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Indigenous Browse Fodders in Different Altitude of Northwestern Ethiopia: Availability, Utilization Practices and Nutritional Value for Goats

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BAHIR DAR UNIVERSITY
College of Agriculture and Environmental Sciences
Department of Animal Sciences

**Indigenous Browse Fodders in Different Altitude of Northwestern
Ethiopia: Availability, Utilization Practices and Nutritional Value for
Goats**

PhD Dissertation

By
Berihun Kibret Tegegne

June, 2025
Bahir Dar, Ethiopia

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**Indigenous browse fodders in different altitude of northwestern
Ethiopia: availability, utilization practices and nutritional value for
goats**

PhD Dissertation

By

Berihun Kibret Tegegne

A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of
Doctor of Philosophy in Animal Nutrition

Advisory Board members:

1. Bimrew Asmare (PhD, Associate Professor; Major supervisor)
2. Likawent Yeheyis (PhD, Lead Researcher; Co-supervisor)

June, 2025
Bahir Dar, Ethiopia

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DECLARATION

This is to certify that the dissertation entitled “**Indigenous browse fodders in different altitude of northwestern Ethiopia: availability, utilization practice and nutritional value for goats**”, submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy/PhD/ in Animal Nutrition to the Department of Graduate Council of Animal Sciences, Graduate Program of College of Agriculture and Environmental Sciences, Bahir Dar University, is a record of original work carried out by me and has never been submitted to this or any other institution to get any other degree or certificates. The assistance and help I received during the course of this investigation have been duly acknowledged.

Name of the candidate: Berihun Kibret

Signature:



Date: June 02/06/2025

Place: Bahir Dar, Ethiopia

APPROVAL OF DISSERTATION

Bahir Dar University
College of Agriculture and Environmental Sciences
Department of Animal Sciences

We hereby certify that we have supervised, read and evaluated this dissertation titled “Indigenous Browse Fodders in Different Altitude of Northwestern Ethiopia: Availability, Utilization practice and Nutritional Value for Goats” by Berihun Kibret Tegegne prepared under our guidance. we recommend the dissertation be submitted for oral defense.

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Approval of Dissertation for Defense Result

As members of the board of examiners, we examined this dissertation titled “**Indigenous browse fodders in different altitudes of northwestern Ethiopia: availability, utilization practice and nutritional value for goats**” by Berihun Kibret Tegegne. We hereby certify that the dissertation is accepted for fulfilling the requirements for the award of Doctor of Philosophy in Animal Nutrition.

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DEDICATION

Dedicated to my mother: Yayesh Teshome and my sisters: Yesh Kibret and Yeshareg Kibret.

ABBREVIATIONS

ADF	Acid Detergent Fiber
ADFD	Acid Detergent Fiber Digestibility
ADFI	Acid Detergent Fiber Intake
ADG	Average Daily Gain
ADL	Acid Detergent Lignin
ADLI	Acid Detergent Lignin Intake
ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemists
BW	Body Weight
CH ₄	Methane
CM	Concentrated Mix
CP	Crude Protein
CPD	Crude Protein Digestibility
CPI	Crude Protein Intake
CR	Crop Residue
CRD	Complete Randomized Design
CSA	Central Statistics Agency
DCP	Digestible Crude Protein
DM	Dry Matter

DMD	Dry Matter Digestibility
DMI	Dry Matter Intake
DOM	Digestible Organic Matter
FAO	Food and Agriculture Organization
FCE	Feed Conversion Efficiency
GHG	Greenhouse Gas
GLM	General Linear Model
GP	Gas Production
ha	Hectare
HH	Household
hr	Hour
IBFS	Indigenous Browse Species
IVDMD	In Vitro Dry Matter Digestibility
IVOMD	In Vitro Organic Matter Digestibility
LT	Lag Time
ME	Metabolized Energy
MJ	Mega Joule
N	Nitrogen
NDF	Neutral Detergent Fiber
NDFD	Neutral Detergent Fiber Digestibility
NDFI	Neutral Detergent Fiber Intake

NGO	Non-government organization
OMD	Organic Matter Digestibility
OMD	Organic Matter Digestibility
OMI	Organic Matter Intake
SAS	Statistical Analysis System
SCFA	Short Chain Fatty Acid
SPSS	Statistical Package for The Social Sciences
TLU	Total Livestock Unit
VFA	Volatile Fatty Acid

Indigenous Browse Fodders in Different Altitude of Northwestern Ethiopia: Availability, Utilization Practices and Nutritional Value for Goats

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ABSTRACT

The study investigated the availability and feeding value of indigenous browse species in northwestern Ethiopia. The study comprised three activities that included the survey, laboratory analysis and feeding experiments. For the survey study, 245 households were used for data collection from lowland (79), midland (86), and highland (81) agro-ecologies. To determine the diversity and distribution of indigenous browse species, eight 20 m × 20 m plots were randomly established in each agro-ecological zone and land use (open grazing and area closure) with a minimum distance of 100 m between any two plots. Leaf samples from eight selected indigenous browse species were collected at each agro-ecology for laboratory analysis. For feeding trial, 25 male intact goats with an initial body weight of 19.1 ± 1.6 kg (Mean $\pm$ SD) were blocked and randomly assigned to five dietary treatments. The treatments were: a control group (T1) fed 100% concentrate mix (CM), 85% CM + 15% *Terminalia brownii* (T2), 70% CM + 30% *Terminalia brownii* (T3), 55% CM + 45% *Terminalia brownii* (T4) and 40% CM + 60% *Terminalia brownii* (T5). The natural pasture hay was offered as a basal diet. The survey data was analyzed using SPSS, version 26 and laboratory and feeding trial data were analyzed using SAS version 9.4. The study showed that 44 indigenous browse species were identified in all agroecologies. From the identified species *Terminalia brownii*, *Albezia amara* and *Cordia Africana* in the lowland; *Cordia Africana*, *Ficus vasta*, *Acacia abyssinica* and *Ficus thonningii* in the midland and *Cordia abyssinica*, *Ficus thonningii* and *Vernonia amygdalina* in the highland were the most preferentially opted for livestock feed. The midland had the highest species diversity index (2.57) of browse species as compared to lowland (2.35) and highland (2.31) agroecology. Palatability (0.213) and multi functionality (0.23) were the main preference criteria for selecting browse species. The highest CP content was recorded from *Vernonia amygdalina* (223.4 g/kg DM), *Dodonaea*

