EVALUATION OF THE NUTRITIVE VALUE OF SELECTED SOUTH SUDAN RANGELAND BROWSES FED TO CROSSBRED GROWING GOATS

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A Thesis Submitted to the Graduate School in Partial Fulfilment of the Requirements for the Award of Master of Science Degree in Animal Nutrition of Egerton University

EGERTON UNIVERSITY

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DECLARATION AND RECOMMENDATION

DECLARATION

I hereby declare that this thesis is my original work and has not been presented in this or any other University for any award.

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KM113/13565/14

SUPERVISORS' RECOMMENDATION

This thesis has been submitted to Graduate school with our approval as University supervisors.

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DEDICATION

This work is dedicated to my beloved wife Monica Alek, my son Emmanuel Deng and my two daughters Teresa Aduot and Yar Mamer, respectively.

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ABSTRACT

More than 78% of the households own livestock in South Sudan. Livestock, particularly cattle, goats and sheep, are an important social and economic asset in South Sudan. Goats are important and are predominant in most rural households with estimated population of 12.5 million heads. Despite the vast potential livestock contribution to the rural household development, livestock products (milk and meat) do not meet the local demands due to low productivity. The available seasonal feed resources are usually scarce, fibrous and deficient of essential nutrients, this is undermining livestock production and as well threatening the livelihoods of more than 78% of South Sudan's population. A study was designed to evaluate alternative feed resources to be included in designing nutrition packages for small ruminants to improve herd productivity. The selected South Sudan browse species namely, *Grewia tenax, Balanites aegyptiaca, Cordia sinensis, Tamarindus indica, Ziziphus spina-christi* and *Kedrostis foetidissima* were studied on the basis of proximate composition, *in vitro* gas production, palatability and the effect on intake, digestibility and body weight change of goats. In palatability, five of the above mentioned browse species were used except *K. foetidissima* whereas in performance (intake, digestibility and daily gain) an experiment was conducted in Completely Randomized Design (CRD) using twelve crossbred (Small East African x Toggenburg) growing goats assigned randomly to 3 treatments (*C. gayana*=control; Control+200g/d of *G.tenax* and Control+200g/d *Z. spina-christi*). The proximate composition showed differences (P<0.05) from 130-224 CP, 292-423 NDF, 172-356 ADF, 85.2-142 Ash, 858-976 OM, and 29.3-96.7 EE except DM (P>0.05). Condensed tannins varied moderately except *T. indica* which was observed to be highest in condensed tannin (≥60g/kg DM). Mineral concentrations varied from species with abundant quantities. After 24 and 48 hours incubation time, *Z. spina-christi* recorded the highest rate of gas production (20.9%/h) and potential gas production (9.56ml/200mg DM) while the lowest rate was in *T. indica* and the lowest gas production was in *B. aegyptiaca*. In Palatability, *G. tenax* was ranked the highest both in average daily intake (134g/kg DM/goat/day) and relative palatability index (76.1%). The results of supplementation showed higher dry matter intake and average daily gain for supplemented than non-supplemented goats. It was concluded that *G. tenax* was the highest in CP, most palatable and with the highest average daily gain (34.1g/day) when supplemented to poor quality *C. gayana* hay, and thus can be used to supplement low quality basal diet.

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LIST OF ABBREVIATIONS/ACRONYMS/DEFININGS

AAS	Atomic Absorption Spectrophotometer
Ad libitum	Free choice feeding
ADF	Acid detergent fiber
ANCOVA	Analysis of Covariance
AOAC	Association of Official Analytical Chemists
ARC	Agricultural Research Council
Browse	Leaf and twig growth of shrubs, woody vines, trees, cacti and other non-herbaceous vegetation available for animal consumption
CAMP	Comprehensive Agricultural Development Master Plan
CO_2	Carbon dioxide
CP	Crude protein
CT	Condensed tannin
Digestibility	A measure of how much of the nutrients in a sample (feed) an animal can actually extract and absorbed for productivity
DM	Dry matter
FEWS	Famine Early Warning Systems
FOA	Food and Agriculture Organization
Forage	plant material eaten by grazing livestock; that is grasses and other plants
GLM	General Linear Model
H_2SO_4	Sulphuric acid
ILRI	International Livestock Research Institute
In vitro	an *in vitro* is a test that is done in glass syringes in the laboratory
MPTS	Multipurpose trees and shrubs
N	Nitrogen
NDF	Neutral detergent fiber
NRC	National Research Council
Rangelands	Are grasslands, shrub lands, woodlands, wetlands and deserts that are grazed by domestic livestock or wild animals.
SAS	Statistical Analysis System
SSCCSE	Southern Sudan Centre for Census, Statistical and Evaluation
TAP	Tatton Agriculture Park
VFI	Voluntary feed intake
WFP	World Food Program

CHAPTER ONE

INTRODUCTION

1.1. Background information

Livestock keeping is critical to many of the poor in the developing world, often contributing to multiple livelihood objectives and offering pathways out of poverty. The rearing of livestock plays an important role in enabling smallholders to have resilient livelihoods and to avoid both food insecurity and poverty. Randolph *et al*., (2007) reported that livestock contributed one-third of the protein that people consumed and also in providing high-quality protein necessary for thinking and physical development. In developing countries like South Sudan, livestock is the key to food security, social welfare and economic wellbeing of about 80% of the population (FEWS, 2006). Livestock signalled status, wealth and serve as the main livelihood asset for pastoralist communities. They provide immediate source of protein to the ordinary citizen. Here, milk and meat constitute 30%, 40% to 65% of the diet in a normal year food economy for the Dinka, Nuer and Toposa communities, respectively (Fielding *et al*., 2000). However, during critical periods, animals hardly meet their high potential production (milk or meat) due to poor and inadequate quality of feed. This is because animals live predominantly on high fibre feeds, which are often deficient in nutrients. Moreover, the conventional feed resources such as, cereals, legumes, grass hay and their residues for livestock production are scarce and expensive not only in the study area but, in many parts of the world. Although, cereal residues are available annually, still there is a challenge in making it accessible with great waste for they are highly lignified. Since one of the major constraints on intensification of small scale livestock production is lack of good quality feed resources, it was worth studying ways of improving use of locally available feed resources, especially browse species (tree, shrub and legume) in the wild.

The six forages selected including *Balanites aegyptiaca*, *Ziziphus-spina Christi*, *Kedrostis foetidissima*, *Cordia sinensis*, *Grewia tenax* and *Tamarindus indica* could constitute vital components in livestock productivity in the region during dry season. The investigated species were selected based on the fact that little have been done for their forage potential. Although there are reporting that livestock feeds on them in the area, they are common and wide spread species which are available throughout the seasons and they are also judged by livestock farmers, who have fairly accurate knowledge of plants eaten by their livestock, to be palatable to goats and sheep.

Desert date (*Balanites aegyptiaca*) and sider (*Ziziphus-spina Christi*) contain crude protein levels that could be sufficient to meet the late dry season requirements of small ruminants (Lazim, 2007). Their leaves and fruits provide valuable animal fodder under open grazing conditions. Tamarind trees growing in woodlands are often the most preferred plant by wild ruminants, such as elephants and giraffes. The seed and kernels are high in proteins (13-20%), while the seed coat is rich in fibre (20%) and tannins (20%) (El-Siddig *et al*., 2006). But little have been tested for use in livestock. Stinking Kedrostis (*Kedrostis foetidissima*) is a perennial climber from the cucurbitaceae family that is common in dry low lands. It is characterized by nasty- smell, simple tendrils and almost circular heart-shaped leaves; fruits pear-shaped, pointed tip, red with long dense hair up to 2 mm long. This plant possesses various biological activities in prevention and treatment of ailments in the ancient history. The antimicrobial activities of various parts of this plant have aligned with old civilization history as food and medicine (Elavazhagan *et al*., 2013; Kavitha *et al*., 2014; Amutha and Lalitha, 2015). Despite its unpleasant smell, cattle has been seen in the study area feeding on it ravenously, but there is little available data on its chemical composition as animal feed, although it is believed by the herds-men to increase milk production of lactating cows. Being one of the potential preferential species, it is pertinent to investigate its chemical composition.

Furthermore, other plants in the area have been identified to have multiple roles in human and animal nutrition in the wild and at the same time as medicine, for example grewia species fruits according to Mohammed and Yagi, (2010) helps in treating anaemia. The species is known for its edible fruits which are nutritionally balanced and rich in iron and calcium. The shrubs are used in apiculture; bees visit the flowers for pollen and nectar. The young leaves are consumed by livestock and have fairly good feed value. However, lack of sufficient data on the nutritive value of the above species, together with absence of essential minerals, occurrence of high fibre and tannin in some native browse species and grass species (Elis, 1982; Fadel Elseed *et al*., 2002) has triggered the possibilities of exploring the browse plants highlighted above for their potential as animal feeds. Other driving factor that triggered further screening is encroaching human activities resulting to vigorous trees cutting and charcoal burning endangering browse species specially the climbing species *Kedrostis foetidissima*. That should be considered in conservation, domestication and improvement plans for this browse. Browse species like these could supplement low quality of pastures for grazing small ruminants, for they are an effective insurance against seasonal feed shortages.

Therefore, the main objective of this study was to evaluate the potential nutritive value of the leaves of *Balanites aegyptiaca*, *Ziziphus spina-christi*, *Kedrostis foetidissima*, *Grewia tenax*, *Cordia sinensis* and *Tamarindus indica* native species in South Sudan rangeland based on their proximate composition, palatability, phenolic concentrations, minerals, *in vitro* digestibility and effect of supplementation on feed intake, average daily weight gain and diet digestibility on crossed weaned growing goats.

