted the nutritive value of woody plants as determined by various factors such as type of browse, chemical content, stage of maturity or season, climatic condition and nutrients in the soil. Crude protein content in fruits and pods tended to be high than other part of the plant, however feeding value are low when the fibre and lignin content are high Tannin content also tended to be high in fruits and young leaves. Such trees also maintain sufficient nutritional level during critical times of the year and available in dry season. Soil nutrient influence the chemical content of the browse indirectly especially in minerals thus mineral supplementation is recommended on browsing animals.

Various studies which had embarked on browse as feed supplements reported beneficial nutritional effects including increased growth in young animals, improved milk production and meat quality and fatty acid composition, improved fibre and wool quality, minimized internal parasitic load in small ruminants and reduced methane and ammonia emissions.

To recapitulate, woody browse have been reported to contain varying amount of anti-nutritive factors, such that if animals consume large quantities of tannin rich feeds may cause toxicity. Browse processing techniques such as the use of tannin-binding agents such as polyethylene glycol (PEG) have been shown to be effective, while recommendations are focused on exploring local treatments such as the use of wood ash and activated charcoal. Their acceptance in subsistence farming could be inhibited with availability and affordability. Therefore, appropriate feeding strategies have been emphasized based on the nutritional evaluation of the woody browse foliages.

CHAPTER 3:

THE CHEMICAL COMPOSITION OF *S. MELLIFERA* MILLED BIOMASS COLLECTED IN NINE BLOCKS AT NEUDAMM FARM.

3.1. Introduction

Browse plants are an important feed resource during the dry season in Southern Africa, when grass biomass and quality is low (Ndlovu and Nherera, 1997). There has been limited animal feeding trials conducted with woody plant browse in Southern Africa (Smith *et al*., 2005b), because of the efforts, cost involved and the difficulty in collecting sufficient quantities of potential browse species. Many studies (Ndlovu and Nherera, 1997; Osuji and Odenyo, 1997; Dube et al,. 2001; Osuga et al,. 2007; Makkar *et al*,. 2007) on nutritive value of woody species have been limited to chemical composition regardless of past recommendations (Le Houerou, 1980) that priority research should be given to *in vivo* digestibility studies.

Numerous browse species have been evaluated as alternative feed resources as protein supplement during dry season (Ndlovu, 1997; Osuji and Odenyo, 1997; Dube *et al*,. 2001; Osuga *et al*,. 2007; Makkar *et al*,. 2007). Tree and shrub species that produce both leaves and pods thus contribute substantially to the diets of livestock (Sikosana *et al*., 2002b). Browse plants are reported to be of good nutritive value ranging between 100- 280 g/kg of CP and low to medium content of NDF from 110- 646 g/kg (Sibanda and Ndlovu, 1993).

In addition to woody plants potential to provide fodder for livestock, they are believed to contain anti-nutritional factors which have varied animal response when ingested (Mueller-Harvey, 2006). Larbi *et al. (*1998) reported data on nutritive value and the seasonal variation in quality of some browse plants in West Africa. The *Senegalia mellifera* species has been identified as the dominant encroacher specie in the Namibian rangelands (de Klerk, 2004; MAWF, 2014 and SAIEIA, 2016). However, its potential as a potential feed supplements for livestock during the dry period in Namibia has not been evaluated (Honsbein, 2016). Therefore, the objective of this study was to evaluate the nutrient and anti-nutrient contents of *Senegalia mellifera* leaves and twigs (less than 5 cm) fractions at Neudamm farm.

3.2. MATERIALS AND METHODS

3.2.1 Study location

This study was conducted at Neudamm Farm, located 30 km east of Windhoek, in the highland savanna of Namibia (Figure 3.1). Neudamm Campus (Figure 3.2) lies between 22^o and 23.30^{o}S and 15.30^o and 18.30^{o}E. The vegetation type in this area is classified as highland savanna (semi-arid savanna) (Figure 3.1). The average annual rainfall around Neudamm ranges from 350-400 mm, with much of the rain experienced during summer season (January-April) (Mendelsohn *et al.*, 2002). The soil is dominated by homogenous Lithic Leptosols and Eutric Regosols soil types.

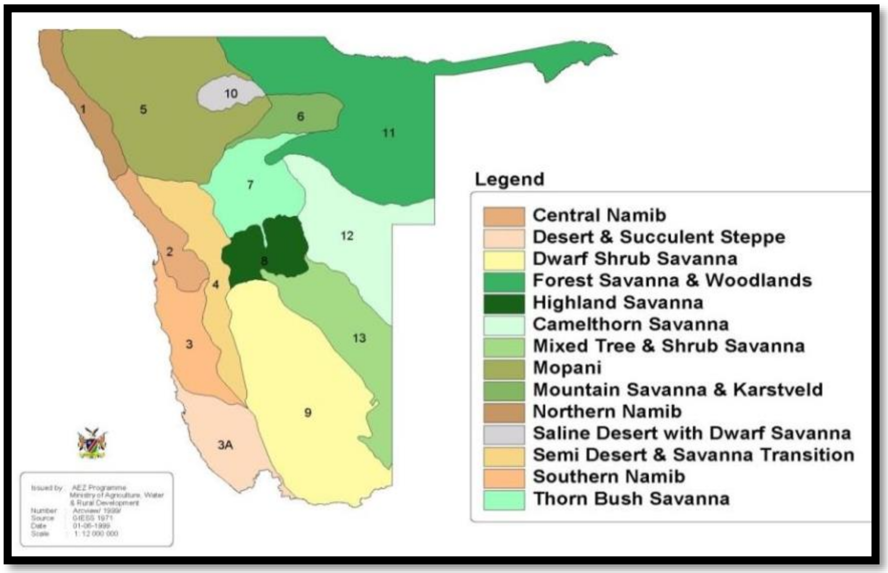

Figure 3. 1.Vegetation types in Namibia depicting the highland savannah (Source: MAWF, 2003).

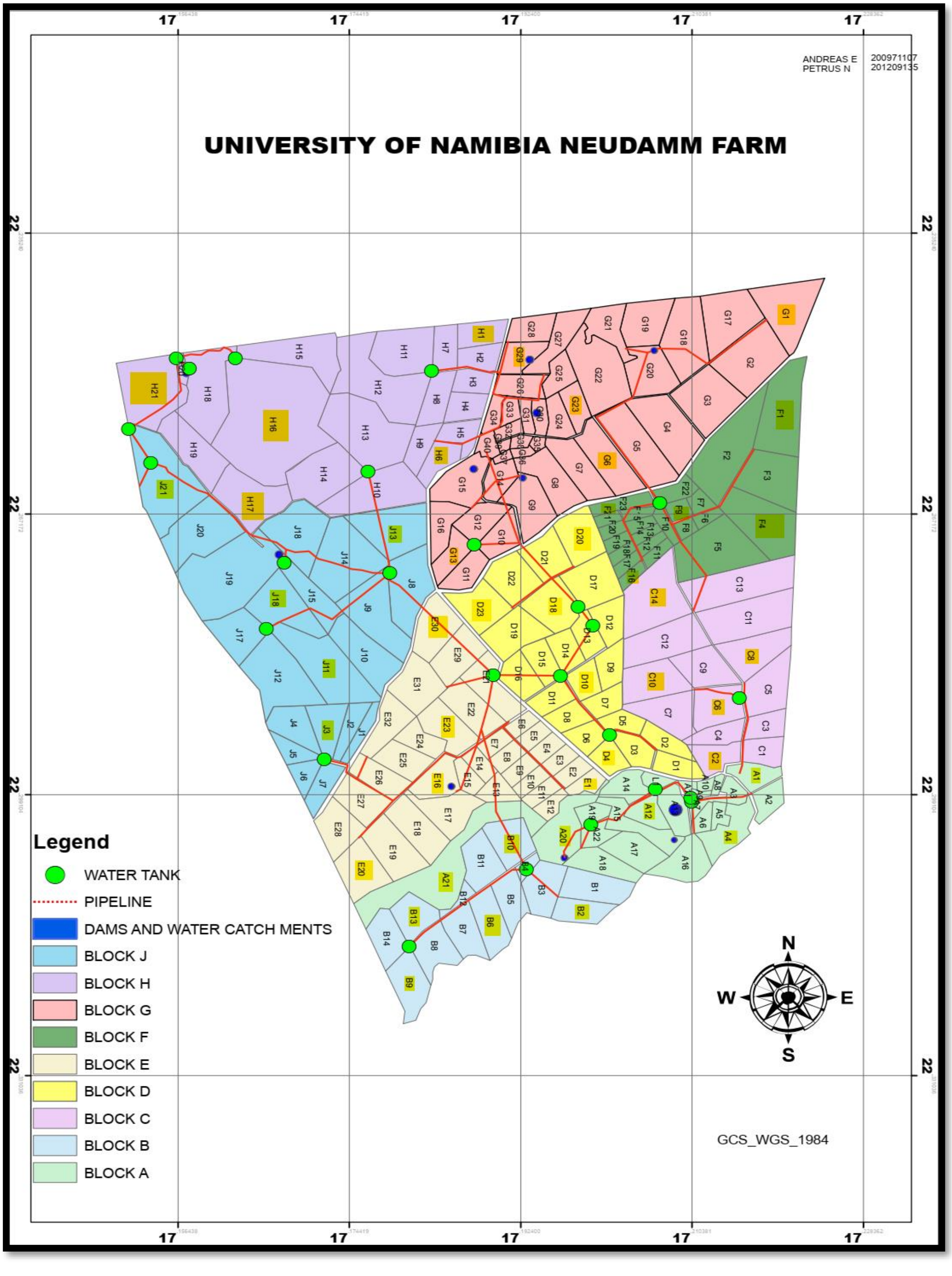

Figure 3. 2. Neudamm farm map (Source: Neudamm Farm, 2018).

3.2.2. Sample collection and procedure

The plant samples used in this study were collected at Neudamm farm (Figure 3.2.). The plant species *Senegalia mellifera* was selected based on its abundance in the area, preference, and accessibility to browsing livestock and game animals. The samples collected were mainly a composition of leaves and twigs of less than 5 cm diameter. Samples were collected through a purposive sampling which is a non-probability sample that is selected based on characteristics of a population. This was achieved by selecting five camps in each of the nine blocks (5 camps in each of the 9 blocks = 45 camps) (Figure 3.3) for the whole area, whereby two belt transects measuring 50m x 2m were laid in each camp and in each of the belt transect 5 plants of *Senegalia mellifera* were chosen randomly and twigs less than 5 cm diameter were harvested. Samples for each transect were combined and this resulted in a total of two samples per camp and an overall of ninety samples, from the 45 camps sampled, of *Senegalia mellifera* leaves and twig fractions. The samples were stored for a week in grey paper bags and shade dried in a warehouse at ambient temperatures. The samples were collected in the month of March to May 2018. The sampled camps in the 9 blocks are shown in Figure 3.3 below.