viscose (207.7 g/kg DM), and *Acacia abyssinica* (216.0 g/kg DM) in the highland, midland and lowland agroecology respectively. In lowland area, NDF, ADF and ADL contents were highest for *Albezia amara* leaves (773.7, 330.5 and 101.4 g/kg DM) and lowest for *Acacia brevispica* (218.8, 95.9 and 26.4 g/kg DM) respectively. *Vernonia amygdalina* (40.66 ml/200mg DM), *Stereospermum kunthianum* (47.61 ml/200mg DM) and *Ficus vasta* (36.95 ml/200mg DM) had the highest gas volume at 24 hour incubation time in high, mid and lowland, respectively. The estimated OMD, ME and SCFA at 24 hour of incubation were the highest for *Vernonia amygdalina* (68.48%, 9.01 MJ/kg DM and 0.91mmol/L), *Stereospermum kunthianum* (68.88%, 9.46 MJ/kg DM and 1.07 ml/L) and *Ficus vasta* (63.33%, 8.26 MJ/kg DM and 0.82 mmol/L) in high, mid and lowland agro ecologies, respectively. At 24 hr of incubation, *Albezia amara* leaves (0.33 ml/200mg DM), *Ficus sycomorus* (0.23 ml/200mg DM) and *Myrica salicifolia* (2.66 ml/200mg DM) had the lowest CH₄ production among the species in the low, mid and highland study areas, respectively. The feeding trial result showed that goats received T5 treatment had higher DM (779.24 g) and CP (181.06 g) intakes than other groups. The average daily gain of goats in T4 (59 g) and T5 (63.4 g) were higher than T1 (36.6 g), T2 (34 g) and T3 (41 g). Goats fed T5 recorded significantly highest lymphocytes count (61%) followed by animals fed T3 (28.17%) while the least lymphocytes count (36.5%) had observed in animal fed T4 treatment. Besides, the highest neutrophil count (56.9%) had obtained in T4. Goats fed T5 recorded the highest hemoglobin (10.74 g/dL) levels. Besides, goats fed T1 diet had the highest cholesterol (1.94 mmol/L) level as compared to other treatments. CH₄ production yield ($P > 0.05$) was comparable between goats fed the *Terminalia brownii* leaves and those fed a concentrate mix. Overall, indigenous browse species have a potential as feed supplements to improve feed quality and reduce enteric CH₄ production in ruminant animals.

Key Words: Agroecology, Blood profile, Diversity, Preference criteria, Methane, Nutritional quality,

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CHAPTER 1: GENERAL INTRODUCTION

1.1 Background and Justification

Ethiopia holds largest livestock population with estimated approximately 70 million cattle, 42.9 million sheep, 52.5 million goat, 2.15 million horse, 10.8 million donkey and 0.38 million mule, 8.1 million camels, 57 million poultry (chicken) and 6.99 million beehives (CSA, 2021). The livestock sector serves as a major source of currency earnings and delivers important products and services (FAO, 2017). Thus, livestock sector has been contributing considerable portion to the economy of the country, and still promising to rally round the economic development of the country (CSA, 2021). Ethiopia has earned \$66.59 million foreign exchange from small ruminant meat and live sheep and goats exports (Mijena and Getiso, 2022). Small ruminants play a decisive role in job creation, income generation and improving food security for smallholder farmers. In Ethiopia, small ruminants are primarily raised in mixed crop livestock production systems under different agroecological conditions with traditional husbandry practices (Abera, 2021). Ethiopia had 52.5 million estimated goats, of which Somalia (16,464,505), Afar (8,843,082), Oromia (8,425,727) and Amhara (7,045,305) accounted for the largest contribution to the country's goat population, respectively (CSA, 2021). The increase in goat meat demand has improved the recent goat meat market in Ethiopia. Approximately 12% of goat meat is annually exported to middle east markets (Tsegaye *et al.*, 2022).

The current livestock contribution in the country is below its potential due to various reasons associated with a number of complex and inter-related factors. The feed shortage, poor genetic makeup of local animals, poor veterinary care, less efforts in introducing the appropriate package of improved livestock technologies of crossbreeding and water scarcity are the major limiting factors of the industry (Selamawit *et al.*, 2017). Feed supply is the most important factor affecting the success of global livestock production. In the tropical area, poor quality natural pastures and crop residues are the main resources of livestock feed (Valence *et al.*, 2022; Mamo *et al.*, 2023; Matovu *et al.*, 2023). These native pastures and crop residues are generally low in nutrient content particularly energy and protein. Moreover, the fiber in these feedstuffs is usually so high as to reduce feed intake and digestibility (Amole *et al.*, 2022; Tulu *et al.*, 2023).

Besides, low-quality feed contributes substantially to methane (CH₄) emissions from livestock digestive systems (Vargas *et al.*, 2022). Ruminant animals loss between 2 and 12% of their consumed energy through CH₄ gas production, negatively impacting their overall productivity (Johnson and Johnson, 1995). This energetic loss is particularly relevant in the tropics, where native grasses are the main source of ruminant diets. Dietary supplementation of poor quality diets is known to improve intake by increasing nitrogen supply to rumen microorganisms (Karimi *et al.*, 2021; Morales *et al.*, 2021). This in turn has a positive effect on increasing the microbial population and digestion rate of feed. As the rate of breakdown of digested feed increases, intake is accordingly increased (Cammack *et al.*, 2018; Liu *et al.*, 2019).

Conventional by product supplements are accessible at a high price in developing countries (Dey *et al.*, 2022; Melesse *et al.*, 2023). Among these, by product feeds such as oil seed meals, sugarcane bagasse and brans from processing units could help to address the feed challenges in Ethiopia (Begna *et al.*, 2023). However, those concentrate feeds are expensive and not reasonable for smallholder farmers of the tropics. The foliage of multipurpose fodder trees used to alleviate crude protein (CP) deficiency for livestock based on fibrous feeds. Moreover, the inclusion of fodder tree leaves as feed could reduce rumen acidosis and other health related problems and improve productivity of livestock (Belete *et al.*, 2024; Wondimu *et al.*, 2024; Ganai *et al.*, 2025). In most tropical countries including Ethiopia, there are potential fodder trees that may be useful as feed supplements to typically low-quality animal feeds particularly during the dry season (Duguma and Janssens, 2021; Adane and Anjulo, 2023; Yusuf *et al.*, 2023). These tropical fodder tree species are well adapted to harsh environments which are resistant to variations in temperature (Sipango *et al.*, 2022; Tulu *et al.*, 2023) and produce considerable good quality foliage (Amad and Zentek, 2023; Dhillon *et al.*, 2023). Most tropical fodder trees species contain reasonably high crude protein (CP), minerals and low fiber contents (Sarkwa *et al.*, 2021; Abraham *et al.*, 2023; Ebrahim *et al.*, 2023; Belete *et al.*, 2024) and they can be considered as supplemental feeds for poor quality roughage for ruminant animals. Apart from the above reports, fodder trees have attributes such as being more nutritious than most grasses and conserve their nutrients in the dry season when feed resources are depleted (Mekonnen *et al.*, 2022; Dhillon *et al.*, 2023;

Kumar *et al.*, 2024). In the dry season, browse species are generally better at conserving nutrients than grasses due to their deeper root systems, which allow them to access water and nutrients from deeper soil layers (Tariq *et al.*, 2024). Additionally, many browse species, can fix atmospheric nitrogen, enriching the soil and boosting the nutrient content of their foliage (Querejeta *et al.*, 2022). This makes them a more reliable source of nutrients for animals during periods when grasses become scarce and less nutritious.

Belachew *et al.* (2020) reported that leaves, fruits, pods and twinges of browse species were the most preferred parts utilized by goats and tend to loop and cut branches from various palatable browse trees in Gamo Gofa and Wolayta zones, Ethiopia. Indigenous browses are the main sources of feed in Abobo woreda, Gambella regional state, western Ethiopia (Gelayenew *et al.*, 2016). In the mid rift valley of Ethiopia, indigenous trees such as *Acacia tortilis*, *Acacia mellifera*, *Celtis africana*, *Grewia bicolor*, *Olea europaea*, *Dichrostachys cinerea* and *Balanitesae gyptiaca* are most favored by goats (Shenkute *et al.*, 2012). In Ethiopia, *Millettia ferruginea*, *Cordia africana*, *Erythrina brucei* and *Vernonia amygdalina* are also used for livestock feed and have potential to increase milk production at household level (Lelamo, 2021).