1.2. The statement of the problem

Species of livestock reared in South Sudan include cattle, goats, sheep and chicken. Although the livestock population of South Sudan has not been accurately determined, (FOA/WFP, 2013) estimates 11.7 million cattle, 12.5 million goats and 12.1 million sheep. Despite the vast potential of 78% livestock contribution to the rural household development, livestock products (milk & meat) do not meet the local demands due to low productivity arising from seasonal poor quality feed resources availability and thus threatening the livelihoods of more than 78% of South Sudan's population. Inadequate livestock nutrition is a common and a major factor affecting the development of viable livestock industries in developing countries like South Sudan. Though, the rich biodiversity rangeland plays important roles in providing browse species and pasture, there were no previous attempts to improve herd productivity through supplementation. Lack or little awareness on the nutritive value of browse species had limited their usage as feed supplements during seasonal feed shortages. Therefore, to boost livestock productivity, this requires evaluation of chemical composition and use of locally available browse species in the rangeland as protein feed supplements.

1.3. Objectives

1.3.1. General objective

To contribute to increasing goats production through the utilization of browse species as alternative feed resource

1.3.2. Specific objectives

i. To determine the chemical composition and *in vitro* rumen fermentation characteristics of six selected local browse species.

ii. To determine palatability of six selected local browse species using crossed weaned growing goats.

iii. To determine the effects of supplementation of the selected browse species on feed intake, digestibility and average daily gain and by crossed weaned growing goats.

1.4. Hypotheses

i. There is no significant difference in chemical composition and *in vitro* rumen fermentation characteristics of six selected local browse species.

ii. There is no significant difference in palatability of the six selected local browse species using goats.

iii. There is no significant difference in the effects of supplementation of the selected forages on feed intake, average daily weight gain and digestibility by crossed weaned growing goats.

1.5. Justification

More than 78% of the households in South Sudan own and depend on livestock as a primary source of livelihood ((SSCCE, 2008). Goats are predominant in terms of numbers with estimated population of 12.5 million heads (FOA/WFP, 2013). The great bulk of all livestock production come from small holders and contribute 15% to the national gross domestic product (GOSS, 2010). However, during dry seasons small ruminants (goats and sheep) rarely meet their nutrient requirements. Consequently this result in low milk production, poor body condition, high mortality rate and inter communal fight over pastures. This is undermining livestock production and as well threatening the livelihoods of 78% of South Sudan's population. There was need to look into alternative local under-utilized browse species as feed supplements to small ruminants. This would increase production (milk & meat). Therefore, in this study, the browse species selected were evaluated and the information generated would be used in designing nutrition packages for small ruminants in Bor County South Sudan.

CHAPTER TWO
LITERATURE REVIEW

2.1. Livestock industry in South Sudan

In South Sudan, livestock is a symbol of status and wealth and most pastoral communities rear livestock for subsistence (milk and meat), to meet social obligations (bride price, stock alliances and stock patronages) and to insure against disaster (drought, epidemics, raids). Species of livestock reared in South Sudan include cattle, goats, sheep and chicken. Although the livestock population of South Sudan has not been accurately determined, the (FOA/WFP, 2013) estimated the figure of 36,222,802-38,402,329 ruminant animals comprising of 11.7 million cattle, 12.5 million goats and 12.1 million sheep. The above official estimates, however, differ from those in (CAMP, 2015) Livelihood Zone Data Book developed by the Ministry of Agriculture, Forestry, Cooperatives and Rural Development and the Ministry of Livestock and Fisheries Industries. This report gave the livestock population of the country as 41,979,705 in total including cattle, sheep, goats, camels, pigs and donkeys. Poultry rearing is a small but growing sector in South Sudan though not recognized in the national level. FAO estimated that there are about 5 million chickens in the country in few advanced farms around major towns and those reared by the poor households in rural areas. Donkeys are used for transport of water and household items during migration. Pigs are reared by few communities in Maban County of Upper Nile State. Other emerging livestock includes ostriches, guinea fowls, crocodiles, ducks and geese.

The great bulk of all livestock production come from small holders and contribute 15% to the national gross domestic product (GOSS, 2010). Although the contribution of livestock to the South Sudanese economy is significant, the national economy does not depend on it much compared to other industries like oil production. Hence there is needed to improve ruminant production (meat and milk) through provision of better feed, access to water and animal health care to increase resilience of pastoralist livelihoods.

2.2. Feed resources and grazing systems in South Sudan

South Sudan being vast country encompasses virtually every climatic and geographical features and wide range of vegetation cover. Vegetation in large parts of South Sudan is influenced by pattern and distribution of rains.

The topography of grazing areas is diverse from open plains to seasonal water ways, flood plains, woodlands, hills and mountains, river banks and associated islands forming a huge major source of feed for the country's national herds (Abate, 2006).

In areas of low rainfall distribution, savannah grassland is predominantly found mixed with acacia species and small bushes whereas in the high rainfall, perennial grass species and inconsistent woodlands are overriding. However, seasonality fluctuate both quantity and quality of pastures resulting to nutritional inadequacy. Livestock production is mainly on free grazing or browsing system, where cattle keepers practice either agro-pastoralism or transhumance. Here, pastoralism has been the principal land use where pastoralist groups migrate with their herds throughout the year following rainfall distribution pattern and availability of green pastures. First movement is during dry season, where they move to river banks and associated islands called **'**toch**'** (swampy areas) and come back to dry land when the river banks and associated islands become flooded. Second movement is during raining seasons when there is the highest rate of tsetse fly infestation, they are forced to move from highlands to low lands and finally is internal and external movement across the borders (Pantuliano *et al*., 2009).

2.3. Nutritional value of fodder trees and shrubs

Fodder trees and shrubs exist either naturally or planted and are used to feed livestock for they provide the nutritional needs of the animals. The use of browse species as fodder for ruminant is increasingly becoming important in many African countries for they complement high cellulose grasses during dry season (Van *et al*., 2005; Babayemi and Bamikole, 2006). Free grazing animals consume almost all parts of the forage trees, but mostly the shoot, tender twigs, the stem of woody plants together with their leaves, flowers and fruits or pods (Aganga and Tswenyane, 2003; Hassen *et al.*, 2010). However, preference varies; in most cases leaves are frequently consumed because of being high in organic matter, crude protein and easily digestible than other parts of the plant. Numerous shrub and tree species have been investigated and multiple attributes of some of them have been confirmed in terms of crude protein, minerals and digestibility than grass (Devendra, 1990; Topps, 1992).

In Sub-Saharan Africa, acacia trees are dominant and have been reported to have high crude protein content. For example in Kenya according to Abdulrazak *et al*. (2000) the crude protein content of the leaves of *Acacia brevispica*, *Acacia nubica, Acacia tortilis, Acacia seyal, Acacia nilotica,* and *Acacia mellifera* were reported to be ranging from 134 to 213g/kg DM. Also *Acacia karroo, Acacia nilotica, Acacia tortilis, Acacia galpinii, Acacia sieberiana, Acacia hebeclada* and *Acacia rhemniana* have been reported to have crude protein levels above 100g/kg DM, with the range of 103g/kg DM in *A. rhemniana* to 183g/kg DM of *A. sieberiana* (Mokoboki *et al.*, 2005).

This amount of crude protein (CP) is more compared to 80 g/kg CP, the minimum requirements that supported microbial growth and optimum roughage intake in ruminants (Minson, 1981; Van Soest 1994; Preston and Leng, 2009) at low to medium production levels. The level of crude protein is known to influence intake of forage and therefore, for optimum rumen function presence of adequate amount of protein in the diet is a must, the opposite is true, for the decline of voluntary feed intake in forages containing less than 70g/kg crude protein (NRC, 2000). This was reported by Komwihangilo *et al., (*2001) where most farmers indicated differences in browse voluntary intake and subsequent performance of browsers on different fodder trees or shrubs with *Dichrostachys cinerea* as most preferable species by both cattle and goats in South African region. Generally, Elevitch and Wilkinson (2000), highlighted other applications and uses of fodder trees and shrubs in enhancing environmental resilience, human food, timber, medicine and as wildlife habitat.

2.3.1. Leguminous trees as source of protein supplement for ruminant animals

Emmanuel and Tsado (2011), distinguished legumes family to play the major role in soil nitrogen fixations and to produce highly digestible and protein-rich fodder in the plant kingdom. Leguminous trees are potential source of relatively high quality fodder readily available to many smallholders in free ranges in the rural and semi-urban areas. The use of well-known tree legume fodders such as *Giliricidia sepium* and *Leucaena leucocephala* as supplements have been reported to improve intake, digestibility and animal performance (Norton, 1994; Abdulrazak *et al*., 1996). The addition of forage legumes to grazing or haying systems provides additional protein, energy, and improve palatability to the feed produced. *Balanites aegyptiaca* and *Acacia seyal* supplemented to grass-based diet had been reported to improve the performance of Dorper sheep (Kitilit *et al*., 2006). In Sudan the leaves of *Balanites aegyptiaca* serve the purpose of fodder for livestock especially for goats for its leaves has been reported to contain 263g/kg crude protein (Rathore and Meena, 2004).

Forage tree legumes provide a cheap and readily available source of high quality protein and can improve animal productivity and hence the sustainable livelihoods of resource- poor smallholder farmers in developing countries. Further, legumes add nitrogen to the soil for grass to utilize and assist in filling in the grass sward to inhibit weed growth. The selection of the "best" grass or legume system must consider both the adaptability of a particular type of forage to a specific site and soil, the nutritional needs of the animals, and the management goals of the producer. Legumes such as *alfalfa*, clover, and *lespedeza* tend to be higher in protein, vitamins, and minerals (especially calcium) than grass hays.