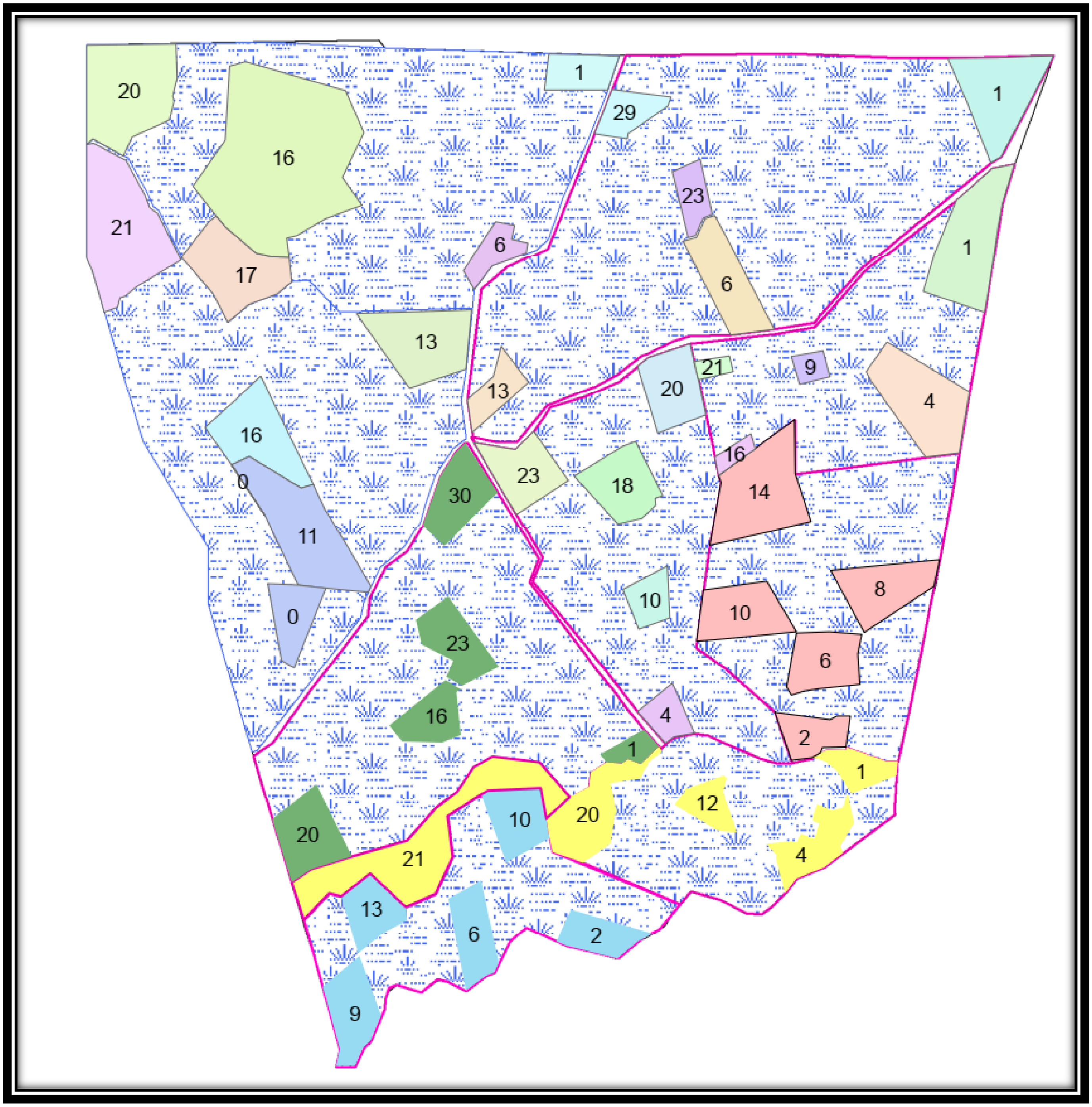

Figure 3. 3. The sampled camps in each block (Source: Neudamm farm).

3.2.3. Chemical analysis

The shade dried *Senegalia mellifera* samples were milled to pass a 2mm sieve screen using a laboratory bench mill. The milled samples were analysed for Dry matter (DM) content by placing the sample in the oven at 105° C for 5 hours (AOAC, 2007). Total ash was obtained by igniting the samples in a muffle furnace at 550° C overnight and the remaining residue was ash. Organic Matter (OM) was calculated by the difference of DM and Ash values. Total Nitrogen (N) was determined by Kjeldahl method and crude protein was obtained by calculating N x factor 6.25. Neutral detergent fibre (NDF) and acid detergent fibre (ADF) was determined as described by van Soest *et al.* (1991). Hemicellulose was calculated as the difference of NDF and ADF. Calcium (Ca) and Phosphorus (P) elements were analysed using the Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) Model; ICAP 6000) (Thermo Fischer Scientific, Bremen, Germany) and the UV-VIS Spectrometer (GR 6000). Total phenols (TP) were analysed using the Folic-Ciocalteu method of Makkar *et al.* (1993), coupled with the use of insoluble matrix, polyvinyl polypyrrolidone (PVPP) for measurement of Total tannins(TT) using a Standard tannic acid solution ($y = 0.0192x + 0.0203$; $R^2 = 0.9996$; Absorbance at 725 nm) and results were expressed as tannic acid equivalent on a dry matter basis Condensed tannins (CT) were determined using the butanol-HCL method ($y = 0.0411x + 0.0057$; $R^2 = 0.9986$; Absorbance at 550 nm) of Porter *et al.* (1986) expressed as (% in dry matter) as leucocyanidin equivalent. All analysis were performed in duplicates.

3.2.4. Statistical analysis

Chemical composition data means were compared in a one way analysis of variance using SPSS version 2.2 of 2010. The differences in the chemical composition means were established by the

Duncan’s new multiple range test (Steel and Torrie, 1980). Unless or otherwise indicated, significance was declared at $p < 0.05$.

3.3. RESULTS

The chemical composition results of *Senegalia mellifera* milled biomass are presented in Table 3.1 and the results showed that there was a significant difference ($p < 0.05$) in nutrient content of *Senegalia mellifera* milled biomass harvested from the nine blocks. The DM content of the *Senegalia mellifera* milled biomass was high ($p<0.05$) in Block C (94.70%) with block J and D higher ($p < 0.05$) than A and B. Blocks E, F and G had the lowest DM content. The highest amount of ash was observed in Block G, C and A (5.97, 5.01 and 5.01 % DM, respectively). The milled biomass organic matter (OM) content was lower ($p<0.05$) in samples from blocks G, A and C compared to the other blocks. There was a significant ($p<0.05$) difference in the crude protein (CP) of the milled biomass from the nine blocks. Block B had the greatest ($p<0.05$) CP content while that of blocks F, H and J were the least. The ether extracts content varied significantly ($p<0.05$) among the nine blocks with values ranging from 1.17 to 1.51%.

The fibre fractions in the milled biomass from the nine blocks differed significantly ($p<0.05$).The Neutral Detergent Fibre (NDF) content was high ($p<0.05$) in Block F (64.33%) with Block D higher ($p<0.05$) than Block C and H. Block A, B, H, J and G had the lowest. The Acid Detergent Fibre (ADF) content from block A, B, C and E were similar ($p>0.05$) to that from the other blocks. The hemicellulose (HC) content was lower ($p<0.05$) in samples from blocks G (13.62%) and C (14.38%) compared to the other blocks. The mineral content among the nine blocks differed significantly ($p < 0.05$). The Calcium (CA) content was high ($p < 0.05$) in all blocks except block H (0.62%) with lowest Ca content. The highest amount of Phosphorus (P) was similar in Block A, B, D, E and F. The results for the phenolic composition of *Senegalia mellifera* milled biomass are presented in Table 3.2. The results showed that there was no significant difference ($p > 0.05$) in the phenolic content of *Senegalia mellifera* milled biomass harvested from the nine blocks. The Total phenols (TP) content of the bush feed was similar in all blocks ($p > 0.05$).The highest amount of Total Tannins content was observed in Block E (1.39%) but not significant different from other blocks ($p > 0.05$). The condensed tannins (CT) content of milled bush feed from all blocks did not differ ($p > 0.05$).

Table 3. 1.Chemical composition (%DM) of *Senegalia mellifera* milled biomass.

BLOCK ID	%DM	%ASH	%OM	%CP	%FAT	%NDF	%ADF	%HC	%Ca	%P
A	94.13±0.01^{cd}	5.01±0.16^{ab}	89.12±0.16^{ab}	9.60±0.00^{c}	1.51±0.01^{a}	60.88±0.21^{d}	44.02±0.06^{d}	16.86±0.1^{ab}	1.28±0.02^{a}	0.07±0.00^{a}
B	93.69±0.00^{d}	4.76±0.14^{b}	88.92±0.14^{a}	9.71±0.00^{a}	1.45±0.02^{ab}	60.49±0.1^{de}	43.77±0.11^{d}	16.72±0.20^{ab}	1.24±0.04^{a}	0.07±0.00^{a}
C	94.70±0.01^{a}	5.01±0.02^{ab}	89.69±0.02^{ab}	9.68±0.01^{b}	1.38±0.01^{c}	61.82±0.1^{c}	44.29±0.03^{d}	17.53±0.10^{a}	1.27±0.09^{a}	0.06±0.00^{ab}
D	94.27±0.02^{bc}	4.76±0.22^{b}	89.51±0.22^{a}	9.61±0.00^{c}	1.17±0.01^{d}	63.47±0.00^{b}	47.38±0.37^{b}	16.09±0.40^{b}	1.27±0.02^{a}	0.07±0.00^{a}
E	93.99±0.03^{de}	4.86±0.32^{b}	89.13±0.32^{a}	9.50±0.01^{d}	1.39±0.02^{bc}	61.97±0.3^{c}	44.71±0.05^{d}	17.25±0.23^{ab}	1.24±0.02^{a}	0.07±0.00^{a}
F	93.90±0.04^{e}	4.73±0.52^{b}	89.17±0.52^{a}	9.42±0.01^{f}	1.19±0.01^{d}	64.33±0.01^{a}	48.01±0.44^{a}	16.32±0.45^{ab}	1.17±0.01^{a}	0.07±0.00^{a}
G	93.95±0.00^{e}	5.97±0.18^{a}	87.97±0.18^{b}	9.47±0.02^{e}	1.39±0.04^{bc}	59.17±0.3^{ef}	45.55±0.29^{c}	13.62±0.60^{d}	1.24±0.00^{a}	0.04±0.00^{c}
H	93.82±0.10^{ed}	4.71±0.13^{b}	89.11±0.13^{a}	9.41±0.00^{f}	1.38±0.00^{e}	62.22±0.1^{c}	46.09±0.52^{c}	16.12±0.44^{b}	0.62±0.02^{b}	0.02±0.00^{d}
J	94.39±0.12^{b}	4.48±0.56^{b}	89.90±0.56^{a}	9.39±0.00^{f}	1.49±0.02^{a}	60.37±0.01^{e}	45.98±0.46^{c}	14.38±0.46^{c}	1.43±0.25^{a}	0.06±0.00^{b}

Legend: DM=Dry Matter; Ash; OM=organic matter; CP=Crude protein; FAT=crude fat; NDF= neutral detergent fibre; ADF=acid detergent fibre; HC=Hemicellulose; Ca= Calcium; P= Phosphorus. ^{abc} Mean with same superscripts in a column do not differ ($p > 0.05$).

