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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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Abstract: The objectives of this study were to quantify and characterise 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 treatment methods were added at a level of 5 g per day during feeding time. We used eight (8) female Boer goats weighing an average of 31.5 kg (± 2.5 kg) for the feeding experiment. We penned the goats individually in metabolic cages. 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 Absorbance at 550 nm). The apparent digestibility coefficients 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 of 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 A. 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 and Nitrogen

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1. INTRODUCTION

In most Southern African countries, livestock production systems are characterised by distinct wet and dry seasons. Namibia is one of the southern African countries rated 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 (Mendelsohn, 2006). 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 (NPC, 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% of the national income (NMBAR, 2011).

Even though livestock contribute most to the agriculture sector, the Namibian rangelands where livestock are produced are heavily encroached upon by invasive woody plants (Joubert and Zimmerman, 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 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 (de Klerk, 2004; Skarpe, 1991; 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 in economic losses are due to bush encroachment from commercial rangelands (Honsbein *et al*., 2010) 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 committed to halting bush encroachment, reactive interventions such as chemical treatments are forbidden, while biological control through the use of 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).

Value chain addition to the harvested bush biomass has recently gained popularity, due to the fact that it does not only aim to pay back the costly debushing, but also develops the local market and creates high valuable products out of the harvested bush biomass. Among these value chains, bush-based feed or bush feed has gained special interest 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 seasons and their ability to retain their protein content make them a valuable protein-rich livestock feed source. 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 also 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.

2. PROBLEM STATEMENT

Despite the fact that bush feeds can be 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 has 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. Regardless of the notable findings of a few farmers using bush-based feed in Namibia, sufficient 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 feeds to avoid the detrimental effects of anti-nutritional feeds have not received any attention and there is no scientific proof of levels of treatment inclusion in bush feeds. Simply put, 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.

3. OBJECTIVES OF THE STUDY

3.1. General objective

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

3.2. Specific objectives

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

4. METHODOLOGY

4.1 Study location

Neudamm Farm, located 30 km east of Windhoek, in the highland savanna of Namibia, served as the site for this study. The Neudamm Campus lies between 22º and 23.30ºS and 15.30º and 18.30ºE. Highland savanna (semi-arid savanna) classifies the vegetation type in this area. The average annual rainfall around Neudamm ranges from 350-400 mm, with much of the rain experienced during the summer season (January-April) (Mendelsohn *et al.,* 2002). Homogenous Lithic Leptosols and Eutric Regosols soil types dominate the soil.

4.2. Sample collection and procedure

We selected the plant species *Senegalia mellifera* because it is abundant in the area, preferred by browsing livestock and game animals, and easily accessible. The samples collected were mainly compose 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 the 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) 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 bush-based feed resources were harvested by selectively cutting down *S. mellifera* bushes and prune off the twigs and leaf 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%); Marula oil press cake (20%) and coarse salt.

4.3. 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 compartments (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 ºC), 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.

4.4. 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.

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.

4.5. Statistical analysis

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.

5. RESULTS

The results of the study showed that there was a significant difference (p <0.05) in the chemical composition (Table. 1.1) of *Senegalia mellifera* milled biomass harvested from different grazing blocks at Neudamm Farm. The CP content of *Senegalia mellifera* milled biomass differs significant (p <0.05) among blocks and ranges from 9.39% to 9.71%.

The fibre fractions differed significantly (p <0.05).The Neutral Detergent Fibre (NDF) content ranges from lowest 59.17% to highest content of 64.33%. The Acid Detergent Fibre (ADF) content ranges from 43.17% to 48.01%. Calcium (CA) content was recorded highest at 1.28% and lowest as 0.62%. The highest amount of Phosphorus (P) in *Senegalia mellifera* milled biomass was 0.07% and lowest as 0.02%.

The Folic-Ciocalteu method results showed the presence of phenolics in *Senegalia mellifera* milled biomass (Table. 1.2). The Total phenols (TP) content of the bush feed was similar in all blocks (p >0.05).The highest amount of Total Tannins (TT) content was 1.39%DM tannic acid equivalent. The condensed tannins (CT) content of milled bush feed from all blocks did not differ (p >0.05) and ranges between 0.02 to 0.03 %DM leucocyanidin equivalent.

The nutritional content of the formulated diets are presented in Table 1.3. The results showed control diet (CNT) had the highest dry matter (94.49%) content, however it was not significant different (p >0.05) 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).

The organic matters content of the formulated diets differs significantly (p < 0.05).The organic matter of the diets was observed lowest in wood ash (WA) treated diet (74.52 %DM) (p <0.05) and in biochar treated diet (77.12%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.

There was significant difference (p <0.05) in the DMI of different treatments (Table. 1.4) .Biochar treated feed had the highest DMI of 963 g/d (p <0.05) compared to other treatments. The DMI of the control feed (CNT), PEG and WA was similar (p >0.05). The apparent digestibility coefficient of DM, OM and NDF were not different among treatments (p >0.05), 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 1.5.). Goats fed Biochar treated feed had the highest nitrogen intake of 13.74g/d (p <0.05).

The nitrogen intake of goats fed the control feed (CNT), PEG and WA was similar (p >0.05). The faecal nitrogen from goats consuming different treatments was different (p <0.05). Goats fed Biochar treated feed had the highest faecal nitrogen of 8.43g/d (p <0.05) 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) .Goats fed Biochar treated feed had the highest Nitrogen retention of 5.11g/d (p <0.05) 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 1. 1: Chemical composition (%DM) of *Senegalia mellifera* milled biomass (Leaves and twigs less than 5cm)

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 1. 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 ($p > 0.05$).

Table 1. 3: 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 ($p < 0.05$).

Table 1. 4. Feed intake (g/day) and apparent digestibility coefficients of diets offered.

TREATMENT	DMI	DMD	OMD	NDF
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 1.5: 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 ($p < 0.05$).

6. DISCUSSION

6.1. *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. 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 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 nutritional analysis of *Senegalia mellifera* bush feed in this study showed that the crude protein (CP) which ranged from 9.39 to 9.71% was 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 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 possibly due to the exclusion of twigs.

The values of NDF recorded in this study were in the range as those reported by van Soest (1994) from 540 to 770 g/kg for different forage species. 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. 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. 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. 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.

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).

The low Tannin content obtained in this study was 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.

The considerable less variation observed could be related to the method of analysis (in this study Folin-Ciocalteu method was used to determine Total phenols (Makkar *et al.,* 1993a). 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).

6.2. *Feed formulation, 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.

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.

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 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 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.

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.

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 (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 (CH_4) 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, CH_4 produced during ruminal fermentation represents a loss of 5-8% of gross energy intake (Lopez and Newbol, 2007).

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.

7. 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 a 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 utilisation 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.

The study concluded that, there was a significant difference in the DMI of different treatment diets. The apparent digestibility coefficients 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 the 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.

8. RECOMMENDATIONS

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 the 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.

The high fibre content of *S. mellifera* bush based feeds still requires 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, fibre, and protein play a participatory role in overall ruminant nutrition, anti-nutrition, and possibly the efficacy of condensed tannins.

Determining the concentaration of 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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