Alike to most developing countries, the demand for livestock products is increasing in Ethiopia due to the current urbanization and population growth in the country. To respond according to the increasing demand for livestock products and utilize the potential of the livestock sector in Ethiopia, comprehensive action against the major problems like feed shortage is mandatory. One potential option to solve the burden of feed shortage under the existing situation in the mixed crop-livestock farming system of Ethiopia is to look for a multipurpose, easily adaptive, highly palatable and less labour demanding browse fodder plant so that it can be used to develop efficient feeding system in the area by farmers.

The scale of exotic fodder tree species planting and utilization undertaken by smallholder farmers in Ethiopia has shown uneven success rates and did not meet the required goals due to different reasons (Mekoya *et al.*, 2008). Failure of some exotic fodder species to expand the production system suggests the need to focus on indigenous browse species to exploit the advantages of indigenous multipurpose browse species over the exotic species in terms of adaptability to the local environment, resistance to pests

and diseases, availability of local planting material and familiarity to the farmers (Balehegn, 2017). Thus, there is a need to assess for locally available potential feed resources, which compete less with human food production and can provide the critical nutrients in the dry season. Moreover, the supplementation of industrial by products such as oil seed cakes, wheat bran and molasses are inaccessible and high priced in many developing countries like Ethiopia (Dejene *et al.*, 2014; Feyisa *et al.*, 2024).

To alleviate the problems of quality feed supply, indigenous tree fodder species play a vital role in animal production in different agro ecology (Raj *et al.*, 2023; Belete *et al.*, 2024). Since, indigenous browse species are good feed resources that remain green year-round and rich in protein, energy, vitamins and minerals in dry seasons (Hamukwaya *et al.*, 2024; Mekuriaw *et al.*, 2024). Abraham *et al.* (2023) reported that browse species have high crude protein content ranging that may make them to consider as a more reliable high quality feed resource. This can help in developing sustainable feeding systems and increase livestock productivity. Therefore, indigenous browse fodders are great importance in dry season livestock feeding as they can provide substantial protein and energy (Derero and Kitaw, 2018; Mudau *et al.*, 2021).

Indigenous browse species are well known to farmers and are better adapted to the environments than the exotic once (Belachew *et al.*, 2020; Lelamo, 2021). It is commonly used as animal feed in many parts of the country although not properly characterized for their feeding values. Fodders from different types of trees and shrubs may vary in ruminant performance and gas and CH₄ production. Therefore, it is necessary to observe variations in nutrient composition, digestibility, and *in vitro* gas and CH₄ emission potential among indigenous browse species. So far, only limited information is available about their *in vitro* gas and CH₄ production potentials of indigenous browse species in Ethiopia (Getachew *et al.*, 1999; Sisay *et al.*, 2017; Abraham *et al.*, 2023).

In northwestern Ethiopia, particularly south Gondar zone, crop production is the dominant practice and indigenous browse species can make a large contribution to livestock feeding during dry season. However, to knowledge of the authors, not many research results have been reported on the identification, animal preference, utilization practice and nutritional value of indigenous browse species in different altitude of northwestern, Ethiopia particularly south Gondar zone, Amhara region. This suggests that

there is a need for research to identify and prioritizes the beneficial indigenous browse species in order to efficiently utilize them in the farming system.

1.2 Objectives of the research

The general objectives of this study was to assess availability, species diversity, utilization practices and nutritional value of indigenous browse species for goats.

The following specific objectives were addressed in order to achieve the overall objective.

- To assess farmer's perception, utilization practice and diversity of the indigenous browse species in the selected districts of northwestern Ethiopia.
- To appraise the nutritive value of major indigenous browse species using different laboratory evaluation techniques.
- To evaluate the effects of *Terminalia brownii* leaves on nutrient intake, digestibility and growth performance of male intact goats.
- To evaluate the effects of *Terminalia brownii* leaves on hematology, serum biochemical profile and enteric CH₄ emission of male intact goats.

1.3. Research Questions

The underlining research questions of this study are:

- What are the major indigenous browse species in the selected district of northwestern Ethiopia?
- What is the perception of farmer's and utilization practice of indigenous browse species for livestock in the study area?
- Do species type affect the nutrient content of indigenous browse species grown in the study area?
- Do the leaves of indigenous browse species replace concentrate feed source to satisfy the nutritional requirements of goat?

1.4. Limitation of the study

While this study provides valuable insights into the availability, utilization practice and nutritional value of indigenous browse species across different altitudes in northwestern Ethiopia. However, it has several limitations:

- The study is limited to specific areas within northwestern (South Gondar Zone), Ethiopia, which may not fully represent other regions with different ecological conditions and indigenous browse species diversity.
- The study have not adequately captured seasonal variations in indigenous browse species availability and nutritional content, which are critical factors in feeding systems for ruminants in tropical regions.
- The number of browse species analyzed may not be sufficient to generalize findings broadly across the region or country.
- Only certain nutritional parameters were measured, potentially overlooking other important components like secondary metabolites, mineral contents and fermentation parameters that could influence fodder quality and animal performance.

CHAPTER 2: LITERATURE REVIEW

2.1. Economic and social role of goats in Ethiopia

Ethiopia has obtained \$66.59 million foreign exchange from live small ruminant and meat exports (Mijena and Getiso, 2022). Small ruminants play a decisive role in job creation, income generation and food security for smallholder farmers. Small ruminants in Ethiopia are primarily raised in mixed crop-livestock production systems under a variety of agroecological conditions with traditional husbandry practices (Abera, 2021).

Goat production is an attraction option for low-income families to improve their livelihoods and an accessible way for poor rural families to generate their income (Namonje-Kapembwaa *et al.*, 2022). Goats have unique characteristics such as, rapid reproductive cycle, high market value, and low operational costs and adapt in harsh environments (Alilo, 2019). They rear for different purposes, including income, saving/insurance, consumption and cultural functions (Sime *et al.*, 2022). Ethiopia had 52.46 million estimated goats, of which Somalia (16,464,505), Afar (8,843,082), Oromia (8,425,727) and Amhara (7,045,305) regions accounted for the largest contribution to the country's goat population, respectively (CSA, 2021). The increase in goat meat export demand has improved the recent goat meat market in Ethiopia. Approximately 12% of goat meat production is exported annually to Middle East markets (Tsegaye *et al.*, 2022)

2.2. Feed resources in Ethiopia

Feed both in terms of quantity and quality is a major bottleneck for livestock production in Ethiopia (Matawork, 2017). Feed resources can be classified as natural pasture, crop residue, improved forage and agro-industrial byproducts of which the first two contribute the largest share (CSA, 2021). Native pastures, crop residues (CR) and multi-purpose trees are the major feed resources in crop-livestock mixed farming systems of central southern Ethiopia (Duguma and Janssens, 2021). Gelayenew *et al.* (2016) and Feyisa *et al.* (2022) also studied that natural pasture was the dominant feed resources during the wet season in Ethiopia.