Table 3. 2. Phenolic composition (%DM) of *Senegalia mellifera* milled biomass.

BLOCK ID	**TP** (%DM tannic acid equivalent)	**TT** (%DM tannic acid equivalent)	**CT** (%DM leucocyanidin equivalent)
A	1.12 ± 0.00^{a}	0.37 ± 0.01^{a}	0.03 ± 0.00^{a}
B	1.13 ± 0.00^{a}	0.39 ± 0.01^{a}	0.03 ± 0.00^{a}
C	1.12 ± 0.00^{a}	0.37 ± 0.01^{a}	0.03 ± 0.01^{a}
D	1.11 ± 0.00^{a}	0.38 ± 0.01^{a}	0.03 ± 0.00^{a}
E	1.13 ± 0.00^{a}	0.37 ± 0.01^{a}	0.02 ± 0.01^{a}
F	1.13 ± 0.00^{a}	0.37 ± 0.01^{a}	0.02 ± 0.01^{a}
G	1.12 ± 0.00^{a}	0.38 ± 0.01^{a}	0.03 ± 0.01^{a}
H	1.13 ± 0.00^{a}	0.39 ± 0.01^{a}	0.02 ± 0.01^{a}
J	1.12 ± 0.00^{a}	0.37 ± 0.01^{a}	0.02 ± 0.01^{a}

Legend: TP = Total phenols; TT= Total tannins and CT= Condensed tannins. ^{abc} Mean with same superscripts in a column do not differ ($p > 0.05$).

3.4. DISCUSSION

3.4.1. Chemical composition of Senegalia mellifera milled biomass.

Browse plants leaves and twigs often remain green until the dry seasons, thus have the ability to provide livestock with supplementary nutrients for maintenance, growth and reproduction. According to Fadel *et al*. (2002) and Osuga *et al.* (2007) the chemical composition of browse species has been reported to be variable due to the different proportion of leaves, petioles and twigs. Despite the significance of the analysis, the reported nutritional values of *Senegalia mellifera* bush feed of this study are almost similar to those reported by Honsbein *et al*. (2017) in Namibia.

The DM of *Senegalia mellifera* milled biomass (leaves and twigs less than 5cm) recorded in this study of 94.70 % was comparable to that recorded in Namibia by Lucia (2010) of 94.47 %in a study of *Senegalia mellifera* leaves and pods. The DM content observed in the current study was higher than 34.1% reported by Hauze and Tran (2015) in a study that focused on *Senegalia mellifera* leaves only.

The ash content of 5.97 % recorded in this experiment was closer to 6.59 % recorded by Lucia (2010) and lower than 9.0% recorded by Abofosian (2003). The 4 to 5 % of ash indicates a considerable amount of minerals available for livestock. The analysis of ash content is simply the burning out of organic matter content, leaving inorganic minerals. The determination of Ash is important as it reveals the physiochemical property of the feeds, as well as retard the growth of microorganisms.

The OM recorded in this study that range from 87.97% to 95.52 % was similar to that reported by Lucia (2010) of 87.88 %DM in Namibia and 88.1-92.4 % reported by Fadel *et al.* (2002) in mature

S. mellifera leaves in Central Sudan. The OM recorded was also comparable to 93% recorded by Abdulrazak (2000) in *S.mellifera* leaves in Kenya. A difference in the ratio of leaf to twigs in samples used for analysis could be partly responsible for the differences in the DM, Ash and OM contents of the bush feed.

The nutritional analysis of *Senegalia mellifera* bush feed shows that the crude protein (CP) which ranged from 9.39 to 9.71% were sufficient to meet the minimum maintenance requirements of 7-8% required for optimum rumen function and feed intake in ruminant livestock (Van Soest, 1994). Given the high CP content of the *Senegalia mellifera*, this fodder resource can be considered a suitable supplement for poor quality (low N content) natural pastures and crop residues such as grass hay, straw and stover (Osuji and Odenyo, 1997; Osuga *et al.*, 2007).

The crude fat (FAT) or Ether extract reported in the present study range from 1.38% to 1.51%. Crude fat content is estimated by extracting a ground feed sample with diethyl ether. The reported results are comparable to the crude fat content of 1.43 % recorded by Abofosian (2003). However, Le Houerou (1980) noted that ether extract is lower as nitrogen extract.

According to Abofosian (2003) the significance of the higher ether extract of shrubs is not understood. The neutral detergent fibre (NDF) in *S.mellifera* bush feed reported in this experiment ranged between 59.17 % and 64.33 %, which is higher in comparison with Lucia (2010) who reported an NDF value of 33.6 % *S.mellifera* leaves. In comparison to other browse species, NDF content was reported lowest (323 g/kg) in *Combretum apiculatum* (Lukhele and Ryssen, 2003) and higher in the leaves of *Terminalia sericea* (647 g/kg DM: Ndlovu and Nherera, 1997). The values of NDF were in the range as those reported by van Soest (1994) from 540 to 770 g/kg for different forage species. Abdulrazak (2000) reported a low NDF value of 26.9 %, while Fadel *et al*. (2002) reported 55.55 %. The neutral detergent fraction (NDF) of the diet describes those forage components that are slowly degradable in neutral solvent such as cellulose, hemicellulose and lignin. The acid detergent fibre (ADF) fraction includes cellulose and lignin. The ADF recorded in this study ranges from 43.77% to 55.55 %. According to Topps (1992) and IAEA (2006), higher values of cell wall fractions in forage have been attributed to woody twigs included during the analysis. The analysed samples constituted a big fraction of energy source hence it can be assumed that more energy would be released to the animal during digestion. Hemicellulose recorded in this experiment was calculated as the difference of NDF and ADF. Hemicellulose content recorded in this experiment ranges from 13.62 % -17.53 %. The recorded hemicellulose fraction was higher as compared to 7.8 % reported by Abdulrazak (2000). The recorded low to moderate fibre content of *S.mellifera* is assumed to benefit the voluntary intake and digestibility of poor quality roughage (Osuji and Odenyo, 1997).

The calcium (Ca) and phosphorus (P) content of 1.2% and 0.1%, respectively, obtained in this indicates a potential mineral content apart from others in the fractions available for animal's maintenance in periods of fodder shortage. According to literature, Browse species in most cases have much higher Ca: P than the requirements of the animal such as that described by Rubanza (2005) of (6.6:1-31.5:1) and Rubanza *et al*. (2006) of 13.8:1-55.1:1. Phosphorus levels for most browse species range from 1-5 g/kg DM as noted by Rubanza *et al.* (2006), Mtengeti *et al.* (2006) and Mtui *et al.* (2008). However, Abdulrazak *et al*. (2000) noted similarly ranges of Calcium and phosphorus as those reported in the present study of 1.2% and 0.1%. Abdulrazak *et al*. (2000) reported that in Acacia species, calcium and phosphorus ranges from 0.7-1.6 g/kg DM. Other authors also concluded that the minerals concentrations in browse species in most legumes have range from 0.1-6.6 g/kg DM (Abdulrazak *et al.*, 2000; Rubanza *et al.*, 2006; Mtengeti *et al.*, 2006 and Mtui *et al.,* 2008). Norton (1994) made similar observations and accounted the differences in chemical composition to harvesting regimes, soil type and age in addition to the aforesaid factors.

3.4.2. The phenolic composition of Senegalia mellifera milled biomass.

The concentration of Total Phenolic (TP) compounds in *Senegalia mellifera* fractions showed considerable less variation among the blocks. The highest Total phenolic (TP) concentration of 1.13g/DM recorded in block E, F and H, may not be due to the plant species only, but also to the time of sample harvest or season, plant maturity and growth stage (Barry, 1999; Makkar *et al.,* 2007). The results of the total phenols obtained provides another insight to evaluate and characterize all types of phenols that constitute the whole, apart from tannins that might all hinder nutrient utilisation in this promising forage materials.

The considerable less variation observed in the analysed fractions when considering the phenolic fractions could be related to the method of analysis (in this study Folin-Ciocalteu method was used to determine Total phenols (Makkar *et al.,*1993a),Tannins were determined by the use of insoluble matrix, polyvinyl polypyrrolidone (PVPP) and Condensed tannins were determined by the HCL-Butanol method by Porter *et al.(*1986), as the type and amount of tannins present in each substrate may have a different reactivity with the chemicals used for each method. The lack of accurate laboratory techniques and reliable compounds to be used as standards are major difficulties in the phenols analysis. Therefore, differences between this study tannin values and others reported in the literature could be due to the nature of the assays used, nature of tannin in different fodder species (Ammar *et al*,. 1999 and 2004; El Aich, 2004 and Alam *et al*,. 2007), standards used for the quantification, plant growth stage, and the influence of soil and climatic factors (Rubanza *et al.,* 2005).

A low content (1.11-1.13g/DM) of Total Tannins recorded in this study was in agreement with values reported by various authors (Al-Soqeer, 2008; Ben Salem *et al.,* 2010, Honsbein, 2018.). *S. mellifera* foliage have been reported that it contains tannins, however the reported tannin content is extremely variable (Fade *et al.,* 2002; Osuga *et al.,* 2007). Condensed tannins have been found to be present either in low amounts (0.2% DM, Osuga *et al.,* 2007 and Wambui *et al.,* 2012), or in much larger quantities: in Sudan, from 1.4% DM in the early dry season (late October) to 5.7% DM in the late dry season (early June) (Fadel *et al.,* 2002). Tannins are a subclass of plant polyphenols, which are distinguished from other polyphenols by their ability to form complexes with and precipitate proteins (Hagerman and Butler, 1978; Hagerman, 2012). Occurring tannins are traditionally broadly divided into two categories: hydrolysable (HT) and condensed tannins (CT), whose structures are distinctly different. Although tannins have been characterized predominately on the basis of their ability to bind proteins, reports dating back to as early as the 1930s describe tannins on the basis of "their astringent taste and for their many precipitation reactions with lime, lead acetate, alkaloids, gelatin, albumin, and other proteins, and also for their color reactions with iron salts" (Maitland *et al.,* 1936).

Many of these interactions with tannins and organic compounds or trace elements are still of interest today in agricultural research, especially where their potential impact on animal production is concerned. This is likely due to the many challenges and limitations associated with definitively answering questions related to the interactions of tannins in animal physiology and nutrition. It has become evident that furthering our understanding of using tannins in animal production is going to require a better understanding of the role of tannin chemistry in animal interactions. Perhaps this was evident in the 1920s, when Freudenberg put forth a classification scheme for tannins including HT, CT, and an unclassified group of tannins (Maitland *et al., 1936*), the latter suggesting the existence of tannin structures that were not well understood. However, given the fact that HT (e.g. punicalagin) have hepatotoxic and nephrotoxic effects on some livestock (Filippich et al., 1991), CT are often the focus of research associated with tannin-animal interactions.