The energy, as well as protein content, depends upon the maturity of the forage when it is being grazed for forage (An Peischel, 2005).

2.3.2. Anti-nutritional factors in tree and shrub forages

The presence of secondary compounds mainly tannins in a wide range of tree and shrub species has been reported to hamper their fodder potentiality (Makkar, 2003). Tannins cause toxicity when present in its two form; that is either hydrolysable or condensed by reducing considerably the nutritive value of browse and tree foliage. Mueller-Harvey (2005) concluded that hydrolysable tannins are harmful, but condensed tannins (CT) are safe as long as they account for less than 50g/kg of dry matter in feed. Tannins form complexes mainly with proteins and also with carbohydrates, amino acids and several minerals; thereby, reducing their availability as well as intake, digestion and animal growth. Several researches had been done on the negative effect of tannins in most of the shrub and trees species available in Africa and Asia. For instance *Acacia cyanaophylla. (Syn.A. saligna)* one of the evergreen leguminous fodder shrub, generates high consumable biomass. Despite its high crude protein content, tannins have been shown to decrease availability of acacia proteins and also those of the whole of the diet resulting to low daily body gain in sheep and goats fed this shrub resulting to low intake of acacia foliage and digestibility (Ben Salem *et al.*, 1997, 1999). However, tannins besides the negative effect, increase the by-pass proteins, and the bound proteins become available post- ruminally. Thus, it acts as a barrier of proteins access to the rumen microbes, making tannins to become an advantageous compound in ruminant feeding system. Several tannin-rich legumes (Makkar, 2003) and Acacia (Ben Salem *et al*., 2005) are suggested to be used in increasing by-pass protein leading to improved ruminant performance.

2.3.3. Medicinal uses of local fodder trees and shrubs

Higher plants, used as sources of medicinal compounds have continued to play a crucial role in the maintenance of human and livestock health since ancient times. From the modern perspective, studies on local fodder trees and shrubs revealed most of plants species have nutritional and therapeutic importance (Kharb and Singh, 2004). For example *Kedrostis foetidissima* has been reported in India to possess antimicrobial properties against *Streptococcus aureus, Escherichia coli, Pseudomonas aeruginosa, Klebsiella pneumonia, Serratia marcescens* (Elavazhagan and Balakrishnan, 2013). Ethno-diagnostic studies in Kenya reported the leaves of the same plant species to cure cattle suffering from pasture bloat (Ole-Miaron, 2003).

In addition, Maphosa *et al.,* (2010) reported other fodder trees from Fabaceae family in treatment of various animal diseases, ranging from bacterial diseases to conditions caused by internal and external parasites. However, not only are fodder trees useful in treatment of livestock diseases, but also in treatment of human diseases. For instance the antibacterial effect of the multipurpose *Balanites aegyptiaca* and *Moringa oleifera* fodder trees have been reported against *Salmonella typhi* which causes the typhoid fever (Dougnariet *et al.,* 2007). Therefore, good management should be done for fodder trees and shrubs that make up an important animal feed source and at the same time as medicines in order not to extinct.

2.4. Preferences and palatability of browse forages

Palatability is a plant characteristic that refers to the relish with which the plant or its parts or feed are consumed as stimulated by the sensory impulses of grazing animal (Heath *et al*., 1985). Yusmadi and Ridla (2008) described palatability as feed characteristics by organoleptics such as appearance, smell, taste, texture and temperature, giving rise to stimuli and attractiveness of animal to consume. While preference refers to selection of a plant species by the animal as a feed or a proportional choice of two or more feeds or relative consumption of one plant over another by a specific class of animal when given free choice of a particular time and place. Grazing animals eat an array of plants, but often prefer some and avoid others that cause toxicosis, inhibit digestion or cause malnutrition. Goats differ from other animals in feeding behaviour, level of intake, diet selection, taste discrimination, and rate of eating due to the in differences in anatomy and physiology (Ngwa *et al*., 2000; Lu *et al*., 2005). The intake of feed is determined by complex interaction of a pre-and post-absorptive factors (Inoue' *et al.*, 1994). If the voluntary intake is too low, the rate of production will be depressed, resulting in requirements for maintenance becoming a very large proportion of metabolisable energy consumed and so giving a poor efficiency of feed conversion (Forbes, 1995).

2.5. Performance of ruminants supplemented with browse forages

One of the major challenges to the productivity of small ruminants in developing countries is poor nutrition resulting in variation in production, birth rate, late pregnancy, neonatal losses and vulnerability to diseases especially the undernourished animals during limited feed supply in dry seasons. Fodder from trees is useful in the dry season when it is used to supplement roughage or hay. Kernel meal, the residue remaining after oil extraction, is widely used in Senegal, Sudan and Uganda as a stock feed. *Balanites aegyptiaca* is one of the most important fodder tree in western Sudan because of its mineral contents, high digestible DM and has a useful crude protein supply especially during dry seasons (Anon, 2004).

ElKhidir *et al*., (1983) reported the use of *Balanites* kernel cake in the diet of fattening sheep. In Burkina Faso, *B. aegyptiaca* contributed up to 30% of DM intake of goats in dry season. Potentially, rangelands legume tree forages, shrubs and small bushes have a lot of studies showing better source of nitrogen, minerals and digestible nutrients than the dominant savannah grasses (Devendra, 1990; Topps, 1992).

In Kenya, farmers feed leaves of fodder trees to small ruminants and cattle, for example *Leucaena leucocephala*, *Sesbania sesban*, *Calliandra calothyrsus* and *Gliricidia sepium.* Also acacia tree species have been seen to improve feed intake, digestibility and animal performance in terms of weight gain and milk production in both goats (Ondiek *et al*., 1999) and cattle (Abdulrazak *et al*., 1996) respectively. Similarly, Osuga *et al*., (2012) observed increased DM intake and body weight gain in goats supplemented with maize bran, *Berchemia discolor* or *Ziziphus mucronata* to a basal diet of low protein (5% CP) *Chloris gayana*. This agreed with results of Ondiek *et al*., (2013) who observed increased intake, diet digestibility and body weight change in goats supplemented with *Acacia tortilis* or *Balanites aegyptiaca* to a basal diet of low protein (4.6% DM CP) maize stover. A research carried by ILRI concluded that *Erythrina abyssinica* has high foraged potential and serve as inexpensive source of protein supplement with low quality diets during the dry season for poor farmers with stall-fed sheep and goats (Larbi *et al*., 1993a). *Dichrostachys cinerea* from Nigeria is one of the valuable fodder trees and its fruits supplemented to goats has been reported to improve performance (Smith *et al.*, 2005). With the foregoing, it was hypothesized that *Ziziphus spina-christi* and *Grewia tenax* would have a similar positive effect in improving feed intake, digestibility and weight gain of goats when supplemented to Rhodes grass hay.

CHAPTER THREE
MATERIALS AND METHODS

3.1. Experimental sites

The experiment was conducted at sheep and goat unit of Tatton Agricultural Park (TAP), Department of Animal Sciences; Egerton University in Njoro Campus during the early rainy season. The area lies at an altitude of 2238 m above sea level, with an annual mean range temperature of 17 to 22^{o}C and annual rainfall of 900-1200 mm (Engineering meteorological Station, 2009).

3.2. Browse species collection and preparation

Fresh leaves from branches of six selected browses plant species; *Grewia tenax*, *Tamarindus indica*, *Balanites aegyptiaca*, *Ziziphus spina-christi*, *Cordia sinensis* and *Kedrostis foetidissima* were harvested or collected from several stands in the rangeland of Bor County, Jonglei state in South Sudan (Figure 1) between November and March 2015. Bor County is characterized by tropical wet and dry climatic zone. It lies between latitude 6^{o}12′ 45″ N and longitude 31^{o} 33′ 39″ E with an altitude of 407-430m above sea level and annual mean rainfall and temperature of 891 mm and 27.3-33.7^{o}C, respectively (Climate-Data.org, 2013). The fresh leaves or foliages of the six selected browse species were harvested separately from several trees/shrubs by hand picking. The browse species were selected based on local farmers' knowledge of the species consumed by goats and also based on their availability throughout the seasons. They were also judged by farmers to be palatable to goats and sheep. Every collected fresh foliage of the selected browse plants were air dried in the shade to constant weight for 2-4 days, then pooled, packed and stored in bags before their export to Egerton University, Kenya for subsequent laboratory analysis and feeding trials. At Egerton University, the dried leaves were ground to pass through 4 and 1mm sieve (Appendix 1; figure 3a and 3b) for feeding trials and chemical analysis, respectively (AOAC, 1990).