2.2.1. Natural pasture

Natural pasture supply the bulk of livestock feed and comprises the largest feed resource (Talore, 2015). In the highland and semi-highland part of Ethiopia, natural pasture account for 80% of animal feed. This is because the availability and quality of native pastures for livestock use vary with altitude, rainfall, soil type and cropping intensity. Seasonal fluctuations of feed resources in the tropics also follow the pattern of vegetation growth which is modified by availability of rainfall (Salo, 2017). Hence, quality and productivity of natural pastures is very poor to meet the nutrient requirement of animals particularly in the dry season, due to seasonal rainfall dynamics (Ayele *et al.*, 2021).

2.2.2. Crop residues

Crop residues are roughages that become available as livestock feeds after crops have been harvested. It is one of main feed in animal production in area which practice livestock and crop farming system (Duncan *et al.*, 2016). It remains also used for construction and fuel (Angassa *et al.*, 2011). The total annual production of crop residues at global and national level is estimated to be about 1.14 billion and 30 million tons of DM, respectively of which 70% is utilized as livestock feed (FAO, 2017). Moreover, crop residues are providing a considerable quantity of dry season feed in most farming areas of Ethiopia (Keno *et al.*, 2021; Desta, 2024b).

However, crop residues are fibrous by-products and their feeding values are limited by their poor voluntary intake, digestibility and low protein, energy, mineral and vitamin contents (Katoch, 2022; Dejene *et al.*, 2024). Strategies used to improve crop residues' nutritive value includes supplementing with protein and energy-rich feeds and physical and chemical treatments (e.g. chopping and ensiling with urea) (Assefa *et al.*, 2022). However, the degree of their adoption by the farmer in Ethiopia is low due to socio-economic factors (Dejene *et al.*, 2024). A survey conducted in the Tigray region showed that lack of capital, knowledge and skill, molasses and urea had influenced the adoption of straw urea-molasses treatment (Tsfay *et al.*, 2016).

2.2.3. Improved forages

Feed availability is one of the major constraints to sustaining improved livestock productivity and building the resilience of livestock keepers. Hence, alternative high yielding forages are essential to alleviate the feed scarcity. Such technologies not only help improve feed supply in the face of climatic shocks but also enable farmers to enhance the quality of the diet of their livestock (Adie *et al.*, 2024). The yield of improved forage is higher than naturally occurring grasses and has higher nutritional value (Andualem, 2016). In the past few years, considerable efforts have been made to test the adaptability of many forages under different agro-ecological conditions in different parts of Ethiopia. Thus, selection of numerous useful forages for different agro-ecological zones has been made to be possible (Mengistu, 2006) and, different improved forage species have been progressively introduced to local farmers of Ethiopia since 1970 (Alemu, 2012) and (Mengistu and Assefa, 2012).

Focusing on feeding practice of green feed and maintaining the health of soil conservation, different improved forage production strategies were implemented. The strategies evolved from experiences of other countries and an understanding of the importance of forages for livestock production (Mengistu *et al.*, 2017). Improved forage species, including Elephant grass, Oats, Phalaris, Panicum, Buffel grass, Desmodium, Fodder beet, Pigeon pea, *Sesbania* species, have been introduced in an endeavor to increase the amount and quality of available forage and have been promoted in the different parts of the country by different government and NGOs for the last decade (Fikre, 2018).

Mengistu *et al.* (2021) showed that desho and elephant grass are the major improved forages introduced in Wolayita zone, Ethiopia which have been serving as the major components of livestock feed in both the dry and wet seasons of the year. The same result was revealed by Gebreegzabher and Tsegay (2016). Moreover, farmers also use improved forage species for soil and water conservation (Desho grass), fencing and as a wind break (*Sesbania* and *Leucaena*) (Assefa *et al.*, 2015; Melese *et al.*, 2018). Nevertheless, it is constrained by many challenges including small land holdings, priority given to food crop production, lack of forage seeds/ plant material and limited knowledge on forage species and their production systems (Mengistu *et al.*, 2021).

2.2.4. Industrial by product

Agro-industrial by-products have special value in feeding livestock mainly in urban and peri-urban livestock production system (Andualem, 2016; Menale *et al.*, 2019). Agro-industrial by-products cover flour mill by-products such as wheat bran and middling, oilseed cakes (Niger seed cake, linseeds, sesame seeds and rapeseeds), brewers' grain and sugarcane by products like molasses and bagasse (Salo, 2017). However, the contribution of these by-products is proportionally low, due to their escalating prices and low accessibility (Feyissa *et al.*, 2015). Thus, the use of agro-industrial by-product is restricted to the emerging private dairy and fattening farms (Hoste *et al.*, 2021).

2.3. Indigenous browse species

Fodder production from trees and shrubs is one of the benefits of agroforestry. Beside grasses, browse species constitute one of the cheapest sources of feed for ruminants (Melesse *et al.*, 2019; Feyisa *et al.*, 2022). Furthermore, browse species could play both ecological and economic roles in livestock production systems (Yaebiyio *et al.*, 2024). Indigenous browse species are critical feed resources for the pastoralist and agro-pastoralist areas in Ethiopia (Derero and Kitaw, 2018). A farmer normally maintains indigenous multipurpose trees in farmland for multiple useful and valuable purposes to optimize the use of environmental resources (Abraham *et al.*, 2022).

2.4. Utilization practice of browse species

Shrubs and trees play a significant role in livestock production in different agro ecological zones of tropical country including Ethiopia. The browse species were found on grazing land, cropland, around homesteads or grown on boundary between farmlands (Abraham *et al.*, 2022). Utilization of browses species offer an opportunity for use as potential feed supplements by smallholder farmers in the tropics due to their high CP content and degradability so that they can keep animals in better body condition (Gelayenew *et al.*, 2016). The utilization practice of indigenous browse species by animals depends on the availability, selection by the animals, their effects after consumption and purposes to be obtained after consumption (Ababu *et al.*, 2021; Mekuriaw *et al.*, 2024).

Belachew *et al.* (2020) reported that leaves, fruits, pods and twinges were the most preferred parts utilized by goats tend to loop and cut branches from various palatable browse species like *A. tortilis*, *B. aegyptiaca*, *T. brownii*, *Z. mucronata*, and *G. bicolor* species to feed their goats during the dry season. Indigenous browse species are the main sources of feed in Abobo woreda, Gambella Regional State, western Ethiopia (Gelayenew *et al.*, 2016).

In the mid rift valley of Ethiopia, indigenous trees such as *Acacia tortilis*, *Acacia mellifera*, *Celtis africana*, *Grewia bicolor*, *Olea europaea*, *Dichrostachys cinerea* and *Balanites aegyptiaca* are most favored by goats and utilized by cattle and sheep (Shenkute *et al.*, 2012). In southern Ethiopia, *Millettia ferruginea*, *Cordia africana*, *Erythrina brucei* and *Vernonia amygdalina* are also used for livestock feed (Abraham *et al.*, 2022). In northwest Ethiopia, *Faidherbia albida* (*Acacia albida*), *Vernonia amygdalina*, *Ficus thonningii*, and *Carissa edulis* are major indigenous fodder trees (Desta, 2024).

2.5. Perception of farmers' towards indigenous browse species

Indigenous knowledge and management practices on browse species offer relevant techniques and insights for farmers and other relevant scientists (Sánchez-Romero *et al.*, 2021). In Southern Ethiopia, farmers believed that, indigenous multipurpose fodder tree species are nutritious and important to livestock production in promoting not only maintenance of animals but also in enhancing growth and milk production (Abraham *et al.*, 2022). Indigenous browse species such as *Vernonia amygdalina* are believed to have traditional medicinal value and the leaves, tips and pods of such plants are ground mixed with coffee *Arabica* leaves and boiled and used as medicine to treat certain illnesses (Gina *et al.*, 2014; Awulachew, 2021).