Nonetheless not all plant species produce CT; and among those that do, concentration and chemical characteristics are highly variable. According to Makkar (2003a) forage plants, such as legumes that are rich in CT, are also generally rich in nutritive value (e.g. protein). For animals that consume CT-containing legumes, perhaps the high nutritive value of the legume helps to counteract the often-observed anti-nutritional effects of CT when animals consume high concentrations of biologically active forms. Although it is frequently overlooked or disregarded, the fact that much of the biologically active CT-producing plants demonstrate anti-nutritional effects on animals that consume them cannot be ignored. However, generalizations regarding anti-nutritional effects of CT on animals are common (Fadel *et al.,* 2002; Hagerman, 2012). Examples of these generalizations include decreased diet palatability, depressed intake at dietary CT concentrations exceeding 5% of dry matter (DM), depressed digestibility of nutrients (protein, carbohydrates, and fats), and depressed feed efficiency and production of animal products.

Mueller-Harvey (2006) provided some much needed clarification and context for better understanding of these anti-nutritional responses. According to Mueller-Harvey (2006), palatability is often based on astringency associated with CT-protein complexes formed from proteins in saliva; thus, the greater the protein bound by CT, the greater the astringency and the lower the palatability. However, not all CT bind protein equally. For example, *Desmodium paniculatum* produces a greater concentration of CT that demonstrate lower protein binding as compared with ,*Neptunia lutea* or *Lespedeza cuneata* that produce lower concentrations of CT with more protein-binding activity (Naumann *et al.,* 2014b). In another study, *Onobrychus* *viciifolia* containing 9-10% CT was more palatable to sheep than *Lotus corniculatus*, which contain much lower concentrations of CT at 2.6-4% (Häring *et al.*, 2008). Intake is, at least initially, related to palatability. The low level (0.18-0.31%DM) of CT analysed in *Senegalia mellifera* bush based feed accounts for nearly 1% of the Dry Matter, which is below the generalized concentration of 5%DM considered not harmful to animals. It is possible that, intake may be depressed at concentrations less than 5% of DM when the CT are more effective at protein binding and at concentrations greater than 5% DM when the CT are less effective. The low content phenolic composition obtained in this study is in agreement with the results of Honsbein *et al.* (2008),who stated that, the underlying assumption that the bush based materials contains tannins might be wrong, after the addition of PEG (5g/d) did not improve protein digestibility in bush based feed resources, However no tannin analysis method was conducted.

3.5. CONCLUSION

Based on the results of this study, *Senegalia mellifera* bush based feed can be considered a protein-rich roughage for ruminants, with its low content of tannins, although its high fibre content is an important constraint that might limit its digestion in the gastrointestinal tract of ruminants. Based on its chemical composition, it is also necessary to validate the nutritive value of such woody plant through animal-feeding experiments. The leguminous fodder tree, showed high protein contents and if mixed with other supplements would be more digestible owing to its lower tannin content. All of this information may be used to define strategies for rational utilization of rangelands in particular to make decisions about the optimum time to use the fodder trees as a feed resource. The study therefore rejected the null hypothesis and concluded that, there is significant difference in the chemical composition of *A. mellifera* milled biomass collected from nine blocks at Neudamm farm.

CHAPTER 4:

FEED INTAKE, DIGESTIBILITY AND NITROGEN BALANCE IN BOER GOATS FED WITH *S. MELLIFERA* BUSH BASED FEEDS TREATED WITH OR WITHOUT DIFFERENT ANTI-NUTRITIONAL DEACTIVATING METHODS.

4.1. INTRODUCTION

Lack of quality feeds, mostly during the prolonged dry season in Southern Africa, has increased the need to provide supplementary feeds to maintain livestock farming (Hove *et al.,* 2001). Nevertheless, there has been a drastic increase in costs of feeds in recent years owing to the economic hardship faced by most African countries.

The concept of producing animal feed from encroaching browse woody plants especially *Senegalia mellifera* has gained interest in recent years as protein supplements during the dry season. However woody trees and shrubs of the former genus *Acacia* has been reported to contain condensed tannins that reduce browse utilisation efficiency by herbivores (Tanner *et al.,* 1990; Phale and Madibela, 2006; Nsahlai, 2011).

Condensed tannins acts as defensive mechanism in plants against herbivory (Cooper and Owen-smith, 1985). According to Zucker, 1985 and Reed *et al.* (1990), condensed tannins are water soluble polymeric phenolics that bind to proteins, preventing microbial attack on proteins and reduce microbial enzymes activity (Ngwa *et al.,* 2003; Nsahlai *et al.,* 2011) in the rumen. In ruminants, condensed tannins is documented to be responsible for reduced forage intake (Tanner *et al.,* 1990; Mueller-Harvey and McAllan, 1992), digestibility and Nitrogen retention (Tanner *et al.,* 1990; Silanikove *et al.,* 1997).

Although the negative effects of tannins on the performance of animals has been documented (Tanner *et al.,* 1990; Silanikove *et al.,* 1997; Ngwa *et al.,* 2003; Nsahlai *et al.,* 2011), it has been distinguished that tannin-protein complexes are stable in near neutral PH environment of the rumen, but disintegrate on reaching the acid environment of the abomasum (Reed, 1995) and the alkaline environment of the small and large intestines.

Given such a trend, tannins increases nitrogen flow to post ruminal sites, thus an increase in nitrogen retention and animal weight gains (Mueller-Harvey and McAllan, 1992; Reed, 1995, Kaitho *et al.,* 1997; Nsahlai *et al.,* 1999). Various detannification treatment methods has been proposed that could increase the efficiency utilisation of protein in different tanniferous forages. However, there are few reports on the effect of treatments on Tannins in *Senegalia mellifera* forage feeds on the intake digestibility and animal performance.

Various treatment methods have been used to alleviate the deleterious effects of tannins in tanniferous browse tree forages, including the use of Polyethylene glycol (PEG, 4000 or 6000), Wood Ash (WA) and the use of Activated charcoal (Biochar). The tannin binding compound PEG, binds to tannins with a higher affinity than protein (Barry and Duncan, 1984; Waghorn, 1990; Silanikove *et al.,* 2001; Smith *et al.,* 2005; Priolo *et al.,* 2005; Mlambo *et al.,* 2007), hence increasing the availability of protein for utilisation by ruminants. Wood ash and Biochar provides an alkaline environment in in the digestive tract in which tannins undergo oxidation to inert forms (Mueller-Harvey and McAllan, 1992; Smith *et al.,* 2005) hence deactivate the protein–tannin complexes bonds and releases protein for digestion and absorption by ruminants (Makkar, 2003; Smith *et al.,* 2005). Nevertheless having this knowledge of the effect of this detannification treatments in tanniferous forages, few attempts have been made to determine their efficacy on *Senegalia mellifera* bush based feeds and the subsequent impact on goats' performances.

Despite the existing scientific evidence that goats produce proline-rich proteins (PRPs) that precipitate tannins and thus allows them to consume tanniferous forages (Shimada, 2006), it has been noted that this adaptations comes about following chronic exposure to tanniferous forages. Nevertheless, Hanovice-Ziony *et al.* (2010) determined that salivary tannin biding proteins did not have an impact in Mediterranean goats upon being fed tanniferous forages. Equally, Makkar (2003) reported that despite goats being fed tannin rich oak leaves, in winter, the saliva of goats did not contain PRPs. In addition, Salem *et al.* (2013) noted that chronic exposure, with daily saliva sampling over a month period to condensed tannins did not increase the protein concentration in parotid saliva of goats. Furthermore, goats have been used by various researchers in evaluating the efficacy of different detannification agents (Getachew *et al.*, 1998; Makkar, 2003; Nguyen and Ly, 2002; Shimada, 2006; Salem *et al.,* 2015). More importantly, goats are the predominant small ruminants in Namibia, owned by both commercial and communal farmers which are often affected by scarcity of nutritional sufficient feeds especially during the dry seasons. Although goats are considered being adapted to tannins (Mlambo, 2004; Shimada, 2006), due to the insufficient intellectual capacity of the tannins adaptation mechanisms combined with different views with regards to the role of PRPs in goats adaptations to tanniferous forages, the mechanisms reported in the literature might not hold under semi-arid conditions of Namibia, hence goats were used in this study. The objective of this study was to determine the effect of treating *S. mellifera* bush based feed with PEG, Wood ash and biochar on intake, digestibility and nitrogen retention in Boer goats.

4.2. MATERIALS AND METHODS

4.2.1 Description of study site

The site is as described in Chapter 3.

4.2.2. S. mellifera bush based feed resources

The bush based feed resources were collected at the Neudamm Farm. The bush based feed resources were harvested by selectively cutting down *S. mellifera* bushes and prune off the twigs and leaves fractions with a panga (machete) in the month of February and March 2018. The twigs and leaves biomass were then chipped into smaller chips using a wood chipper (Junkkari chipper, YLIHARMA Pvt., FINLAND) and shade dried at ambient temperatures for one week on a black polythene plastic in warehouse. After shade drying, the biomass was further fine milled by passing through a 4mm sieve using a hummer mill and packed into bags awaiting diet formulation, treatment and feeding to goats.

The larger stems and branches were chopped (cut) into shorter logs and burned in a Kon Tiki Kiln to produce activated charcoal (Biochar) and the remaining fragments and chips were burned up on a concrete floor to produce wood ash powder. Polyethylene glycol (PEG, 6000) was purchased at a local animal feed retailer (Agra, Windhoek Namibia). The three (Biochar, wood ash and PEG) were the detannification treatments used in the experiment.

During feed formulation, the milled biomass of *S. mellifera* (30% inclusion) was mixed using a clean concrete mixer with the following ingredients to formulate a complete diet: yellow maize meal (26%), liquid molasses (20%) as energy source; Marula oil press cake (20%) as a protein source and coarse salt (1%) as a source of minerals, while treatments were added at 3%.

4.2.2. Animals and treatments

Eight (8) female Boer goats, aged 30 to 35 moths, with an average initial body mass of 31.5 kg (± 2.5 kg), were used in the feeding trial. The goats were penned individually in the metabolic cages measuring 120 cm long, 54 cm wide and 90 cm above the ground, allowing the total collection of faeces and urine separately. The metabolic cages used in the experiment had two compartment (one compartment for clean water that was available *ad libitum* and the second compartment was for the feeds). Before commencing with the experiment the goats were dewormed with Swavet Rox-Trami-cide, (3.0 ml /10 kg body mass) a remedy against roundworms, liver fluke and Nasal bot. The goats were weighed before the feeding trial and at every beginning of a new period during the experiment. The goats were allowed to adapt to the metabolic cages and the diets for ten (10) days which was sufficient to reach a stable consumption level, followed by 7 days of total collection of faeces and urine daily during each period .Two goats were assigned on each treatment diet per period in four (4) periods and the diets were rotated allowing all goats' exposure to each diet. Each period lasted for 17 days, resulting in 68 days of experimental feeding. The goats were fed twice daily at 09:00h and 16:00h. The level of dry matter (DM) of feed offered was 4% of body weight BW). The three treatments were offered at a level of 5g/goat/day at feeding time by mixing (2.5g in the morning and 2.5 grams in the afternoon) it with the feed offered. The PEG used had a molecular weight of 6000 and a pH of 6, while Biochar and Wood ash had a pH of 10 and 12, respectively. Total output of faeces and urine from each goat were collected at 7:00 a.m. from the metabolic cages every morning. Faeces were then weighed and 10% of the total faecal matter was dried in an oven at 60^0C for 48hs and milled to pass to pass a 2mm screen using a bench mill awaiting analysis. A measuring cylinder was used to determine daily urine volume and 10 ml of 0.1 N sulphuric acid was added to urine to prevent nitrogen volatization (Dube, 2003). The urine samples which was 10% of the total output, were bulked over the collection period and stored in a freezer (-20 ^{o}C), awaiting analysis. Feed intake for each day during the collection period were determined by subtracting the mass of the feed refused from the mass of feed offered, before putting the feed for the next day. The goats were fed with the experimental feeds in a 4X4 cross over Latin square design with four periods of experimental feeding as shown in Table 4.1

Table 4. 1. The 4X4 cross over Latin square experimental design used in the Feeding trial.