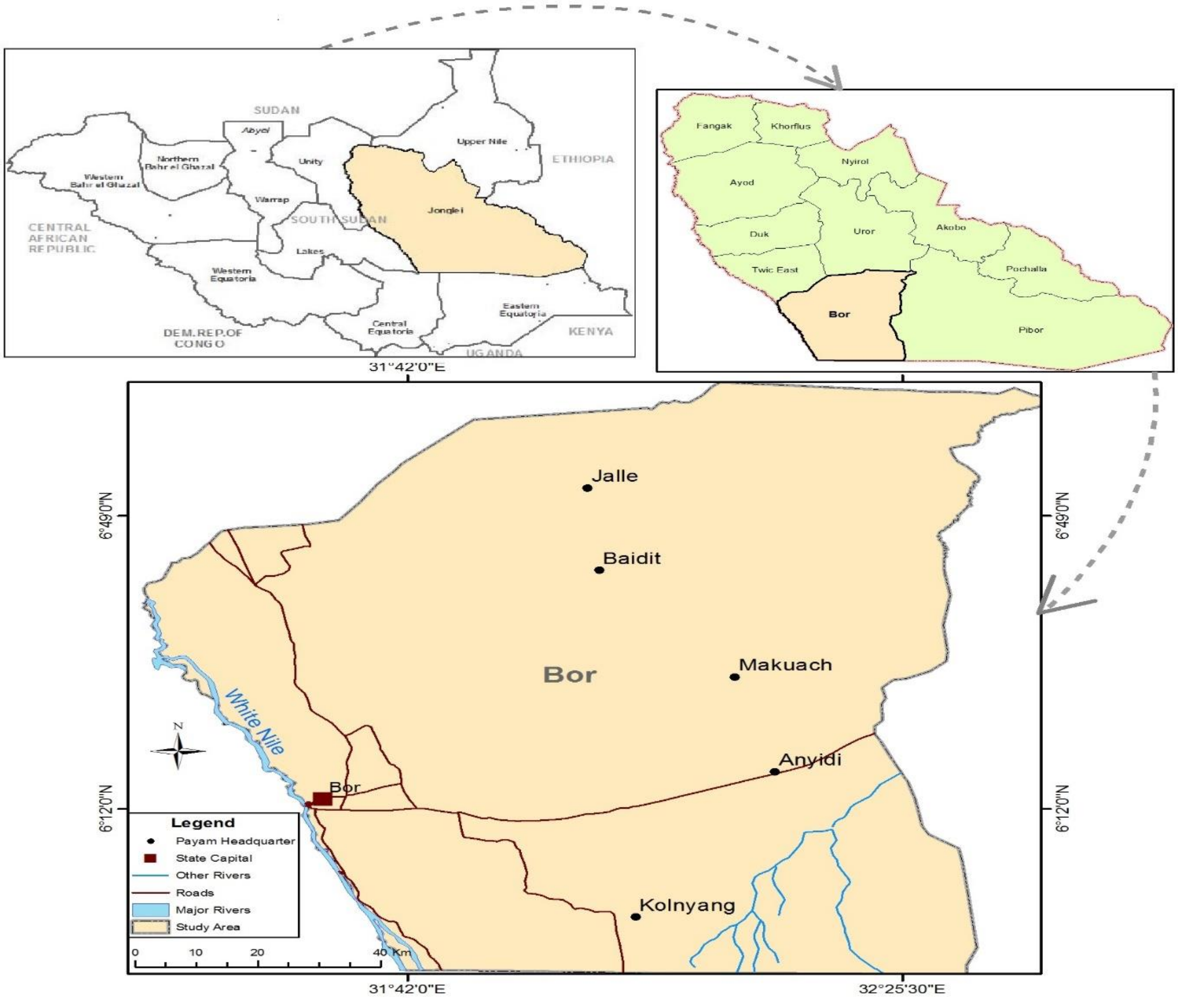

Figure 1. Map of Bor browse species collection site (Source: DIVA-GIS Website, 2017)

3.3. Proximate, fibre, mineral contents and *in vitro* gas production determination

3.3.1. Proximate, fibre, mineral and condensed tannin contents determination

Proximate analysis was examined and expressed on dry matter basis according to method described in (AOAC, 1990). Neutral detergent fibre and Acid detergent fibre were determine according to ANKOM^{200} Technology (2014). Condensed tannins (CT) were measured and calculated as leucocyanidin equivalent, following the method of Porter *et al*., (1986). Elements (Ca, Mg, Na, P, K, Fe, Co, Zn, Cu and Mn) were determined using Atomic Absorption Spectrophotometer (AAS).

3.3.2. *In vitro* gas production

The *in vitro* gas production was determined according to Menke and Steingass, (1988). Three male goats were fed grass hay and browse leaves (*Grewia tenax, Ziziphus spina-christi, Balanites aegyptiaca, Cordia sinensis, Tamarindus indica and Kedrostis foetissima*) in 75: 25 ratios, respectively (%DM basis).

The goats were offered half of the total grass hay and the browse leaves once at 9: 00 am and the remaining half of hay at 2:00 pm. The goats had free access to clean drinking water and were maintained under hygienic conditions. After 2 weeks of feeding rumen liquor was collected from goats with use of a suction tube (Appendix 2; figure 4a) prior to morning feeding. The collected rumen liquor was sieved through four layers of cheese cloth and kept at 39°C. All laboratory handling of rumen fluid was carried out under a continuous flow of carbon dioxide (CO_2). Samples (0.2g) of the oven dry and milled leaves of each browse species were accurately weighed into 100 ml calibrated glass syringes fitted with plungers. *In vitro* incubation of the samples was conducted in triplicate. Syringes were filled with 30 ml of rumen-buffer (1:2) mixture consisting of 10 ml of rumen fluid and 20 ml of buffer solution and three blank samples containing 30 ml of medium (inoculums and buffer) only were incubated at the same time. The syringes were placed in a rotor inside the incubator at 39°C (Appendix 2; figure 4b) with about one rotation per min. The gas production was recorded at 3, 6, 9, 12, 18, 24, 36, 48, 72 and 96h. The average of the volume of gas produced from the blanks was deducted from the volume of gas produced from sample. The mean gas volume readings were fitted according to Ørskov and McDonald, ((1979) model using Neway` computer program (Chen, 1997) Rowett Research Institute, Aberdeen.

$P = a + b\left(1 - e^{-ct}\right)$ where: *p*, is gas production at time *t*; *a+b* are the potential gas production; *c* =the rate of gas production and;
a, b and *c* are constants.

3.4. Preference and Palatability rating procedures

Palatability study was conducted in a cafeteria feeding approach described by Larbi *et al*., **(**1993b) using *Grewia tenax*, *Balanites aegyptiaca*, *Tamarindus indica*, *Ziziphus spina-christi* and *Cordia sinensis*. *Chloris gayana* hay was provided as basal diet to the goats. In Completely Randomized Design, four crossed (Small East African x Toggenburg) weaned growing goats with initial mean body weight (16.6 ± 0.04 kg) and 4-5 months of age were housed in individual pens of (1.5 x 2.5m). The goats were vaccinated and treated against internal and external parasites with Ivermectin and adapted for 2 weeks. The adaptation phase was necessary for familiarizing goats to the tested browse species. Each pen was provided with water container and a hanged feed trough designed in a way that each has six partitions or compartments to accommodate each of the five tested browse species and hay. This was to ensure that each goat has free access to any of the five tested browse species.

The 4 mm chopped browse species was offered 200g each every day with allowance of 30 minutes feeding time. The refusals (residual material) were collected, weighed and intakes were determined. Each day, the physical positioning of the tested browse species in the feed troughs were altered to eliminate possible biasness from goats' inborn preferences for one side (to avoid habit reflex). Chopped Rhodes grass hay, water and mineral supplement were offered *ad libitum*. Palatability was calculated for each browse, separately for each goat as daily feed intake divided by that of the highest feed intake and expressed as percentage means (Larbi *et al*., 1993b) and then ranked for each goat and separated into classes of high (>60%), medium (35-55%) and low palatability (<25%) (Lambart *et al*., 1989; Obour *et al*., 2015). Palatability studies could be used in designing supplemental feeding programs for ruminants in the tropics. Feed intake and relative palatability index were calculated using formulae as shown below:

$$\text{Feed intake, DM basis (g)} = \text{Feed intake, fresh basis} * \text{DM content of the tested diet}$$

$$\text{Relative Palatability index} = \frac{\text{Daily feed intake}}{\text{Highest feed intake}} * 100$$

3.5. Effect of supplementing *Chloris gayana* with either *Grewia tenax* or *Ziziphus spina-christi* on feed intake, faecal digestibility and daily weight gain of crossbred (Small East African x Toggenburg) growing goats

3.5.1. Housing and experimental goats

The experiment on effect of supplementation used crossbred weaned growing goats of 4-5 months of age to measure feed intake, digestibility and daily weight gain. The goats were housed individually in well-ventilated pens (1.5 x 2.5m) with timber slated floors under congregated roofed house to protect from rain and direct adverse sun light. The pens were designed with wire mesh and polythene sheet beneath it to collect faeces and urine separately. Prior to placing of the goats, pens were cleaned and disinfected. The goats were treated with Ivermectin (0.5ml/10 kg live weight) to control internal and external parasites followed by 2 weeks of adaptation to the experimental treatments and pens.

3.5.2. Dietary treatments and experimental design

The effect of three treatments on intake, digestibility and daily gain of crossbred (Small East African x Toggenburg) growing goats were investigated. Weight at the beginning of the experiment (initial weight) was recorded, but not used in the assignment of goats to treatment. The experimental plan was in a Completely Randomized Design (CRD) with three (3) treatments and four replications.

The experimental treatments designated as T_1, T_2 and T_3 were from *C. gayana* hay, *G. tenax* and *Z. spina-christi*, respectively. Treatment (T_1) served as control and contained no browse species supplement whereas T_2 and T_3 contained 200g/day of *G. tenax* and *Z. spina-christi* supplement, respectively. The two browse species were selected based on the previous follow-up experiments on proximate composition, palatability and *in vitro* gas production. Based on 3-4% body weight, the goats were offered half of the total Rhodes grass hay and the browse leaves once from 9-10:00 am and the remaining half at 3:00 pm daily (Appendix 3; figure 5a) East African time. Experimental goats had free access to clean drinking water and were maintained under hygienic conditions. The daily data on feed offered and residual materials for each goat was weighed and recorded in the morning before fresh feeds were offered and daily intake was calculated by difference besides subsequent daily gain eight weeks data collection (Appendix 3; figure 5b). After the feeding trial, a nutrient digestibility trial was conducted.