2.6. Farmers' preference criteria for selection of indigenous browse species

Farmer's preference criteria on browse fodder encompass multiple objectives beyond feed value and soil rehabilitation. Ayenew *et al.* (2021) mentioned that farmer's preference criteria for selection of indigenous browse fodder was based on plant characteristics of the various species and the perceived animal preference includes availability, biomass yield, growth and re-growth ability and multi functionality of the

plant species. The above report was in line with Ababu *et al.* (2021) conducted in north Shewa zone Amhara region, Ethiopia. Correspondingly, Mekoya *et al.* (2008) showed that biomass yield, adaptability to the environment, palatability, ease of propagation, growth and re-growth potential, multi-functionality, ability to stay for many years after planted under recurrent cutting and compatibility were the farmer's selection criteria of multi-purpose fodder trees. Begashaw and Niway (2018) also reported that farmer's preference criteria were based on availability of fodder tree. Likewise, Steven *et al.* (2014) mentioned farmer's criteria for evaluating local fodder trees and shrubs were either animal-related or tree-related such as drought resistance or effect on soil fertility.

2.7. Biomass yield of indigenous browse species

Productivity in terms of foliage yield per unit area has linked with habitat and soil texture. Bayssa *et al.* (2016) studied on biomass of 15 selected tropical browse species from Afar rangeland, northeastern of Ethiopia. The result showed that plant density (plant/ha) ranged from 73-1209, leaf biomass yield (kg/plant) ranged from 8.6-36.8, biomass yield (kg/ha) ranged from 790.2-3308.5 and crude protein (CP) yield (kg/ha) ranged from 125-631. These values revealed that the browse species could supplement poor quality rangeland grass species during the dry season which agrees with the suggestions of (Adane and Anjulo, 2023).

2.8. Chemical composition and digestibility of indigenous browse species

The chemical composition and *in vitro* digestibility of indigenous browse species depend upon the types of browse species used. Mudau *et al.* (2021) reported that the CP content of indigenous browse species was better than natural pasture and crop residue. Correspondingly, Bayssa *et al.* (2016) also stated that the browse species in Afar rangeland had 12.2% to 25.1% CP content and in Borana rangeland, it ranged from 13.8% to 28.7%. Where, the browse species had low to medium concentration of NDF, ADF and ADL composition but higher secondary metabolized contents. The variation of chemical composition among species might be season, soil characteristics, age and species of the plant.

Chemical composition and *in-vitro* digestibility of indigenous browse species also varied from season to season. The CP and IVDMD of indigenous browse species were

higher in the wet season than during the dry season whereas the NDF, ADF, and ADL were higher during the dry season than wet season (Mosisa *et al.*, 2021). The CP concentration varied from 95 to 245 g kg⁻¹ DM during the wet season, and from 61 to 205 g kg⁻¹ DM during the dry season. The NDF and ADF ranged from 315 to 518 g kg⁻¹ DM and from 200 to 403 g kg⁻¹ DM, respectively, during the wet season, and from 364 to 545 g kg⁻¹ DM and 243 to 417 g kg⁻¹ DM, respectively, during the dry season. The IVDMD of indigenous browse species ranged from 510 to 908 g kg⁻¹ DM during the wet season, and from 433 to 802 g kg⁻¹ DM during the dry season (Feyisa *et al.*, 2022). the nutritive content of browse species showed a wide significant variation among the browse species found in different soil types (Mudau *et al.*, 2021).

Table 2.1 Chemical composition and IVDMD of browse species (% DM)

Species	Plant part	Processing	CP	NDF	IVOMD	CT	References
<i>A. dicurrens</i>	Foliage	Dried	14.71	51.06	-	-	Ababu <i>et al.</i> (2021)
<i>M. stenopetala</i>	Leaves	Dried	22.35	25.05	-	-	Asmelash <i>et al.</i> (2020)
<i>A. Seyal</i>	Leaves		18.4	35.6	-	-	Ayenew <i>et al.</i> (2021)
<i>V.amygdolina</i>	Leaves	Dried	29.74	20.93	47.33	-	Fekade <i>et al.</i> (2021)
<i>F. thonningii</i>	Leaves	Dried	15.87	44.69	51.09	-	
<i>C. Africana</i>	Leaves	Dried	18.13	47.51	65.65	-	
<i>G. ferruginea</i>	Leaves	Dried	19.4	33.7	-	10.6	Bayssa <i>et al.</i> (2016)
<i>F. sycamorus</i>	Leaves	Dried	23.2	36.5	-	10.0	

2.9. Browse species on nutrient intake and digestibility of ruminants

Isah and Okunade (2015) investigated the effect of browse fodder supplementation on nutrient intake of goats fed threshed sorghum top as a basal feed. The result showed that intakes of DM and nutrients, feed conversion ratio, digestibility of nutrients and nitrogen utilization were superior in threshed sorghum top supplemented diets compared to the control diet. Similarly, Mengesha *et al.* (2017) involved supplementation of dried Tagasaste leaves at 100, 200, 300 and 400 g/day and intake and

digestibility DM and nutrients increased linearly as Tagasaste supplementation increased from 100 to 400 g/day.

Correspondingly, effects of supplementation with air dried leaves of African wild olive, *Acacia lahai* and their mixtures on performance of ruminant were evaluated by Hagos *et al.* (2017). The result presented that supplementation with air-dried leaves of these multipurpose trees and their mixtures significantly improved feed intake and body weight change. Hidosa *et al.* (2018) also conducted the effect of lablab leaf meal on feed intake and digestibility of goats with the dietary treatments. The result concluded that 35% lablab leaf meal was found to be a very promising supplement in sheep fed low-quality crop residues. However, the above result was contradicted with Alemu *et al.* (2014) who used twenty four yearling male local Washera lambs to assess the nutritional value of *Millettia ferruginea* and the treatments used were sole natural pasture grass hay, and 150, 300 and 450 g DM of *Millettia ferruginea* leaf hay with *ad libitum* natural pasture grass hay. The result showed that, the hay DM intake of the non-supplemented sheep was higher than *Millettia ferruginea* leaf supplementation.

2.10. Browse species supplementation on growth performance of small ruminant

Many trees and shrubs can be used in ruminant feeding since they are inexpensive local products and have good contents of nutrients (Seidavi *et al.*, 2018). Shenkute *et al.* (2013) studied that supplementation of dried Peagon pea leaves in dry season increase the weight gain of Arsi Bale kids. Similarly Isah and Okunade (2015) and Hagos *et al.* (2015) suggested that supplementation of multipurpose browse trees and their mixtures significantly improved growth performance of ruminant animal. Mekuriaw and Asmare (2018) revealed that *Ficus thonningii* leaves could serve as an alternative crude protein supplement in natural pasture hay-based feeding of Washera sheep and can be used to replace concentrate mix up to 75% to improve the growth performance. Likewise Taddesse *et al.* (2014) showed that mixtures of chopped and dried cactus and the browse species reversed body weight loss of goats in the dry season. Kholif *et al.* (2016) explained that better productive performances of goats achieved by offering *Moringa oleifera* as silage, followed by the fresh form and hay. Similarly, Damor *et al.* (2017)

showed that offering *Moringa oleifera* leaves to grazing kids at 1% of body weight level in substitution of concentrate increase the average daily gain by 21%.