Legend: CNT= untreated feed; **PEG**= control feed treated with PEG; **BIO**= control feed treated with BIOCHAR and **WA**= control feed treated with WOOD ASH.

4.2.3. Chemical analysis.

GOAT NUMBER	**PERIOD 1**	**PERIOD 2**	**PERIOD 3**	**PERIOD 4**
GOAT 1 and GOAT 2	CNT	PEG	BIO	WA
GOAT 3 and GOAT 4	PEG	BIO	WA	CNT
GOAT 5 and GOAT 6	BIO	WA	CNT	PEG
GOAT 7 and GOAT 8	WA	CNT	PEG	BIO

A sample from each experimental feed and faeces was dried in an oven at 60^0C for 48hs and milled to pass to pass a 2mm screen using a bench mill awaiting analysis. Dry matter (DM) content of the feed and faeces was determined by placing the sample in the oven at 105° C for 5 hours (AOAC, 2007). Total ash was obtained by igniting the samples in a muffle furnace at 550° C overnight and the remaining residue was ash. Organic Matter (OM) was calculated by the difference of DM and Ash values. Total Nitrogen (N) was determined by Kjeldahl method and crude protein was obtained by calculating N x factor 6.25. Neutral detergent fibre (NDF) and acid detergent fibre

(ADF) was determined as described by van Soest *et al.* (1991). The difference between nitrogen intake and nitrogen output in faeces and urine was a measure of nitrogen retention.

4.2.4. Statistical analysis

Chemical composition means of the diets, digestibility coefficients, faeces and nitrogen output were compared in a one way analysis of variance using SPSS version 2.2 of 2010. The differences were established by using the Duncan's new multiple range test (Steel and Torrie, 1980). Unless or otherwise indicated, significance was declared at $p < 0.05$.

4.3. RESULTS

The nutritional content of the diets are presented in Table 4.2. The results showed control diet (CNT) had the highest dry matter (94.49%) content, however it was not significant different ($p > 0.05$) (Table 4.2) with that of the other diets. The wood ash (WA) treated diet had the most ash content of 19.88%DM ($p < 0.05$), followed by biochar treated diet of 17.12%DM ($p < 0.05$) compared to the PEG treated diet of 10.10 %DM ($p > 0.05$) and the control died diet of 11.12($p > 0.05$) (Table 4.2).

The organic matters content of the formulated diets differs significantly ($p < 0.05$) (Table 4.2).The organic matter of the diets was observed lowest in wood ash (WA) treated diet (74.52 %DM) ($p < 0.05$) and highest in PEG treated diet (84.21%DM) ($p < 0.05$) and the control diet (83.37%DM) ($p < 0.05$). The protein content (CP) of all diets were similar ($p > 0.05$) and ranges between from 13.47 to 13.55 %DM. The Neutral detergent fibre (NDF) was similar in all diets ($p > 0.05$), with the control diet (CNT) and wood ash (WA) treated diet having the most NDF of 41.52%DM and 41.86% DM, respectively.

Table 4. 2. Nutrient composition of *S.mellifera* formulated diets.

TREATMENT	%DM	% ASH	%OM	% CP	%NDF
CNT	94.49±0.32^{a}	11.12±0.3^{c}	83.37±0.34^{a}	13.55±0.02^{a}	41.52±0.15^{a}
PEG	94.31±0.14^{a}	10.10±0.21^{c}	84.21±0.07^{a}	13.48±0.19b^{a}	40.49±0.43^{a}
BIO	94.21±0.05^{a}	17.09±0.19^{b}	77.91±0.24^{b}	13.49±0.17b^{a}	40.85±0.07^{a}
WA	94.40±0.33^{a}	19.88±0.17^{a}	74.52±0.16^{c}	13.47±0.04b^{a}	41.86±0.19^{a}

Legend: DM=Dry Matter; Ash; OM=organic matter; N=nitrogen; NDF= neutral detergent fibre; CNT= untreated feed; PEG= control feed treated with PEG; BIO= control feed treated with BIOCHAR and WA= control feed treated with WOOD ASH. ^{abc}Means within columns with different superscripts are significant different ($p < 0.05$).

There was significant difference ($p < 0.05$) in the DMI of different treatments .Biochar treated feed had the highest DMI of 963 g/d (Table. 4.3) ($p < 0.05$) compared to other treatments. The DMI of the control feed (CNT), PEG and WA was similar ($p > 0.05$) (Table. 4.3). The apparent digestibility coefficient of DM, OM and NDF were not different among treatments ($p > 0.05$) (Table 4.3), however all treated diets were all lower than their counterparts that were given biochar treated diet ($p > 0.05$).

The nitrogen intake of goats fed different treatments was significantly different ($p < 0.05$) (Table 4.4). Goats fed Biochar treated feed had the highest nitrogen intake of 13.74g/d ($p < 0.05$) (Table. 4.4). The nitrogen intake of goats fed the control feed (CNT), PEG and WA was similar ($p > 0.05$) (Table. 4.4). The faecal nitrogen from goats consuming different treatments was different (Table 4.4). Goats fed Biochar treated feed had the highest faecal nitrogen of 8.43g/d ($p < 0.05$) (Table.

4.4) while faecal nitrogen from goats consuming control feed (CNT), PEG and WA was similar ($p > 0.05$).

Urinary nitrogen from goats consuming different treatments was not significant different ($p > 0.05$) (Table 4.4). Goats fed Biochar treated feed had the highest nitrogen retention of 5.11g/d ($p < 0.05$) (Table. 4.4) compared to other diets. The nitrogen retention of goats fed the control feed (CNT), PEG and WA was similar ($p > 0.05$). All treatments and the control diet resulted in a positive nitrogen retention ($p > 0.05$) with mean values of 3.79 to 5.11 g/d.

Table 4. 3. Feed intake (g/day) and apparent digestibility coefficients of diets offered.

TREATMENT	DMI	DMD	OMD	NDFD
CNT	790 ± 42.09^{b}	0.46 ± 0.04^{a}	0.33 ± 0.03^{a}	0.29 ± 0.03^{a}
PEG	779 ± 58.97^{b}	0.45 ± 0.03^{a}	0.32 ± 0.04^{a}	0.30 ± 0.04^{a}
BIO	963 ± 62.23^{a}	0.48 ± 0.05^{a}	0.35 ± 0.04^{a}	0.31 ± 0.04^{a}
WA	764 ± 50.99^{b}	0.46 ± 0.04^{a}	0.33 ± 0.03^{a}	0.30 ± 0.03^{a}

Legend: DMI=dry matter Intake; OMD= Organic matter digestibility; NDFD= neutral detergent fibre digestibility; CNT= untreated feed; PEG= control feed treated with PEG; BIO= control feed treated with BIOCHAR and WA= control feed treated with WOOD ASH. ^{abc}Means within columns with different superscripts are significant different ($p < 0.05$).

Table 4. 4. Nitrogen (g/d) balance in goats offered *S. mellifera* formulated diets.

TREATMENT	N-INTAKE	FAECAL-N	URINARY-N	N-RETENTION
CNT	11.54±0.6^{b}	6.64±0.6^{b}	0.20±0.04^{a}	4.7±0.87^{b}
PEG	12.23±0.9^{b}	7.85±0.5^{b}	0.28±0.06^{a}	4.1±0.77^{b}
BIO	13.74±0.9^{a}	8.43±0.2^{a}	0.20±0.03^{a}	5.11±0.90^{a}
WA	10.85±0.7^{b}	6.83±0.3^{b}	0.23±0.06^{a}	3.79±0.49^{b}

Legend: CNT = untreated feed; PEG= feed treated with PEG; BIO= feed treated with BIOCHAR and WA= feed treated with WOOD ASH. N-INTAKE =diet nitrogen; FAECAL-N=faecal nitrogen; URINARY-N= urine nitrogen; N-RETENTION=nitrogen retained. ^{abc}Means within columns with different superscripts are significant different ($p < 0.05$).

4.4. DISCUSSION

4.4.1. Composition of diets

There are few reports on the use of *S. mellifera* as livestock feed in the literature. Of these there is lack of uniformity in standards used, therefore hindering comparisons. The quality of the bush based diets was generally good in terms of improved chemical composition. Irrespective of the type of supplements used and the treatments applied, the DM of the bush based diets was fairly similar to each other (Table 4.2).The DM recorded in the formulated diets had a mean of 94.21 to 94.49% and were in the range of those reported by Honsbein *et al.* (2018) on S. *mellifera* formulated diets fed to sheep's in Namibia. The results of this study had shown that the added supplements (yellow maize, Marura oil cake, liquid molasses and coarse salts) had increased the crude protein (CP) levels from 9% to 14% respectively, which is sufficient to meet the requirements for microbial growth (Van Soest, 1994) of ruminants and enough to meet the minimum protein requirements of ruminants, 10-12%, estimated by ARC (1985).The fibre content ranged among acceptable levels (NDF ranged between 36 and 41%) in the diets. Since roughage constituted a big fraction of energy source (Van Soest *et al,*. 1993) in the experimental diets, it was expected that more energy would be released as the roughage get digested by goats during the feeding trial. Norton (1994) also indicated that tree forages with a low NDF content (20-35%) are usually of high digestibility and species with high lignin content are often of low digestibility. It is recognized though that the ultimate indicators of quality are the animals themselves hence feeding trials are proposed in order to study the responses from the various feedstuffs. These observed moderate NDF results could be an indication that the inclusion levels of the milled bush and the type of supplements added to the milled bush was beneficial in topping up the required nutrients by the animals such as protein and lowering the NDF fibre fraction. The result clearly indicated the dilution effect of wood on the nutritional content of bush feed. Similarly, the lower the wood materials is included in the feed, the lower the total fibre content of the feed (NDF), which will eventually had less influence on the intake (how much of that feed is voluntarily eaten by the animal). The addition of wood ash, PEG and biochar did not affect the nutritional composition of the diets and hence it was assumed that their addition will improve the feed digestibility during feeding.