3.5.3. Digestibility trial

After the growth trial, the three groups of four animals each were used for digestibility trial. Each goat in an individual pen was an experimental unit with facilities for collecting faeces. Total faeces aliquot voided by the experimental goats were collected for 1 week in separate plastic containers (Appendix 4; figure 6a). The total daily (24h) faecal output were weighed and a 10% aliquot of each was sampled oven dried at 60^{o}C (Appendix 4; figure 6b) for 48 hours and milled through a 1 mm sieve and packed in airtight bottles pending laboratory analysis. Nutrient digestibility (g/kg DM) such as organic matter (OMD), dry matter digestibility (DMD) and crude protein (CPD) in the faeces were calculated using the formula of Njidda and Nasiru, (2010) as shown.

$$\text{Nutrient digestibility}\left(\frac{\text{g}}{\text{kg}}\right)\text{DM} = \frac{\text{nutrient in feed} - \text{nutrient in faeces}}{\text{nutrient in feed}} * 1000$$

3.6. Chemical analysis

Proximate fractions, including dry matter (DM), ash, organic matter (OM), ether extracts (EE) and total nitrogen (N), in feed and faeces was determined following standard methods (AOAC, 1990). Crude protein (CP) was obtained by multiplying Nitrogen (N) in feeds (browse species) and faeces by the factor (6.25). Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were determined according to ANKOM^{200} Technology, (2014). The extraction of phenolics was carried out by using 70% aqueous acetone and total extractable phenols (TEPH) determined using Folin Ciocalteu procedures as described by Julkunen- Titto, (1985) and Evitayani *et al*., (2004).

The concentration of TEPH was calculated using the regression equation of tannic acid standard. The condensed tannin (CT) were measured and calculated as leucocyanidin equivalent, following the method of Porter *et al*., (1986). Macro and micro minerals: calcium (Ca), phosphorus (P), magnesium (Mg), sodium(Na), potassium (K), iron (Fe), copper (Cu), zinc (Zn), cobalt (Co), and manganese (Mn) were analysed using atomic absorption spectrophotometer (AAS).

3.7. Statistical analysis

The data collected on proximate composition, condensed tannin, mineral concentration, *in vitro* gas production characteristics, dry matter intake (DMI), Relative palatability index (RPI), Average daily gain (ADG) and OM, DM and CP digestibility were subjected to Analysis of Covariance (ANCOVA) using General Linear Model procedure of Statistical Analysis System (SAS version 9.0, 2002). Initial live weight was used as covariates in testing the effect of treatments for digestibility (DM, OM & CP) and average daily gain (ADG). Significant differences in the means were tested and adjusted using a multiple comparisons: using Turkey's test at (P<0.05).

The model used in the analysis of variance was:

$\gamma_{ijk} = \mu + \tau_i + (\beta_j) + \varepsilon_{ijk}$ where:

γ_{ijk} ,= is response variable of interest for example ADG;

μ =overall mean common to all;

τ =fixed effect of the ith treatments (*Chloris gayana*, *Grewia tenax*, and *Ziziphus spina-christi*);

$\beta\ j$ =fixed effect of the individual goat's induction body mass used as covariates (dependent variables) and;

ε_{ijk} =random error

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1. Chemical composition of the browse forages

The chemical composition of the leaves of the browse species is presented in Table 1. There were considerable significant ($P<0.05$) variation in browse specie chemical composition except DM. The ash and OM contents varied moderately among the species. The NDF and ADF ranged from (292-689 g/kg DM) and from (172-494g/kg DM), respectively for all species. *Chloris gayana* had the highest ($P<0.05$) NDF (689g/kg DM) and ADF (494g/kg DM) followed by *Cordia sinensis* NDF (423g/kg DM) and ADF (356 g/kg DM). Higher NDF and ADF contents are practically qualities of poor feed for they stimulated longer eating time, low feed intake, low digestibility as well as animal's poor performance (McDonald *et al*., 2002; Linn, 2004). The lowest detergent insoluble cell walls (NDF and ADF) were obtained in *Balanites aegyptiaca*, *Kedrostis foetissima*, *Grewia tenax* and *Ziziphus spina-christi* respectively and may be attributed to good characteristic of feed (Bakshi and Wadhwa, 2007). The concentration of crude protein (CP) and condensed tannin (CT) significantly ($P<0.05$) varied from the browse species. The lowest CP content was observed in *C. gayana* (41.4 g/kg DM), whereas the browse species had CP content ranging from 130 g/kg DM in *T. indica* to 224 g/kg DM in *G. tenax*. *Chloris gayana* hay CP had a CP that was below 8%, the minimum CP for microbial growth and optimum roughage intake (Minson, 1981; Preston and Leng, 2009). The CP values of browse species were above the minimum critical level (8%) that supports normal intake and rumen functioning (Ikhimioya, 2008), the requirement for lactation (12% CP) and growth (11.3% CP) in the diets of ruminants (ARC, 1984). The concentration of CT ranged between (3-38 g/kg DM) which is of nutritional benefits of ruminants. *T. indica*, however had CT (≥60g/kg) which is detrimental. The condensed tannins, phenolic, chemical and the mineral composition of browse species in this study, were consistent with values reported by Fadel Elseed and Amin (2015) for *B. aegyptiaca* and *Z. spina-christi* and by Balehegn *et al*., (2015) and Welay (2011) for other browse species in the rangelands.

Table 1. Chemical composition (g/kg DM) of selected browse species of South Sudan as feeds for goats

Species	DM	OM	Ash	CP	EE	NDF	ADF	PHE	CT
B.aegyptiaca	635	858^{f}	142^{b}	152^{c}	39.3^{b}	292^{e}	222^{d}	21.7^{c}	6.74^{c}
G. tenax	919	894^{d}	106^{d}	224^{a}	41.6^{b}	358^{c}	172^{f}	12.5^{d}	8.43^{c}
Z.spinachristi	927	908^{c}	89.5^{e}	166^{c}	29.3^{bc}	364^{c}	180^{f}	42.6^{b}	37.6^{b}
K. foetissima	882	976^{a}	239^{a}	195^{b}	30.7^{bc}	310de	248^{c}	13.6^{d}	3.56^{c}
T. indica	919	915^{bc}	85.2^{ef}	130^{d}	88.1^{a}	336^{cd}	205^{e}	73.3^{a}	61.8^{a}
C.sinensis	890	881^{e}	119^{c}	160^{c}	96.7^{a}	423^{b}	356^{b}	5.47^{e}	3.37^{c}
C. gayana	921	921^{b}	79.0^{f}	41.4^{e}	20.8^{c}	689^{a}	494^{a}	4.31^{e}	1.97^{c}
±SEM	103	0.220	1.86	4.17	3.66	8.09	3.21	0.292	1.45
P	.434	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001

^{abc} Means in the same column with different superscripts are different at (P<0.05); DM=dry matter; OM=organic matter; CP=crude protein; EE=ether extracts; ADF=acid detergent fibre; NDF=neutral detergent fibre; CT=condensed tannin; PHE=extractable phenolics; SEM=standard error of means

4.2. Macro and micro mineral concentration of browse species

The macro and micro mineral concentration of browse species is presented in Table 2. There were considerable significant (P<0.05) variation in browse species. *B. aegyptiaca* was outstandingly high in Ca (26.6g/kg DM), Fe (266mg/kg DM), Co (5.61g/kg DM) and Mn (50.7mg/kg DM). *C. sinensis* besides being the highest in Zn (336mg/kg DM), contained the least concentrations of (Cu, Fe, Mn, K, Na & Ca). In contrast to this current study, Kuria *et al*., (2004) reported higher (Na, Fe, K, & Ca) and lower (Cu & Zn) contents in *C. sinensis*, respectively, whereas in the same study, Kuria *et al*., (2004) reported lower (Cu, Zn, K & Na) in *G. tenax* and *B. aegyptiaca*. Many authors have reported *T. indica* leaves as fair source of vitamin C, alpha carotene in addition to high mineral contents especially P, K, Ca and Mg (Nordeide *et al*., 1996; El_siddig *et al*., 2006; De Caluwe *et al*., 2010), which is similar to the current study except Zn which is relatively greater than the reported value by Nordeide *et al*., (1996). Although, *Kedrostis foetidissima* has low K (3.60g/kg DM) and low Fe (120mg/kg DM) it is relatively high in the other macro and micro mineral although the information about the browse species is limited. Furthermore, *G. tenax*, *B. aegyptiaca* and *Z. spina-christi* mineral contents were comparably consistent with the work of (Niemat Abdalla *et al*., (2012) and Fadel Elseed *et al*., (2015).

In this work, Ca, Mg, Cu, Fe, Zn, Co values obtained except P and Mn were similar with results of Rubanza *et al*., (2007). Macro and micro mineral concentrations in this study were higher than the recommended requirements for various physiological and production functions of ruminants (Underwood and Suttle, 1999; Meschy, 2000; NRC, 2001).