2.11. Browse species supplementation on blood biochemical profiles of ruminants

The biochemical and hematological variables of blood can be used to monitor and evaluate health, nutritional and physiological status of ruminants (Khalil *et al.*, 2022). Furthermore, Jastaniah *et al.* (2024) reported that blood constituents are markers to determine the efficacy of feed nutrient content and its utilization. Tantawi *et al.* (2023) observed that biochemical and hematology profiles used to assess the immunity status of goats while they can also be an index of transportation stress. Among other factors, nutrition, age, sex, genetics and management have profound effects on the biochemical profiles of small ruminants.

Amina *et al.* (2020) reported that the serum biochemical profiles of west African dwarf goats fed some browse species supplemented with a concentrate diet were not affected by the leaf supplementation. While Ganai *et al.* (2025) reported that leaf meal mixture can be incorporated up to 15% level in the concentrate mixture of adult goats without affecting their digestibility and blood biochemical profile. Babeker and Bdalbagi (2015) consistently revealed that *Moringa oleifera* leaf meal could be used to improve production performance of small ruminants without any adverse health effect.

CHAPTER 3: GENERAL MATERIALS AND METHODS

3.1 Description of the study area

The survey and fieldwork part were conducted in three districts of south Gondar zone of Amhara National Regional State, Northwestern Ethiopia. The three districts were selected based on accessibility and representation of different altitudinal ranges. The districts were Ebinat (representing lowland), Libo Kemkem (representing midland) and Farta (representing Highland) agro ecology. The general materials and methods are given in this section and the detailed methodologies are available in the specific manuscripts (Chapters) imbedded here. The on-station studies were conducted at Zenzelima campus of Bahir Dar University, located in Northwest Ethiopia.

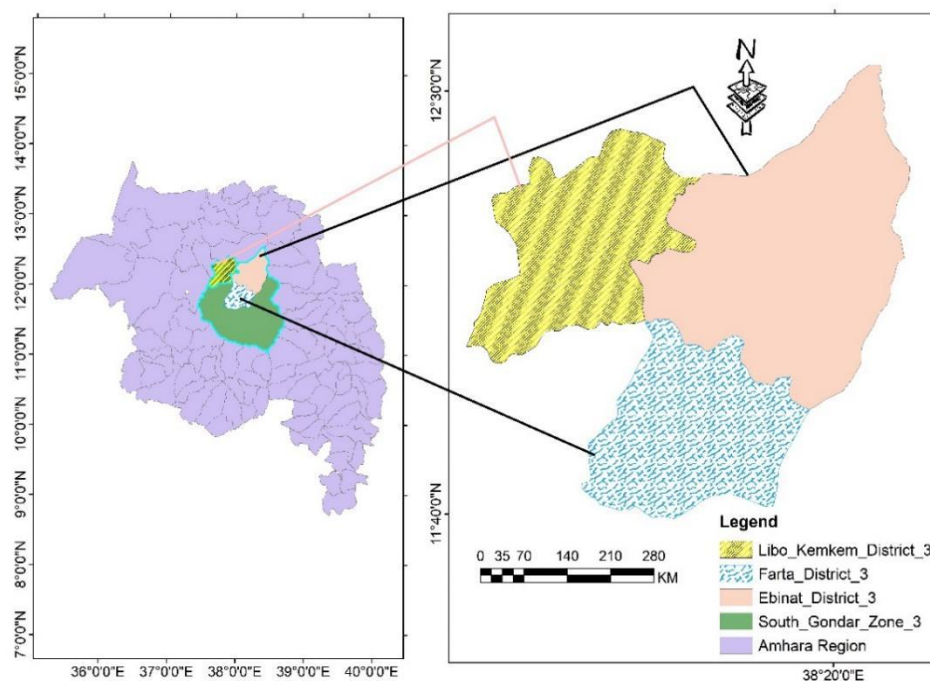


Figure 3.1. Map of the study area

3.2 Sampling methods and data collection

The study districts were selected purposively from the three agro ecology, Ebinat (lowland), Libo Kemkem (midland) and Farta (Highland) from which two kebele were selected purposively from each of the districts based on the potentials of IBFS and agro ecologies in consultation with extension and development experts in the districts. Primary data were obtained through a formal household survey (i.e. individual interviews and focus group discussions) using a semi-structured questionnaire while the secondary data were obtained from zonal and district agricultural offices. The sample size of households was determined based on the (Cochran, 1977) formula as follows:

$$no = \frac{Z^2 \times (P \times q)}{d^2}$$

Where, no = desired sample size according to Cochran when population is greater than 10,000;

Z = standard normal deviation (1.96 for the 95% confidence level);

P = 0.2 (proportion of population to be included in the sample, i.e.20%);

q = 1 – P;

d = degree of accuracy desired (0.05).

Plant identification was done with the help of key informants, knowledgeable farmers, forage experts and snap application. Moreover, identification of the scientific names of species was carried out using books of Azene (2007) and Flora of Ethiopia and Eritrea Hedberg *et al.* (2004). During group discussion, commonly agreed criteria were set for evaluating/scoring the multipurpose browse species with farmers. The ranking criteria were fast growth and regrowth potential, palatability, Feeding value, Relieve hunger, Adaptability, Multifunctionality and Biomass yield. For each district, the most commonly agreed criteria were used for ranking of IBFS.

The species diversity and evenness were determined using the Shannon-Weiner diversity index (H') according to the formula of Shannon and Weiner (1963):

$$\text{Shannon – Weiner Diversity Index (H')} = - \sum_{i=1}^s (P_i)(\ln P_i)$$

Where, s = number of species; P_i = proportion of species i in the community

The Evenness or Equitability (J) was quantified by using Shannon and Weiner index formula:

$$\text{Species Evenness (J)} = \frac{H'}{\ln(S)}$$

Where, H' = Shannon's diversity index; S = Number of species pooled in all study site

3.3 Foliage sample collection and preparation

Following the assessment, samples of leaf and pod of browse species were collected in the wet season from August – September 2022. Based on **objective 1**, leaves and pods of eight dominant indigenous species were selected for evaluation of nutrient content, *in vitro* gas production and post incubation parameters (OMD, ME, SCFA and CH₄ production) in each agro ecology. From each browse species, ten plants were randomly harvested and bulked to form representative samples. The petioles of the leaves were removed by hand. All plant samples were spread on a floor and air dried under shade and ground to pass a 1mm sieve size. The ground feed samples were kept in airtight plastic containers until used for laboratory analysis (**objective 2**).

3.4 Experimental animals and treatments

For the feeding trial (**objective 3 and 4**), twenty-five male local goats with average age of one year were purchased from local market. The age of the experimental animals was determined by dentition and information from the owners. The experimental animals were ear tagged for identification. The goats were quarantined for 15 days to observe incidence of any disease. During this quarantine period, each animal was treated against internal and external parasites. Animals were continuously observed for incidence of any ill health and disorders during the experimental period.

The design of the experiment was randomized complete block design (RCBD). Experimental animals were grouped into five blocks of five animals each based on their initial body weight. The experimental animals from each block were randomly assigned to each treatment feed. Natural pasture hay was provided as a basal diet and offered *ad*

libitum. The five treatment rations were formulated based on the result of the laboratory analytical data. *Terminalia brownii* leaves were included to substitute 0, 15, 30, 45 and 60% by concentrate mixture supplement in T1, T2, T3, T4 and T5 respectively. The five treatment rations were formulated comparably equi nitrogenous. Soon after the formulation, representative samples were taken from each of the experimental treatment for chemical analysis and adjustment in terms of protein contents.