4.4.2. Feed intake, digestibility and nitrogen retention

Many studies focusing on woody plants nutritive value have been limited to chemical composition regardless of past recommendations (Le Houerou, 1980) that priority research should be given to intake and digestibility studies.

The relative difference in DMI and digestibility coefficients (DM, OM and NDF) in this study reflect partly the medium to high structural fibre concentrations of *S. mellifera.* The addition of

PEG, Wood ash and Biochar was found to have no significant effect on the nutritional content of *S. mellifera* diets. The DMI of all treated diets and the control diet in this study ranged from 764 to 963 g/day respectively. The results of this study are in agreement with Ben Salem *et al*. (2000) who showed that the DMI of acacia foliages by sheep was not affected by the addition of PEG. In contrast to the present study findings, Ben Salem *et al.* (1999) reported that, the intake of *Acacia cyanophylla* by sheep increased as the level of PEG increased and PEG inactivated the condensed tannins in *Acacia cyanophylla*, thus improving microbial organism synthesis and growth of sheep. Ben Salem *et al.* (2005) reported that soaking *Acacia cyanophylla* in Acacia wood ash solution (120 g of wood ash DM/L of water, pH=12.4) decreased total extractable phenols, total extractable tannins and extractable condensed tannins, but also reduced OM and CP content. In agreement with our study results, Ben Salem reported that, Feeding *Acacia cyanophylla* treated with wood ash solution did not affect intake and OM digestibility and NDF digestibility of Barbarine rams.

Several studies (Pritchard *et al.*, 1988; Silanikove *et al.*, 1996; Ben Salem *et al.*, 2000) have contended that it is possible to deactivate condensed tannins and increase the intake and digestibility of shrub foliages containing 1-20% of condensed tannins by the addition of PEG. In our study, PEG treated diet DMI was similar to the control diet. According to Barry and Duncan (1984), treating *Lotus penduncul*a*tus* with PEG deactivated tannins and increase the intake of forage by sheep. Mlambo *et al.* (2004) reported an increase in intake by 50% when PEG was used to treat tannins in *Dichrostachys cinerea* fruits. The factors involved in the digestibility variation among browse fodders include the concentration of N, cell wall content, especially lignin, and tannins (Moore and Jung, 2001). A low level of CP (less than 80 g/kg DM) is shown to depress digestibility, as it is not sufficient to meet the needs of the rumen bacteria (Norton, 1998).On the other hand, low NDF content (20 to 35%) has been shown to result in high digestibility, while lignification of the plant cell wall decreases the digestibility of plant material in the rumen (Moore and Jung, 2001).

The high intake of 963 g/day in Biochar treated diets in this study was in agreement with Poage *et al.* (2000) who reported that Activated charcoal (Biochar) can adsorb and decrease bioavailibility of phytochemicals in the gastrointestinal tract through the interaction of its positively charged surface with negatively charged toxins, allowing them to be excreted in the faeces of Ruminants. According to Poage *et al*. (2000), Sheep and goats supplemented with 10 g of activated charcoal consumed more total biomass of high-terpene shrubs when offered either three (*Juniperus phoenicea, Helichrysum italicum,* and *Juniperus oxycedrus*;), two (*Juniperus phoenicea,* and *Helichrysum italicum*) or one shrub (*Juniperus phoenicea*;) species. The effects found in our study, and other biochar, studies, are difficult to compare without a better characterization of the biochar products. It appears that the effects of biochar differ and may be due to biochar product differences (Biochar produced from different plant materials). A standardized method of characterization including porosity and density is needed. The mechanisms behind the positive effects found in the literature and in this research need to be illuminated.

The unprocessed woody materials were considered indigestible by ruminants (Millet *et al,* .1970), but using various chemical or physical treatments, their digestibility were markedly increased. Many studies (Buxton and Redfearn, 1997; Moore and Jung, 2001) have reported a negative correlation between lignin concentration and cell wall digestibility by its action as a physical barrier to microbial enzymes. Negative correlations between tannin and protein or DM digestibility have also been studied (McSweeney *et al.,* 1999; Balogun *et al.,* 1998). Hence information on the NDF, ADF, lignin and tannin content of tree foliage is essential for the assessment of their digestibility.

A wide range of variation in digestibility is reported in tropical browse species. Breman and Kessler (1995) showed a mean OMD of 0.53 in Sahelian and Sudanian zones of West Africa. Fall (1991) reported large variations in DMD, ranging from 0.26 to 0.88 between species and plant parts. Sanon (2007), reported high OMD (0.56 to 0.66 g/kg) and CPD (0.64 to 0.73 g/kg DM) compared to the mean values reported by other authors for West African browses. The results obtained in the present study are in contrast with the reports of this authors, suggesting that tannins found in *S. mellifera* (0.02 - 0.03 g/DM) did not respond to any of these treatments.

The results of this study are in agreement with that of Osuga *et al.* (2007) and Wambui *et al.* (2012) who concluded in an experiments aimed at alleviating the effect of acacia tannins on protein digestibility, that the addition of PEG (polyethylene glycol) to black thorn (*S.mellifera*) foliage did not increase gas production, probably because the black thorn does not contain large amounts of tannins. A no response was also reported by Mlambo (2002) when he compared PEG treated and Alkali treated fruits in an *in vitro* fermentation experiment. Mlambo (2002) concluded that *A. nilotica* fruits contains less condensed tannins and more hydrolysable tannins and low molecular weight soluble phenolics, hence tannins deactivating methods were not effective. Makkar *et al.*, (2000) reported that PEG, 6000 has been shown to be more effective in *in vitro* experiment than in *in vivo* experiments such as of this study. According to Silanikove *et al.* (1996) the amount of detannification method such as PEG needed to produce a maximum increase in feed intake by goats varies with plant species.

The highest dry matter intake was obtained after PEG supplementation at a level of 10 g/day in acacia foliages according to Silanikove *et al.* (1996). Ben Salem *et al.* (2000) concluded that the optimum response of acacia intake was obtained in sheep given feed blocks supplemented with 18% PEG equivalent to 23 g/day, while goats in the present study were supplemented with 5 g/day of each treatment (wood ash, biochar and PEG) which may not have been enough to affect the intake of *S.mellifera* diets. Honsbein *et al.* (2008), stated that, it is possible that the quantity of PEG added to bush feeds in their study was not effective enough or underlying assumption that the bush based materials contains tannins might be wrong, after the addition of PEG (5g/d) did not improve protein digestibility in sheep's.

Nitrogen excretion is shifted from urine to faeces in feeds that are rich in phenolic compounds (Reed and Soller, 1987). In the present study, a large proportion of nitrogen excreted by goats was in faeces (Table 4.4) despite detannification method applied to the diets. The high faecal nitrogen can be attributed to the woody fibre content of the diets. According to Baer *et al*. (2014) fibrous plants contains amounts of protein which is usually indigestible and could influence the protein digestibility value.

The protein value within the fibre increases fecal nitrogen concentration (Baer *et al*., 2014). In general, fermentable and viscous fiber (pectin), decreases the digestion of protein more than non-viscous and non-fermentable fiber (cellulose), based on weight (Reed and Soller, 1987; Baer *et al*., 2014). Fermentation may decrease protein digestion by the activity of stimulating the growth of microbes, while viscosity may decrease digestion by reducing the rate of protein metabolism in the small intestine (Baer *et al*., 2014). Most refined fiber, with respect to its type and source, decreases protein digestibility in animals (Silanikove *et al.*, 1996).

There was an observation that protein phytate interaction negatively influenced protein digestibility in *in vitro* conditions (Carnovale *et al.,* 1988). However, there were other observations that stated that protein levels increased in the small intestines during dietary consumption of dietary cellulose (Paulino *et al.,* 2008). Hence, regarding the alterations in the protein and/or fiber levels of the feeds, and the procedure of fiber supplementation into the feeds, evaluations among studies using similar fiber sources are usually not promising. From the accessible literature, it is clear that dietary fiber and fiber-rich diets decrease protein digestion, in a linear manner.

High faecal nitrogen observed in this study could also be attributed to the indigestible fibre bound to tannins (Krebs *et al.,* 2007) and protein macro structures and increased lignification in *S.mellifera* bush based feeds, resulting in dietary nitrogen being excreted in faeces as tannin protein complexes. With no significance difference in the faecal nitrogen between the controls feed and the treated diets, this study suggest that a higher inclusion level of more than 5g/day of wood ash, biochar and PEG could have had further benefits.

Regarding the tannin-protein complex, literature has highlighted that there are variations in types and quantities of tannins among forages (Madibela *et al.*, 2006).Different tannins acts differently, affecting intake and digestibility of forages (Silanikove *et al.,* 2001). According to Min *et al.* (2003) two plant species (*Lotus corniculatus* and *L. pendunculatus*) have been reported to have the same amount of condensed tannins but ruminants respond differently to them, possibly because tannins are chemically different. In the current study, the low level of condensed tannins in *S.mellifera* did not respond to any of the treatment. Like other Acacia species, *S. mellifera* foliage have been reported that it contains tannins, however the reported tannin content is extremely variable (Fade *et al.,* 2002; Osuga *et al.,* 2007). Condensed tannins have been found to be present either in low amounts (0.2% DM, Osuga *et al.,* 2007 and Wambui *et al.,* 2012), or in much larger quantities: in Sudan, from 1.4% DM in the early dry season (late October) to 5.7% DM in the late dry season (early June) (Fadel *et al.,* 2002). In agreement with Osuga *et al.,* 2007, *S. mellifera* contains low quantity of condensed tannins as reported in the current study. This study suggest that *S. mellifera* might contain more hydrolysable tannins that may have inactivated the digestive enzymes owing to the fiber content.

Zucker (1983) suggested that the role of hydrolysable tannins are to inactivate the digestive enymes of herbivore. However the effect of hydrolysable tannins are pronounced on insect herbivores than in animals. Little attention have been given to the way these hydrolysable tannins can be counteracted in ruminants.

The nutritional behavior of CT is defined along the digestive tract where pH changes occur (Silanikove *et al.,* 2001; Makkar, 2003; Mueller-Harvey, 2006). One of the most important effects of CT ingestion by ruminants is associated with their ability to improve the digestive utilization of feed proteins (Makkar, 2003; Mueller-Harvey, 2006). The potential of CT to increase the digestive utilization of dietary protein is associated with their ability to bind proteins under the rumen pH conditions (pH 5.5 to 7.0), preventing their excessive microbial degradation (Mueller-Harvey, 2006). The tannin-protein complexes are often dissociated in the acidic pH of the abomasum (pH 2.5 to 3.5) and in alkaline conditions of the distal small intestine (pH <7.5), releasing protein for digestion and absorption (Jones and Mangan, 1977; Mueller-Harvey, 2006).