Table 2 Macro and micro mineral concentration contents of browse species of South Sudan

	Macro minerals (g/kg DM)						Micro minerals (mg/kg DM)			
Species	**Ca**	**Na**	**P**	**Mg**	**K**	**Co**	**Fe**	**Mn**	**Cu**	**Zn**
G. tenax	23.8[c]	118[c]	2.52[c]	5.07[c]	49.1[a]	5.59[d]	124[d]	29.1[b]	94.9[b]	123[c]
Baegyptiaca	26.6[a]	119[b]	1.35[f]	11.3[b]	14.2[d]	5.61[a]	266[a]	50.7[a]	53.2[e]	87.3[f]
Zspinachrisi	17.0[e]	121[a]	1.95[d]	3.36[d]	20.5[c]	5.30[e]	208[b]	19.7[c]	62.9[d]	93.6[e]
T. indica	21.5[d]	113[e]	1.87[e]	13.4[a]	9.11[e]	5.60[c]	129[c]	19.8[c]	99.8[a]	114[d]
Kfoetidissima	24.0[b]	119[b]	3.55[a]	13.4[a]	3.60[g]	5.61[b]	120[e]	14.8[d]	72.0[c]	125[b]
C. sinensis	16.9[f]	0.75[d]	1.15[g]	5.07[c]	8.37[f]	ND	74.6[f]	8.12[e]	29.3[f]	336[a]
C. gayana	2.49[g]	ND	3.27[b]	1.29[e]	22.1[b]	.000	.004[g]	.00[f]	.40[g]	.013
±SEM	.001	.001	.003	.003	.014	.012	.016	.022	.147	.034
P	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001

[abc] Means in the same column with different superscripts are different at (P<0.05); ND=not done; Co=was expressed in g/kg DM; SEM=standard error of the means

4.3. Gas production and estimated parameters

Gas production and fermentation parameters (a, b, c, and a+b) at 24hour and 48hour (h) are presented in Table 3. There were significant (P<0.05) variations in the browse species in gas production and estimated parameters. Differences in gas production could be due to the amount of substrate fermented *in vitro*. The gas production of *Z. spina-christi* (12.6ml/200g DM) and *G. tenax* (16.7ml/200g DM) were significantly (P<0.05) higher than the others at 24 and 48h, respectively. *T. indica* produced the lowest (4.71ml/200g DM) gas volume while in potential gas production the highest and the lowest were recorded in *Z. spina-christi* (9.56ml/200g DM) and *B. aegyptiaca* (6.43ml/200g DM), respectively. The rate of gas production was the highest in *Z. spina-christi* (20.9%/h) and the lowest in *T. indica* (0.042%/h). The *in vitro* gas production and fermentation parameters indicate the presence of potential degradable nutrient in browse species which underscores the importance of these indigenous browse species as source of nutrition for ruminants.

The high extent of gas production of *Z. spina-christi* maybe due to organic matter (OM) availability which was fermented to form volatile fatty acids and, therefore, high gas volumes was produced or maybe attributed to nutrient availability for ruminal microorganisms and high extent of fermentation. The observed low gas production of *T. indica* might be due to its high condensed tannin content which reduces the population of fiber degrading bacteria in the rumen and hence low activity (Makkar and Becker, 1996; Getachew *et al*., 2000). *B. aegyptiaca* ranked the lowest in gas production potential, this trend could be due to level of tannins and other anti-nutritive factors. The highest rate of gas production observed in *Z. spina-christi* was probably due to presence of fermentable carbohydrate or nutrient availability, on the other hand, it is a reflection of microbial growth and accessibility of feed to microbial enzymes (Getachew *et al*., 2000; Fievez *et al*., 2005).

Table 3. Mean *in vitro* gas production and characteristic parameters of selected browse species of South Sudan

Species	Reading Hour		Estimated Parameters				
	24h	48h	a	b	a+b	c(%h)	Rsd
T. indicus	4.71^{c}	7.48^{bc}	0.449^{a}	6.02^{f}	6.47^{e}	0.042^{f}	1.98^{f}
B. aegyptiaca	9.92^{ab}	6.62^{c}	0.368^{a}	6.06^{e}	6.43^{f}	13.0^{c}	4.22^{b}
K. foetissima	9.83^{ab}	7.19^{c}	0.808^{a}	6.46^{d}	7.27^{d}	18.6^{b}	3.00^{e}
Grewia tenax	6.53^{bc}	16.7^{a}	0.433^{a}	8.01^{c}	8.45^{c}	0.082^{d}	4.74^{a}
C. sinensis	7.49^{bc}	14.2^{a}	0.446^{a}	8.37^{b}	8.82^{b}	0.07^{e}	3.85^{d}
Z. spina_christi	12.6^{a}	12.9^{ab}	0.888^{a}	8.67^{a}	9.56^{a}	20.9^{a}	3.96^{c}
±SEM	0.925	1.16	0.707	0.0008	0.0006	0.0007	0.0009
P	.0001	.0001	.0001	.0001	.0001	.0001	.0001

^{abc} Means in the same column with different superscripts are different at ($P<0.05$); ^{C}gas=gas production rate; ^{a}gas=gas production (ml) from readily soluble fraction; ^{b}gas=gas production (ml) from insoluble fraction; (a+b)=potential gas production; SEM=standard error of the means

4.4. Palatability trial

The mean values of daily intake and palatability of the five selected browse species are presented in Table 4. The order for preference ranking is from the most palatable species to the least palatable one based on dry matter daily intake and relative palatability index:

G. tenax > *Z. spina-christi* > *B. aegyptiaca* > *C. Sinensis* > *T. indica*. These results have shown significant ($P<0.05$) differences in the species. Means were grouped into high (>60%), medium (35%-55%) and low (<25%) preference classes. Preference for *T. indica* and *C. Sinensis* was ranked low while for *Z. spina-christi* and *G. tenax* was ranked high. The high preference observed in *G. tenax* and *Z. spina-christi* could be attributed to adequate CP which influence intake of forages (NRC 2000). The low preference or depression in *T. indica* and *C. sinensis* intake could be attributed to high ether extract (fat) and condensed tannin contents. High NDF and fat content restricted the goat's ability to consume a more. In addition, some tree, shrub herbaceous foliages rejection maybe attributed to other factors such as unwanted smell, texture and bitterness. In this study, preference parameter such as ether extracts (EE) was the highest in *T. indica* and *C. sinensis*. This was in agreement with Obour *et al*., (2015) who found *Broussonetia papyrifera* with the highest ether extracts (EE) was least preferred among the investigated species. These results, however, contradicted the finding of Hardison *et al*., (1954) who reported that high ether extract (EE) indicates high preference. Preference studies have indicated that the consumption of plant species with high CT contents (> 50 g/kg DM) significantly reduces voluntary feed intake and palatability due to its astringent protein binding property, while medium or low content (<50 g/kg DM) seems not to affect consumption (Barry *et al*., 1984; Waghorn *et al*., 1994; Hervás *et al*., 2003; Frutos *et al*., 2004 and Waghorn, 2008). This is in agreement with the current studies for the case of *T. indica* which was least preferred in the trial with 73.3g/kg DM and 61.8 g/kg DM contents of Phenolics and condensed tannin, respectively.

Table 4. Mean daily feed intake (g/kg/d) and relative palatability index (RPI%) of browse species of South Sudan

Species	Feed intake	RPI (%)	Preference class
G. tenax	134^{a}	76.1^{a}	high
Z. spina-christi	126^{a}	67.5^{a}	high
B. aegyptiaca	79.1^{b}	45.1^{b}	medium
C. sinensis	8.21^{c}	21.9^{c}	low
T. indica	3.63^{c}	16.7^{c}	low
±SEM	5.94	3.71	
P	.0001	.0001	

^{abc} Means in the same column with different superscripts are different at ($p<0.05$); high (>60%); medium (35-55%) and low (<25%); SEM=standard error of the means.

4.5. Feed intake, digestibility and body weight change

Effect of *Grewia tenax* or *Ziziphus spina-christi* supplementation on dry matter intake (DMI), live weight change and apparent digestibility in crossed (small east African x Toggenburg) weaned goats fed *C. gayana* and supplemented with *G. tenax or Z. spina-christi* is presented in Table 5. Intake of basal diet varied from 296-416g/day and the values were different (P<0.05). Total dry mater intake (DMI) increased with supplementation significantly (P<0.05). The goats supplemented with *G. tenax* had higher intake (473g/day); followed by goats supplemented with *Z. spina-christi* (460g/day) and the least was unsupplemented goats (416g/day). The explanation in total DMI increased may be due to increased microbial fermentation in the rumen and subsequently higher rate of passage of digester through the gastric intestinal tract. Supplementation improved the total DMI by supplying fermentable carbohydrates or proteins for the cellulolytic microbes upon degradation in the rumen. However, the low total DMI found in this experiment in unsupplemented goats might be attributed to poor quality feeds characterized by low protein and high fiber contents of the hay.

The results of this study are consistent with the report on Osuga *et al*., (2012) who observed increased DM intake and body weight change in goats supplemented with maize bran, *Berchemia discolor* or *Ziziphus mucronata* to a basal diet of low protein (5% CP) *C. gayana*. Similarly, Ondiek *et al*., (2013) observed increased intake, diet digestibility and body weight change in goats supplemented with *Acacia tortilis* or *Balanites aegyptiaca* to a basal diet of low protein (4.6% CP) maize stover. Other Studies had also shown multipurpose tree/shrub species as cheaper protein source supplements that improved not only DM intake and digestibility but also performance of animals fed low quality feeds (Mupangwa *et al*., 2000; Kakengi *et al*., 2001). Voluntary DMI was expressed as percentage body weight (%BW) to account for differences in body size affecting voluntary intake. DM intake (%BW) values were different (P<0.05) among the treatments with similar trend of differences as that of total DMI. *G. tenax* (3.14% BW) and *Z. spina-christi* (2.88% BW) had higher %BW DMI compared to *C. gayana* hay (2.02% BW). However, the values of DM intake (%BW) of this finding, were considerably similar to Ondiek *et al*., (1999) who reported 2.9-3%BW DMI in goats supplemented with *Gliricidia sepium* and *Leucaena leucocephala* to a basal diet of *C. gayana* hay but lower than the value reported by Ondiek *et al*., (2013) who observed DMI of 2.6-5.1%BW in goats supplemented with *Acacia tortilis* and *Balanites aegyptiaca* to a basal diet of *Zea mays* (corn) stover. There were significant (P<0.05) differences in average daily gain (ADG) or loss among the treatments (Table 5). Supplemented goats had higher ADG compared to non-supplemented.