3.5 Statistical analysis

Statistical Package for Social Sciences (SPSS version 26) was used for semi-structured questionnaire data (**objective 1**). One way ANOVA was carried out on nutrient content, *in vitro* gas production, CH₄ concentration, *in vitro* dry matter digestibility for each agro-ecological zone due to the difference in the types of available browse species between agroecologies (**objective 2**). The nutrient intake, feed conversion efficiency, digestibility, average daily weight gain, methane emission, hematology and serum biochemical profile (**objective 3 and 4**) analysis were also done using General Linear Model (GLM) procedure of Statistical Analysis System (SAS, 9.4). Means were separated using Tukey's multiple range test.

The Model were;

$$Y_{ij} = \mu + A_i + e_{ij} \text{ (objective 1)}$$

Where, Y_{ij} = response variable, μ = overall mean, A_i = Altitude effect and e_{ij} = random error

$$Y_{ij} = \mu + A_i + e_{ij} \text{ (objective 2)}$$

Where, Y_{ij} = response variable, μ = overall mean, A_i = species effect and e_{ij} = random error

$$Y_{ij} = \mu + T_i + B_j + e_{ij} \text{ (objective 3 and 4)}$$

Where,

Y_{ij} is the response variable (the observation in j^{th} block and i^{th} treatment)

μ is overall mean

T_i is treatment effect

B_j is block effect and e_{ij} random error

3.6 The research framework

The research involved four distinct but interrelated activities. These were cross-sectional questionnaire-based surveys, field measurements, laboratory works and animal experiment. The following diagram depicts the deeds within the activities.

Figure 3.2. The research framework

Questioner Based Survey	Field Work	Laboratory Work	Feeding trial
• Identification of the IBFS • Farmer's preference criteria • Utilization practice of IBFS	• Determine the diversity of IBFS • Sample collection	• Nutrient content of IBFS • Gas production characteristics • Methane concentration	• Nutrient intake • Body weight gain • Blood profile • Methane emission

CHAPTER 4
DIVERSITY, PREFERENCE CRITERIA AND FEEDING PRACTICE
OF INDIGENOUS BROWSE FODDER BY LIVESTOCK FARMERS
IN NORTHWEST ETHIOPIA

Diversity, preference criteria and feeding
practice of indigenous browse fodder by
livestock farmers in northwest Ethiopia

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Abstract

The study was conducted in South Gondar zone to assess farmer's perception and utilization practice of indigenous browse species. The study areas were selected based on agro-ecology representation and availability of fodder species. A total of 245 households were used for data collection. Twenty-four sampling plots of each with a dimension of 20 m × 20 m were used for inventories of the diversity of fodder species. The diversity index was used to determine the species diversity. The collected data was analyzed using SPSS, version 26 and SAS, version 9.4 software. The result showed that 44 indigenous browse species were identified in all agro ecologies. Of the identified species *T. brownii*, *A. amara* and *C. Africana* in the lowland; *C. Africana*, *F. vasta*, *A. abyssinica* and *F. thonnigii* in the midlands and *C. abyssinica*, *F. thonnigii* and *V. amygdalina* in the highlands were preferentially opted for livestock feed. The midland showed the highest species diversity of browse fodder. Palatability and multi functionality were the main preference criteria for selecting browse fodder in the study area. The majority of farmers (42.27%) fed their livestock in partially cut and carry and, browsing. Incorporating locally available resources based on farmers' preference criteria and scientific knowledge is vital to efficiently utilize indigenous browse.

Key Words: Diversity, Indigenous browse, Preference criteria and Utilization

4.1 Introduction

Ethiopia has a huge livestock resource with an estimated population of 70 million cattle, 42.9 million sheep, 52.5 million goats, 2.15 million horse, 10.8 million donkey, 0.38 million mule, 8.1 million camels, 57 million poultry and 6.99 million beehives (CSA, 2021). The livestock sector has an enormous contribution to the national economy and livelihood of Ethiopians (FAO, 2017). However, the current livestock contribution in the country is below its potential due to a number of factors such as feed shortage, poor genetic makeup of animals, poor veterinary service, underdeveloped marketing system, and less effort in introducing the appropriate package of livestock technologies (Selamawit *et al.*, 2017).

Out of the aforementioned factors, feed is the main factor affecting the success of livestock production. In tropical areas including Ethiopia, poor quality natural pastures and crop residues are the main resources of livestock feed (Duguma and Janssens, 2021). These feeds are low in nutrients, particularly energy and protein. Besides, the fiber in these feedstuffs is usually so high which reduces feed intake and digestibility. In many areas of Ethiopia, livestock farming is increasingly dependent on supplemental feed, particularly during crucial drought intervals. But like most farmers in the tropics and subtropics, small farmers in Ethiopia cannot purchase concentrated feeds, therefore they almost only rely on locally accessible substitute feeds to replenish their herd of ruminants (Barry *et al.*, 2017; Avornyo *et al.*, 2018). To increase feed availability and handle issues with feed billing and other feed production concerns for ruminants, (Alimi *et al.*, 2024) underlined the need to use innovative alternative feeds for livestock feeding.

The use of browse species as animal feed is the most promising option to combat the existing deficiency of crude protein. Indigenous browse species are good feed resources that remain green year-round and rich in protein, energy, vitamins and minerals in dry seasons (Takele *et al.*, 2014). Furthermore, including fodder leaves as feed could reduce rumen acidosis and other health-related problems and improve productivity (Revell *et al.*, 2020). In Ethiopia, indigenous browse species are well known to farmers and are better adapted to environments than exotic ones (Belachew *et al.*, 2020; Latamo, 2021).

In the study area, particularly the south Gondar zone, crop production is the dominant practice, where crop residues and some grazing are the only feed suppliers. However, many indigenous browse feeds can make a large contribution to livestock feeding during the dry season and alleviate nutritional problem. Nevertheless, information about the perceptions of farmers on the management and utilization of indigenous browse species is limited. To bridge this gap, it is crucial to assess the perception and utilization practice of the identified indigenous browse-fodders to prioritize the beneficial indigenous browse species. This could help efficiently utilize the browse species in improving livestock productivity. Hence, the objective of this study was to assess farmers' perception, diversity and distribution in terms of agroecology and

land use systems, and utilization practice of indigenous browse species in the selected districts of south Gondar zone, Ethiopia.

4.2 Material and Methods

4.2.1 Description of the study area

The study was conducted in three districts of south Gondar zone of Amhara National Regional State, Northwestern Ethiopia. The three districts were selected based on accessibility and representation of the three different agroecologies. The districts were Ebinat (representing lowland), Libo Kemkem (representing midland) and Farta (representing Highland).