Various studies have confirmed the reduction of the effective degradability of protein (Min *et al.*, 2003; Theodoridou *et al.*, 2010; Dentinho *et al.*, 2014), by the presence of CT in the diet, mainly due to a reduction in initial solubilisation and a reduction of the fractional rate of degradation, increasing the flux of undegradable dietary protein into the post ruminal compartments without detrimentally affecting the post-ruminal digestion. The reduction in rumen protein degradation leads to a lower level of N-NH3 production in the rumen. As a result, the urinary N is reduced and the faecal N slightly increases, owing to the undegraded tannin protein complexes formed along the digestive tract (Mueller-Harvey, 2006).

At the environmental level the shift from urinary to faecal N is very important, because urinary N is predominantly urea, which is rapidly converted to ammonia and nitrous oxide (N2O), which has implications for environmental pollution, while the feacal N is retained in the soil and will benefit the content of organic matter (Hristov *et al.,* 2013). In addition, tannins are considered a promising group of compounds for decreasing enteric methane (CH4) emissions from ruminants. Methane production in rumen represents not just an ecological problem, but also an economic one. As is well known, methane is a potent greenhouse gas, and methane produced by ruminant's accounts for 28% of total anthropogenic methane (Beauchemin *et al.*, 2008). Moreover, CH4 produced during ruminal fermentation represents a loss of 5-8% of gross energy intake (Lopez and Newbol, 2007).

The importance of tannins in animal diets is also associated with their effects in respect of reducing intestinal parasites. Alternative parasitic control strategies have been studied, and the use of tannin-rich feeds has been one of the proposed alternatives (Niezen *et al.,* 1995; Barry *et al.,* 2001; Min *et al*., 2003). Although the CT in this study was found to be considerably lower in comparison to literature, such comparison may not be a true indicative of protein precipitation capacity and thus only provide an indicative guide to browse foliage value or antinutritional potential.

4.5. CONCLUSION

The study concluded that, there was significant difference in the DMI of different treatment diets. The apparent digestibility coefficient of DM, OM and NDF were not different among goats fed different treatment diets. The Nitrogen intake of goats fed different treatments also differs significantly .Goats fed Biochar treated feed had the highest nitrogen intake while nitrogen intake of goats fed the control feed (CNT), PEG and WA was lowest. The faecal nitrogen from goats consuming different treatments also differs, with goats fed Biochar treated had the highest faecal nitrogen while faecal nitrogen from goats consuming control feed (CNT), PEG and WA was lowest.

Urinary nitrogen from goats consuming different treatments did not differ. Goats fed Biochar treated feed had the highest Nitrogen retention as compared to other diets. All treatments and the control diet resulted in a positive nitrogen retention.

CHAPTER 5

GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1. *The chemical composition of S. mellifera milled biomass*

The milled biomass (leaves and twigs) of *Senegalia mellifera* indicated relative contents of DM, Ash, OM, CP, NDF, ADF, Ca, P and Tannins. Variation observed were consistent with previous reports on browses in Southern Africa (Aganga *et al.,* 1998, Mlambo *et al.,* 2008, Ndlovu and Nherera, 1997, Makkar *et al,.* 2003). In agreement with Fadel *et al.* (2002) and *Osuga et al.* (2007) the study suggested that, the chemical composition was variable due to the different: proportion of (leaves, petioles and twigs), harvesting regimes, soil type and stage of growth and age of the plant.

The nutritional analysis of Senegalia mellifera bush feed shows that the crude protein (CP) which ranged from 9.39 to 9.71% were sufficient to meet the minimum maintenance requirements of 7-8% required for optimum rumen function and feed intake in ruminant livestock (Van Soest, 1994). Given the high CP content of the Senegalia mellifera, this fodder resource can be considered a suitable supplement for poor quality (low N content) natural pastures and crop residues such as grass hay, straw and stover (Osuji and Odenyo, 1997; Osuga *et al.,* 2007).

The calcium (Ca) and phosphorus (P) content of 1.2% and 0.1%, respectively, obtained in this indicates a potential mineral content apart from others in the fractions available for animal's maintenance in periods of fodder shortage. According to literature, Browse species in most cases have much higher Ca: P than the requirements (Rubanza, 2005; Rubanza *et al,* .2006; Mtengeti *et al,* .2006; Mtui *et al.,* 2008). Influences such as soil, climate, stage of maturity and season contribute to differences in the concentration of minerals in forages (Le Houerou, 1980; Topps, 1992).

The neutral detergent fibre (NDF) in *Senegalia mellifera* bush feed reported in this experiment ranged between 59.17 % and 64.33 %, which is higher in comparison with Lucia (2010) who reported an NDF value of 33.6 % *Senegalia mellifera* leaves. In comparison to other browse species, NDF content was reported lowest (323 g/kg) in *Combretum apiculatum* (Lukhele and Ryssen, 2003) and higher in the leaves of *Terminalia sericea* (647 g/kg DM: Ndlovu and Nherera, 1997). The values of NDF were in the range as those reported by van Soest (1994) from 540 to 770 g/kg for different forage species. Abdulrazak (2000) reported a low NDF value of 26.9 %, while Fadel *et al*. (2002) reported 55.55 %. The neutral detergent fraction (NDF) of the diet describes those forage component that are slowly degradable in neutral solvent such as cellulose, hemicellulose and lignin. The acid detergent fibre (ADF) fraction includes cellulose and lignin. The ADF recorded in this study ranges from 43.77% to 55.55 %. According to Topps (1992) and IAEA (2006), higher values of cell wall fractions in forage have been attributed to woody twigs included during the analysis. The analysed samples constituted a big fraction of energy source hence it can be assumed that more energy would be released to the animal during digestion. Hemicellulose recorded in this experiment was calculated as the difference of NDF and ADF. Hemicellulose content recorded in this experiment ranges from 13.62 % -17.53 %. The recorded hemicellulose fraction was higher as compared to 7.8 % reported by Abdulrazak (2000). The recorded low to moderate fibre content of *S.mellifera* is assumed to benefit the voluntary intake and digestibility of poor quality roughage (Osuji and Odenyo, 1997). The analysed samples constituted a big fraction of energy source hence it can be assumed that more energy would be released to the animal during digestion.

The low content of Tannins composition obtained in this study was in agreement with the results of Fadel *et al.* (2002), Osuga *et al*. (2007), Al-Soqeer (2008), Ben Salem *et al.* (2010), Wambui *et* *al.* (2012) and Honsbein *et al.* (2018), who concluded that, there is either low or no tannins in Senegalia mellifera and the underlying assumption that the bush based materials contains tannins might be wrong. The low concentration of Tannins in S.mellifera fractions was attributed to the time of sample harvest or season, growth stage and method of analysis used (Barry, 1999; Makkar *et al.,* 2007).

5.2. *Feed intake, digestibility and nitrogen retention*

The addition of PEG, Wood ash and Biochar was found to have no significant effect on the nutritional content of *S. mellifera* diets. The DMI of all treated diets and the control diet in this study ranged from 764 to 963 g/day respectively. The effect of the treatments used in this study were in agreement with Ben Salem *et al*. (2000) who showed that the DMI of acacia foliages by sheep was not affected by the addition of PEG. In contrast to the present study findings, Ben Salem *et al.* (1999) reported that, the intake of *Acacia cyanophylla* by sheep increased as the level of PEG increased and PEG inactivated the condensed tannins in *Acacia cyanophylla*, thus improving microbial organism synthesis and growth of sheep. Ben Salem *et al.* (2005) reported that soaking *Acacia cyanophylla* in Acacia wood ash solution (120 g of wood ash DM/L of water, pH=12.4) decreased total extractable phenols, total extractable tannins and extractable condensed tannins, but also reduced OM and CP content. In agreement with our study results, Ben Salem reported that, Feeding *Acacia cyanophylla* treated with wood ash solution did not affect intake and OM digestibility and NDF digestibility of Barbarine rams.

Several studies (Pritchard *et al.,* 1988; Silanikove *et al.,* 1996; Ben Salem *et al.,* 2000) have contended that it is possible to deactivate condensed tannins and increase the intake and digestibility of shrub foliages by the addition of PEG at an increased inclusion levels. In our study, PEG treated diet DMI was similar to the control diet. Mlambo *et al.* (2004) reported an increase in intake by 50% when PEG was used to treat tannins in *Dichrostachys cinerea* fruits. The factors involved in the digestibility variation among browse fodders include the concentration of N, cell wall content, especially lignin, and tannins (Moore and Jung, 2001). A low level of CP (less than 80 g/kg DM) is shown to depress digestibility, as it is not sufficient to meet the needs of the rumen bacteria (Norton, 1998).On the other hand, low NDF content (20 to 35%) has been shown to result in high digestibility, while lignification of the plant cell wall decreases the digestibility of plant material in the rumen (Moore and Jung, 2001).

The high intake of 963 g/day in Biochar treated diets in this study was in agreement with Poage *et al.* (2000) who reported that Activated charcoal (Biochar) can adsorb and decrease bioavailibility of phytochemicals in the gastrointestinal tract through the interaction of its positively charged surface with negatively charged toxins, allowing them to be excreted in the faeces of Ruminants. According to Poage *et al*. (2000), Sheep and goats supplemented with 10 g of activated charcoal consumed more total biomass of high-terpene. The effects found in our study, and other biochar, studies, are difficult to compare without a better characterization of the biochar products. It appears that the effects of biochar differ and may be due to biochar product differences (Biochar produced from different plant materials). A standardized method of characterization including porosity and density is needed. The mechanisms behind the positive effects found in the literature and in this research need to be illuminated. Given that this study was conducted for the first time in Namibia, additional and more accurate studies that would include a number of variables are recommended in order to clarify a broad range of effects of different detannification methods. The study therefore recommends that each detannification method should be tested at different levels of inclusion in *S. mellifera* bush based feed before total dismissal of the potential of these treatments.

Apart from the promising protein content, the high fibre content of *S. mellifera* bush based feeds still require further interventions to reveal the prospective of utilising the woody plant as animal feed. Therefore, interventions that directly degrade fibre to release the energy and other nutrients contained in the milled bush should be considered for future research. Although the woody plant species under investigation showed a low Condensed tannin concentration, the extent to which livestock's will utilise the protein in the feed is not yet fully established. Furthermore the degree to which the low tannin content is beneficial or deleterious to the animals need to be established.

Furthermore, a growth study is recommended to determine the effect of bush based feeds on the growth of livestock. In addition, the effect of bush based feed on meat and milk quality are not measured at this stage. In addition to polyphenols especially tannins, the woody plant under investigation may produce other secondary metabolites such as: organic acids, terpenes, alkaloids, and cyanogenic glycosides among others. These metabolites combined with factors of dietary fat, fiber, and protein play a participatory role in overall ruminant nutrition, anti-nutrition, and possibly the efficacy of condensed tannins.

Determining the concentaration and how these different plant-specialized metabolites and other dietary constituents interact in the rumen is recommended in order to understand if they are additive, synergistic, or antagonistic with respect to animal nutrition (or anti-nutrition), nutrient utilization, mineral binding, the process of methanogenesis, and anthelmintic activity.

The future research suggestions, presented in order of priority are recommended below with a focus on small stock (sheep and goats).

- Interventions to degrade fibre in bush based feeds require investigation.