The ADG was the highest in goats supplemented with *G.tenax* (34.1g/d) followed by *Z. spina-christi* (25.6g/d) whereas the goats on sole *C. gayana* lost body weight at a rate of 32.0/d. The growth line graph for 8 weeks (56 days) is shown in (figure 2). The higher ADG recorded in supplemented groups could be attributed to higher protein (CP) which was essential for growth compared to non-supplemented group fed low CP content of *C. gayana* hay. CP rich browse species improved the intake by supplying fermentable carbohydrates or proteins for the cellulolytic microbes upon degradation in the rumen (Osuji *et al*., 1995; Kariuki, 1998). In line with this finding, Worku and Urge (2014) reported body weight loss of 30.2 g/d in Somali goats fed untreated groundnut pod hull, whereas supplemented goats gained at a rate of 18-53g/d. Ondiek *et al*., (2010) reported weight loss of 4.91g/d in small east African goats fed a basal diet of *Chloris gayana* hay and daily body weight gain of 12.9-28.1g/d when the same goats were supplemented with *Maerua angolensis* and *Ziziphus mucronata* mixed. Also, Betsha and Melaku, (2009) reported weight loss of 31g/d in Somali goats fed sole grass hay and daily body weight gain of 39.9-44.7g/d when supplemented with groundnut cake and wheat bran. These are within findings of Hango *et al*., (2007) where supplementation of small east African goats with 12, 18, and 24g DM /d concentrate mixture gained at the rate of 29.2, 44.5g/d, and 50.5 g/d, but, those goats fed a basal diet of *C. gayana* hay *ad libitum* gained only 12 g/d.

4.6. Apparent digestibility

Apparent nutrient digestibility (CP, OM and DM) was significantly different from treatments ($P<0.05$). It was lower for the control group in all parameters DM, CP, OM, and DM, and was the highest for goats supplemented with *G. tenax* and *Z. spina-christi*. The lower DM, CP, OM digestibility in the control group might be most likely due to low level of CP and high cell wall contents. *G. tenax* (580g/kg DM) was the highest in crude protein digestibility followed by *Z. spina-christi* (283g/kg DM). This may have been because supplementation increased total nitrogen (N) supplied. This, together with an increase in diet digestibility, would have contributed to the better performance in supplemented groups. This is in agreement with the report that digestion of feed in ruminant animals is highly influenced by the level of protein and fibre in the diet (Peyraud and Astigarraga, 1998).

Table 5. Mean dry matter feed intake, average daily gain and apparent digestibility of goats fed *C. gayana* and supplemented with either *G. tenax* or *Z. spina-christi*

	Species				
Body weight (kg)	***C. gayana***	***G. tenax***	***Z. spina-christi***	**P**	**±SEM**
Initial live weight (kg)	15.7[a]	15.6[a]	15.6[a]	.0787	0.0255
Final weight (kg)	13.6[c]	17.6[a]	17.2[b]	.0001	0.0129
Dry Matter Intake(g/day)					
Basal DMI (g/d/)	416[a]	308[b]	296[b]	.0001	7.61
Supplement DMI	0.00[b]	165[a]	164[a]	.0001	1.71
Total DMI	416[b]	473[a]	460[a]	.0001	7.74
DMI (%BW)	2.02[b]	3.14[a]	2.88[a]	.011	0.210
ADG (g/d)	-32.0[b]±8.87	34.1[a]±8.20	25.6[a]±7.94	.0001	
Apparent digestibility (g/kg DM*)*					
CP	46.6[c]	548[a]	281[b]	.0001	17.4
OM	51.2[c]	65.2[a]	55.4[b]	.008	2.09
DM	47.7[c]	42.1[b]	46.5[a]	.007	0.834

[abc] Means in the same column with different superscripts are different at (P<0.05); CP=crude protein; OM=organic matter; DM=dry matter; %BW=percentage body weight

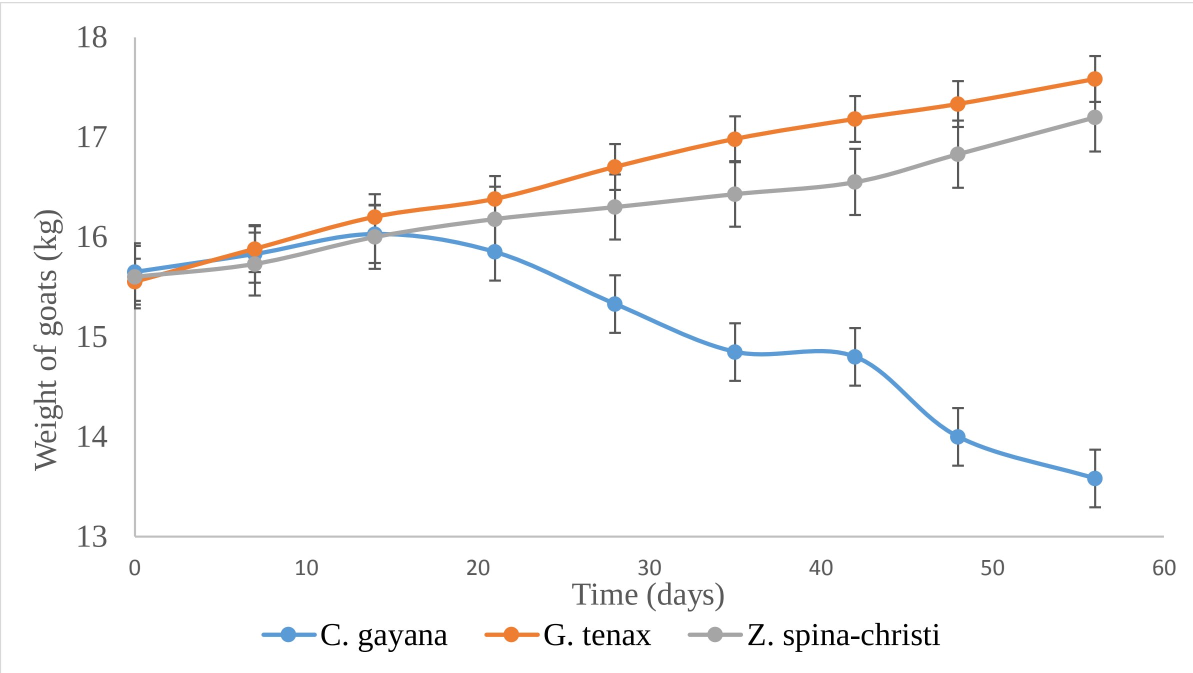

Figure 2. Trends in goats' weekly weight gain across 8 weeks (56 days) feeding period

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

i. The browse species had higher CP above the minimum required to support intake, rumen functioning and for growth in ruminants. They also had low to moderate cell wall contents, adequate quantities of both macro and micro mineral contents, low PHE and CT except *T. indica*. The highest fermentation rate and potential gas production was observed in *Z. spina-christi*.

ii. In Palatability, *G. tenax* was ranked the highest both in average daily intake and relative palatability index.

iii. Supplementation of low protein *C. gayana* hay with *Z. spina-christi* and *G. tenax* browse increased feed intake, digestibility and growth rates of goats.

5.2. Recommendations

i. The browse species have nutritional potential as supplements to low quality basal forages (cereal residues and hay).

ii. Though, *T. indica* was the least preferred, presence of variety of browse species may be important during periods of scarcity and severe shortages.

iii. *Grewia tenax* supplemented at 200g/d was relatively better as protein supplements to hay.

5.3. Areas for further research

i. Future research should be conducted to establish the optimum level of incorporating *G. tenax* and *Z. spina-christi* leaves in the diet for long- term feeding and to evaluate the cost/benefit and their effect on carcass quality.

ii. Further studies should be conducted to assess the feeding behaviour of goats and sheep in South Sudan area, their selection and the utilization availability of the most appreciated browse species.

iii. Conservation of browse species should be undertaken either by drying, or silage preparation for use in feed formulation during dry season.