- There is need to evaluation of various secondary metabolites besides tannins in bush based feeds
- More research required to determine dry matter intake (DMI), apparent digestibility coefficients and nitrogen retention in different species of goat/sheep fed with bush based feeds.
- Extensive evaluation of growth performances of goats/sheep fed with bush based feeds.
- Application of different detannification method at different levels of inclusion in bush based feed
- Research on the health and safety evaluation of goats/sheep carcass fed with bush based feeds feeding trials.

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APPENDICES

APPEDIX 1

EXPERIMENT 1. Harvesting and collection of *S.mellifera* bush based feed resources (AP1A-E).

AP1 (A) Harvesting

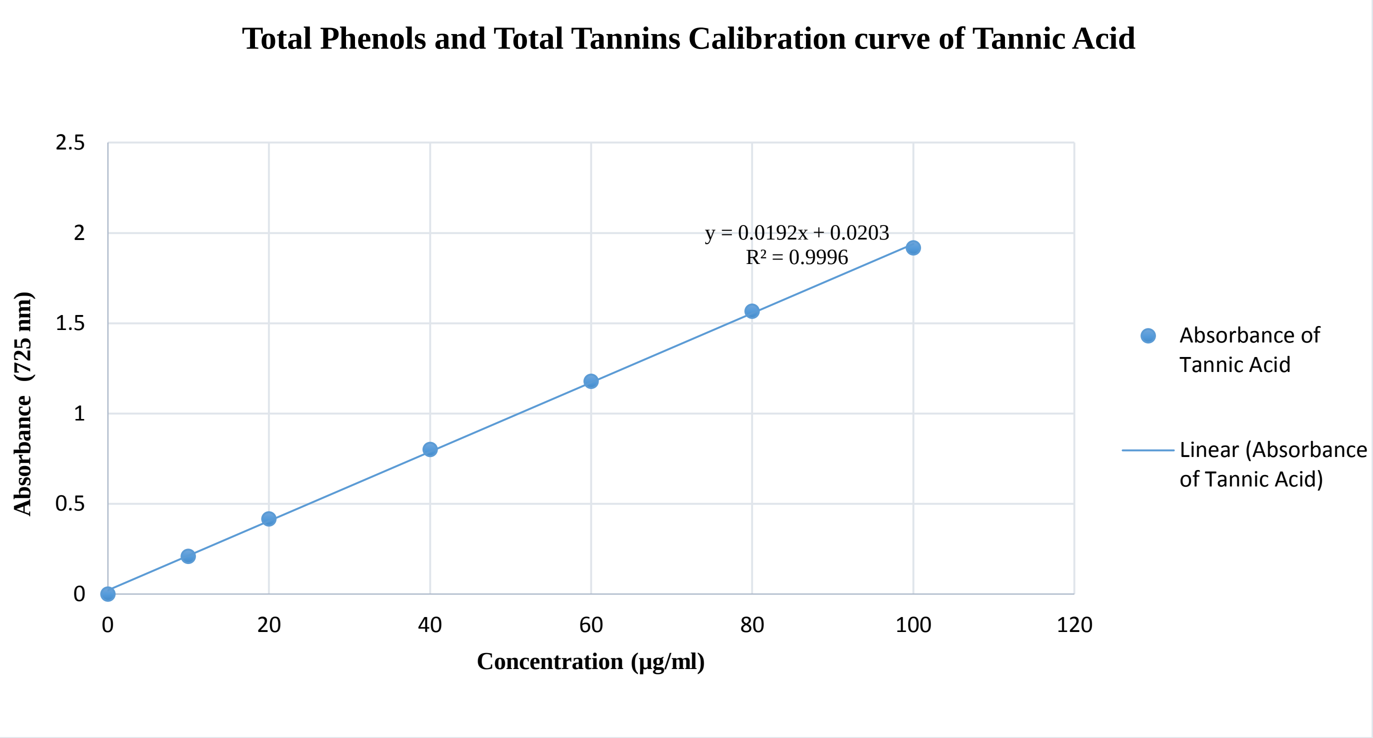
AP1 (B) Harvesting

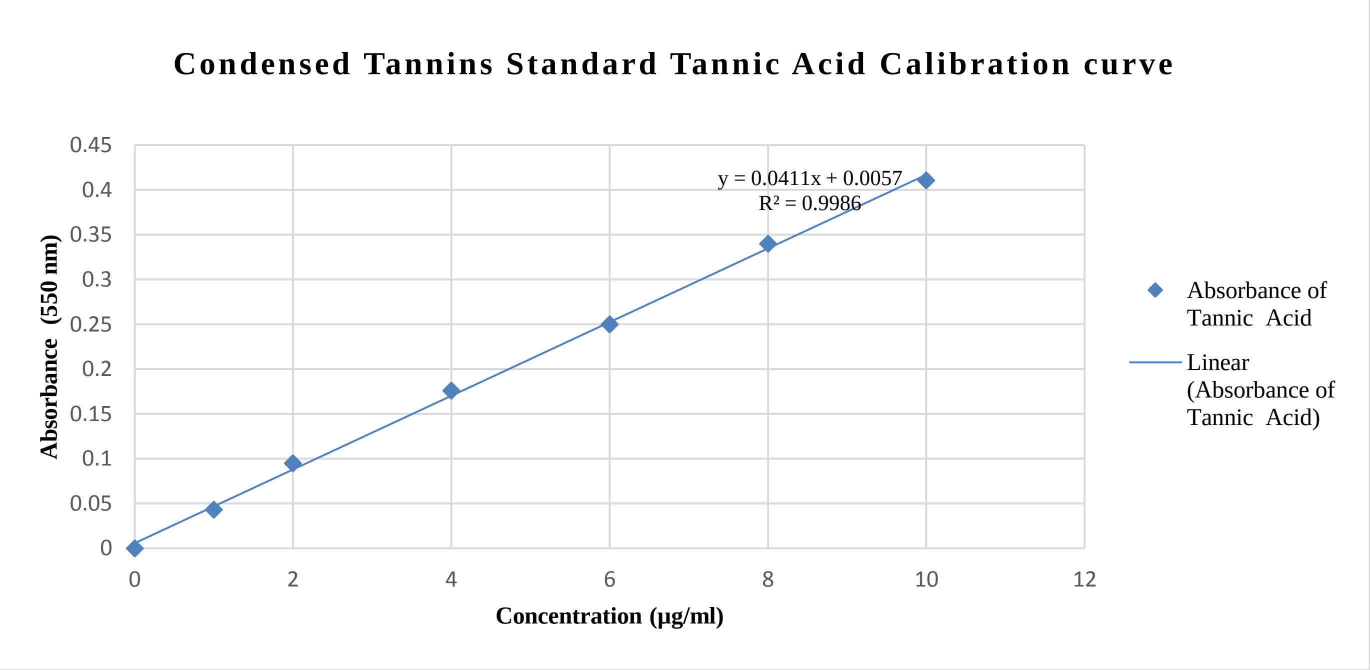
AP1(C) Transporting harvested biomass for chipping and milling

AP1 (D) Chipped biomass

AP1 (E) Dried chipped biomass ready for milling

AP 1 (F). Calibration curves of Standard Tannic acid used for the estimation of Total Phenols, Total Tannins and Condensed Tannins.





APPENDIXES 2

EXPERIMENT 2: *S.mellifera* diet formulation.

AP2 (B)

AP2(C)

AP2 (D)

Biochar production (AP2 (B)-AP2 (D))

AP2 (E): Supplements mixed with milled *S.mellifera* biomass.

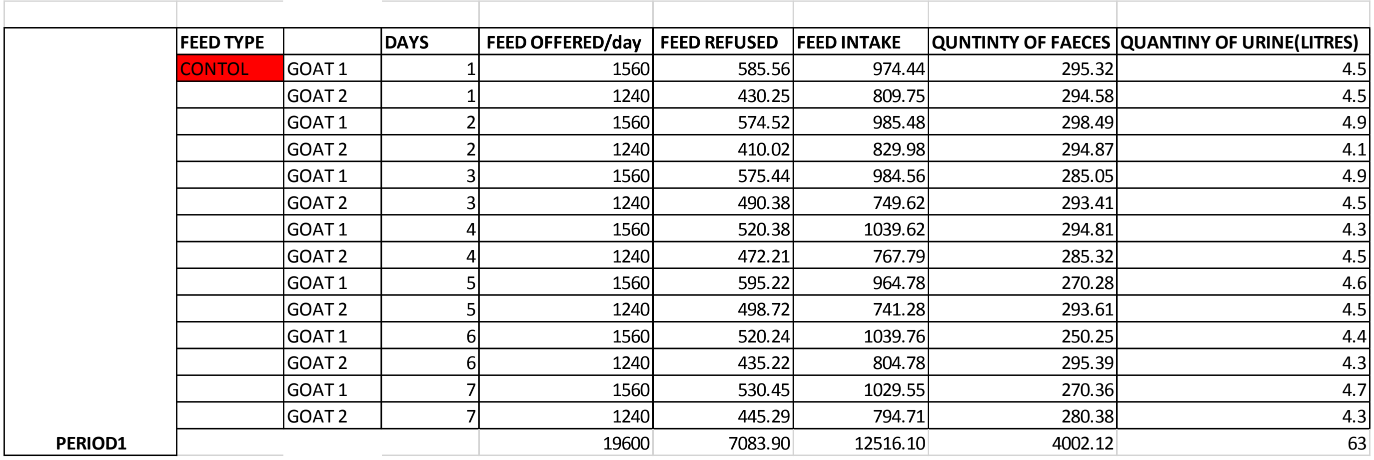
AP2 (F): Drying of formulated diets

AP2 (G): Metabolic cages in which were kept during the feeding trial

AP2 (H): Weighing daily faeces excreted output

AP2 (I). Measuring daily urine

AP2 (J): Feeding trial recording sheet. An example of the control diet, offered to goat 1 and 2 in period 1.



	FEED TYPE		DAYS	FEED OFFERED/day	FEED REFUSED	FEED INTAKE	QUNTINTY OF FAECES	QUANTINY OF URINE(LITRES)
	CONTOL	GOAT 1	1	1560	585.56	974.44	295.32	4.5
		GOAT 2	1	1240	430.25	809.75	294.58	4.5
		GOAT 1	2	1560	574.52	985.48	298.49	4.9
		GOAT 2	2	1240	410.02	829.98	294.87	4.1
		GOAT 1	3	1560	575.44	984.56	285.05	4.9
		GOAT 2	3	1240	490.38	749.62	293.41	4.5
		GOAT 1	4	1560	520.38	1039.62	294.81	4.3
		GOAT 2	4	1240	472.21	767.79	285.32	4.5
		GOAT 1	5	1560	595.22	964.78	270.28	4.6
		GOAT 2	5	1240	498.72	741.28	293.61	4.5
		GOAT 1	6	1560	520.24	1039.76	250.25	4.4
		GOAT 2	6	1240	435.22	804.78	295.39	4.3
		GOAT 1	7	1560	530.45	1029.55	270.36	4.7
		GOAT 2	7	1240	445.29	794.71	280.38	4.3
PERIOD1				19600	7083.90	12516.10	4002.12	63