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APPENDICES

Appendix 1. Experimental feed processing and packaging of subsequent samples for laboratory analysis

Figure 3. Process of browse species grinding for feeding trials and subsequent samples for laboratory analysis

Appendix 2. Extraction of rumen liquor from goats using suction tube and *in vitro* incubation in 100ml calibrated glass syringes fitted with plungers

Figure 4. Process of rumen liquor extraction and *in vitro* incubation in 100ml calibrated glass syringes

Appendix 3. Feeding trials and weekly weighing of goats on daily weight gain for a period of 8 weeks (56days)

Figure 5.Feeding trial and weekly weighing of experimental goats to determine average daily weight gain

Appendix 4. Faecal collection and drying for determination of apparent digestibility

Figure 6. Faecal output collections and drying in an oven at 60^{o}C

DATA ANALYSIS OUTPUTS

ANOVA of chemical composition of browse species

Dependent Variable: CP

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	59905.51139	9984.25190	191.53	<.0001
Error	14	729.78793	52.12771		
Corrected Total	20	60635.29932			

R-Square	Coeff Var	Root MSE	CP Mean
0.987964	4.732164	7.219952	152.5719

Dependent Variable: OM

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	24867.73550	4144.62258	285.93	<.0001
Error	14	202.93140	14.49510		
Corrected Total	20	25070.66690			

R-Square	Coeff Var	Root MSE	OM Mean
0.991906	0.419508	3.807243	907.5505

Dependent Variable: DM

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	199705.8712	33284.3119	1.05	0.4358
Error	14	443987.4133	31713.3867		
Corrected Total	20	643693.2845			

R-Square	Coeff Var	Root MSE	DM Mean
0.310250	20.46332	178.0825	870.2525

Dependent Variable: EE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	16413.49601	2735.58267	68.19	<.0001
Error	14	561.60731	40.11481		
Corrected Total	20	16975.10332			

R-Square	Coeff Var	Root MSE	EE Mean
0.966916	12.79354	6.333625	49.50643

Dependent Variable: CT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	9593.653448	1598.942241	252.24	<.0001
Error	14	88.745533	6.338967		
Corrected Total	20	9682.398981			

R-Square	Coeff Var	Root MSE	CT Mean
0.990834	14.27362	2.517730	17.63905

Dependent Variable: PHE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	11251.93668	1875.32278	7306.80	<.0001
Error	14	3.59316	0.25665		
Corrected Total	20	11255.52984			

R-Square	Coeff Var	Root MSE	PHE Mean
0.999681	2.044513	0.506611	24.77905

Dependent Variable: ash

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	56111.52945	9351.92158	904.07	<.0001
Error	14	144.81968	10.34426		
Corrected Total	20	56256.34914			

R-Square	Coeff Var	Root MSE	ash Mean
0.997426	2.617105	3.216250	122.8934

Dependent Variable: ADF

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	246965.2582	41160.8764	1333.48	<.0001
Error	14	432.1411	30.8672		
Corrected Total	20	247397.3993			

R-Square	Coeff Var	Root MSE	ADF Mean
0.998253	2.072138	5.555827	268.1205

Dependent Variable: NDF

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	332713.0640	55452.1773	282.59	<.0001
Error	14	2747.2170	196.2298		
Corrected Total	20	335460.2810			

R-Square	Coeff Var	Root MSE	NDF Mean
0.991811	3.537702	14.00820	395.9690

ANOVA of macro and micro mineral concentrations of browse species

Dependent Variable: Ca

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	1160.494584	193.415764	405.20	<.0001
Error	14	6.682723	0.477337		
Corrected Total	20	1167.177307			

R-Square	Coeff Var	Root MSE	Ca Mean
0.994274	3.621645	0.690896	19.07686

Dependent Variable: Co

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	75.27235918	15.05447184	35541.1	<.0001
Error	12	0.00508295	0.00042358		
Corrected Total	17	75.27744213			

R-Square	Coeff Var	Root MSE	Co Mean
0.999932	0.443955	0.020581	4.635842

Dependent Variable: Cu

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	22224.70494	3704.11749	7927.39	<.0001
Error	14	6.54158	0.46726		
Corrected Total	20	22231.24652			

R-Square	Coeff Var	Root MSE	Cu Mean
0.999706	1.155034	0.683561	59.18102

Dependent Variable: Fe

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	134517.6978	22419.6163	41683.4	<.0001
Error	14	7.5300	0.5379		
Corrected Total	20	134525.2277			

R-Square	Coeff Var	Root MSE	Fe Mean
0.999944	0.556102	0.733385	131.8796

Dependent Variable: K

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	4176.248087	696.041348	8012.82	<.0001
Error	14	1.216123	0.086866		
Corrected Total	20	4177.464211			

R-Square	Coeff Var	Root MSE	K Mean
0.999709	1.617074	0.294730	18.22614

Dependent Variable: Mg

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	455.3722478	75.8953746	133630	<.0001
Error	14	0.0079513	0.0005680		
Corrected Total	20	455.3801991			

R-Square	Coeff Var	Root MSE	Mg Mean
0.999983	0.315420	0.023832	7.555571

Dependent Variable: Mn

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	4778.369620	796.394937	536241	<.0001
Error	14	0.020792	0.001485		
Corrected Total	20	4778.390412			

R-Square	Coeff Var	Root MSE	Mn Mean
0.999996	0.189632	0.038538	20.32224

Dependent Variable: Na

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	34482.30123	6896.46025	6781.63	<.0001
Error	12	12.20318	1.01693		
Corrected Total	17	34494.50441			

R-Square	Coeff Var	Root MSE	Na Mean
0.999646	1.020369	1.008430	98.83000

Dependent Variable: P

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	15.17492067	2.52915344	119622	<.0001
Error	14	0.00029600	0.00002114		
Corrected Total	20	15.17521667			

R-Square	Coeff Var	Root MSE	P Mean
0.999980	0.205580	0.004598	2.236667

Dependent Variable: Zn

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	180142.9805	30023.8301	1088.73	<.0001
Error	14	386.0758	27.5768		
Corrected Total	20	180529.0563			

R-Square	Coeff Var	Root MSE	Zn Mean
0.997861	4.262901	5.251366	123.1876

ANOVA of *in vitro* rumen fermentation characteristics of browse species

Dependent Variable: 24h gas

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	153.4173053	30.6834611	154.95	<.0001
Error	12	2.3763067	0.1980256		
Corrected Total	17	155.7936120			

R-Square	Coeff Var	Root MSE	gas Mean
0.984747	5.526356	0.445001	8.052333

Dependent Variable: 48h gas

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	283.4314836	56.6862967	176.65	<.0001
Error	12	3.8506667	0.3208889		
Corrected Total	17	287.2821503			

R-Square	Coeff Var	Root MSE	gas Mean
0.986596	5.545146	0.566471	10.21561

Dependent Variable: a+b

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	29.02470450	5.80494090	629.39	<.0001
Error	12	0.11067800	0.00922317		
Corrected Total	17	29.13538250			

R-Square	Coeff Var	Root MSE	ab Mean
0.996201	1.244840	0.096037	7.714833

Dependent Variable: rate

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	1409.300770	281.860154	15490.5	<.0001
Error	12	0.218349	0.018196		
Corrected Total	17	1409.519119			

R-Square	Coeff Var	Root MSE	rate Mean
0.999845	1.557430	0.134892	8.661163

ANOVA of palatability and preference trial of browse species

Dependent Variable: ADI

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	1061926.924	265481.731	110.61	<.0001
Error	335	804079.132	2400.236		
Corrected Total	339	1866006.056			

R-Square	Coeff Var	Root MSE	ADI Mean
0.569091	69.66979	48.99221	70.32059

Dependent Variable: RPI

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	227438.6426	45487.7285	48.62	<.0001
Error	334	312490.4803	935.6002		
Corrected Total	339	539929.1229			

R-Square	Coeff Var	Root MSE	RPI Mean
0.421238	67.31684	30.58758	45.43824

ANCOVA of the effect of supplementation of *C. gayana* with either *Z. spina-christi* or *G. tenax* on feed intake, digestibility and average daily gain of goats

Dependent Variable: ADG

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	125588.2882	41862.7627	21.98	<.0001
Error	92	175219.5530	1904.5604		
Corrected Total	95	300807.8412			

R-Square	Coeff Var	Root MSE	dg Mean
0.417503	473.0184	43.64127	9.226125

Dependent Variable: basal

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	1965814.74	982907.37	75.71	<.0001
Error	669	8685506.27	12982.82		
Corrected Total	671	10651321.01			

R-Square	Coeff Var	Root MSE	basal Mean
0.184561	33.49271	113.9422	340.1999

Dependent Variable: TDMI

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	391405.664	195702.832	14.57	<.0001
Error	669	8985405.718	13431.100		
Corrected Total	671	9376811.383			

R-Square	Coeff Var	Root MSE	TDMI Mean
0.041742	25.77027	115.8926	449.7145

Dependent Variable: supp

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	4030133.762	2015066.881	3079.80	<.0001
Error	669	437717.270	654.286		
Corrected Total	671	4467851.032			

R-Square	Coeff Var	Root MSE	supp Mean
0.902030	23.35619	25.57901	109.5171

Dependent Variable: %bw

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	2.75686667	1.37843333	7.78	0.0109
Error	9	1.59400000	0.17711111		
Corrected Total	11	4.35086667			

R-Square	Coeff Var	Root MSE	%bw Mean
0.633636	15.72275	0.420846	2.676667

Dependent Variable: DMD

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	52.61926667	26.30963333	12.61	0.0071
Error	6	12.52293333	2.08715556		
Corrected Total	8	65.14220000			

R-Square	Coeff Var	Root MSE	DMD Mean
0.807760	3.181923	1.444699	45.40333

Dependent Variable: OMD

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	312.5240222	156.2620111	11.95	0.0081
Error	6	78.4718667	13.0786444		
Corrected Total	8	390.9958889			

R-Square	Coeff Var	Root MSE	OMD Mean
0.799303	6.317050	3.616441	57.24889

Dependent Variable: CPD

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	532144.9064	266072.4532	292.09	<.0001
Error	6	5465.4658	910.9110		
Corrected Total	8	537610.3722			

R-Square	Coeff Var	Root MSE	CP Mean
0.989834	11.56815	30.18130	260.9000

Appendix 5. Publication

Deng M T, Ondiek J O and Onjoro P A 2017: Chemical composition and in vitro gas production of lesser known South Sudan browse species. *Livestock Research for Rural Development*, 29(4). Retrieved May 16, 2017, from
http://www.lrrd.org/lrrd29/4/mame29081.html