4.2.2 Sampling method and sample size determination

A multistage sampling procedure was performed to select respondents' households in the study area. In the first stage, three representative agroecological zones (Ebinat, Libo Kemkem and Farta representing lowland, midland and highland, respectively) were selected following a stratified sampling technique. In the second step, six kebeles (two from each agroecology) were chosen based on livestock population and diversity. Kebele is a lower-level administrative name in Ethiopia. The respondents were chosen in the third stage based on the results of a preliminary survey that revealed the households feeding practice of indigenous browse species. A total of 245 households (79, 86 and 81) from low, mid and highlands, respectively, were selected based on simple random sampling for individual interview. The sample size of households was determined based on the (Cochran, 1977) formula as follows:

$$no = \frac{Z^2 \times (P \times q)}{d^2}$$

where no = desired sample size according to Cochran when population is greater than 10,000;

Z = standard normal deviation (1.96 for the 95% confidence level);

P = 0.2 (proportion of population to be included in the sample, i.e.20%);

q = 1 – P;

d = degree of accuracy desired (0.05).

4.2.3 Methods of data collection

Data collection was performed after a verbal agreement was made with district agricultural offices and target farmers of the research. In each agroecological zone, an interview was conducted with the individual respondents and key informants (model farmers and development agents) to produce information about indigenous browse species in the study areas. Data on socioeconomic characteristics of households and information related to indigenous browse fodder were collected with a semi-structured questionnaire. Focus group discussions with a group of farmers (10 participants in each agro ecology), selected based on their background about browse species in each agroecological zone, was organized separately to supplement the collected data using questionnaire.

4.2.4 Identification of indigenous browse species

Indigenous browse species identification was conducted with the help of key informants and forage experts and leaf snap application in each ago-ecological zone. Moreover, identification of the scientific names of species was carried out using books of Azene (2007) and flora of Ethiopia and Eritrea (2004).

During the group discussion, common-agreed criteria were set for evaluating indigenous browse species with farmers. Therefore, after commonly agreed criteria were determined during the group discussion, all farmers scored each species individually.

4.2.5 The diversity of indigenous browse species

The study area was divided into two tiers within each agroecological zone, namely area closure and open grazing area, according to the use of the land for the location of the sample plot. Eight 20 m × 20 m plots were randomly established in each ago-ecological zone and land use with a minimum distance of 100 m between any two plots (Jimoh and Lawal, 2016). The numbers of individual indigenous browse species were counted in the sampled plot and recorded on a species diversity sheet. The species richness index was calculated using the following equation, which is the number of species present in a particular plot.

$$S = \sum n$$

where ‘S’ is the species richness and ‘n’ is the number of browse species in a given plot. Species diversity was calculated using the Shannon–Wiener diversity index as follows:

$$H' = - \sum_{i=1}^n P_i \ln(p_i)$$

Where, H' is Shannon–Wiener, diversity index; n is the total number of species in the community; P_i (proportionate) is the proportion of n made up of the i^{th} species; and $\ln$ is natural logarithm.

The Evenness or Equitability (J) was quantified by expressing Shannon index using the formula:

$$\text{Species Evenness } (J) = \frac{H'}{\ln(S)}$$

Where, H' = Shannon’s diversity index; S = Number of species pooled in all study site

4.2.6 Data analysis

Statistical Package for Social Sciences (SPSS version 26) was used for the analysis of the data collected using semi-structured questionnaire. Descriptive statistics such as percentage and means were used for appropriate parameters to present the results. Data on the species richness and diversity indices of indigenous browse fodder were subjected to one-way analysis of variance (ANOVA) using the GLM procedure of the Statistical Analytical System (SAS, 2002, version 9.4). The Tukey multiple range test was used for mean comparison. The farmer’s evaluation criteria were analyzed by index method. The index was computed with the principle of weighted average according to the following formula as employed by Musa *et al.* (2006).

$$\text{Index} = \frac{R_n * C_1 + R_{n-1} * C_2 \dots R_1 * C_n}{\sum R_n * C_1 + R_{n-1} * C_2 \dots R_1}$$

Where; R_n : Value given for the least ranked level (example if the least rank is 5th rank, then $R_n=5$, $R_{n-1}=4$ and ... $R_1= 1$) C_n : Counts of the least ranked level (in the above example, the count of the 5th rank = C_n , and the counts of the 1st rank = C_1).

The Model was;

$$Y_{ij} = \mu + A_i + e_{ij}$$

Where, Y_{ij} = response variable

μ = overall mean

A_i = agroecological effect and e_{ij} = random error

4.3 Result and Discussion

4.3.1 Household characteristics of the respondent

The demographic characteristics of the interviewed respondents are presented in Table 4.1. Of the total 245 households interviewed, the majority (88.9%) of them were male-headed. This finding is consistent with Kebede *et al.* (2019) in central and eastern Ethiopia and Ababu *et al.* (2021) in the north Shewa zone of the Amhara region showed that the majority of households in mixed crop livestock production system were male headed.

The mean age of the respondents in the study area was 39.5, 44.8 and 46.3 years in low, mid and highland areas, respectively with the overall average age of 43.53 ± 1.5 years. This mean indicated, there is an active working force that has a progressive effect on livestock production development. In line with this, Atinafu *et al.* (2022) and Dissanayake *et al.* (2022) demonstrated that age is one variable for the adoption of agricultural technology.

The majority of the households (54.6%) were illiterates while the rest were literates. This difference might be due to access to schools and inefficient transfer of knowledge, skills, and technologies from governmental institutions and development agencies to local farming communities (Zerssa *et al.*, 2021). The fact that the majority of the respondents were illiterate would likely affect acceptance, adoption and use of improved feed and livestock production technologies. Therefore, providing basic education to them would be essential for the easy acceptance of improved livestock technologies. Zegeye *et al.* (2022) reported that low education level of farmers could have an influence on transfer of improved agricultural technologies and their participation in agricultural improvement. Likely, Solomon *et al.* (2021) showed that the educational level of the farmer positively affects the probability of adoption, as farmers

with more educational levels allow to acquire, analyze and evaluate information on agricultural technology and market opportunity.

The mean average family size of households in the study areas was 6.3. The highest average family size was recorded in the highland area (7.23 ± 0.25). This variation might be due to the difference in family planning program between farmers.

Table 4.1 Household characteristics in the study area

Variables	Description	Lowland (79)	Midland (86)	Highland (81)	Over all Mean	P value
Gender	Male	67(85 %)	73(85.24%)	79(96.4%)	88.9%	
	Female	12(15%)	13(14.76%)	2(5.6%)	11.8%	
	Illiterate	49(61.67%)	48(55.73%)	38(46.42%)	54.6%	
Education	Literate					
	Religious education	8(10%)	7(8.12%)	4(5.34%)	7.82%	
	Read and write	4(5%)	-	30(35.71%)	20.36%	
	Elementary	12(15%)	31(36.06%)	10(12.5%)	21.19%	
Age	Secondary	6(8.33%)	-	-	8.33%	
	Mean $\pm$ SE	39.5 ± 1.4	44.8 ± 1.9	46.3 ± 1.2	43.53 ± 1.5	0.131
Family size	Mean $\pm$ SE	$5.93^b \pm 0.27$	$5.75^b \pm 0.26$	$7.23^a \pm 0.25$	6.30 ± 0.18	0.004

^{a, b} = the different subscripts within the row are significantly different ($p < 0.05$)

4.3.2. Land ownership and land use pattern

The land ownership and land use pattern of the different agro-ecologies are presented in Table 4.2. The overall average landholding of the respondents was 1.01 ± 0.1 hectare per household (ha/HH), which was lower than the average national landholding size (1.4 ha/HH). The land holding in the present finding is slightly lower compared to the result (1.4ha) stated by Hassan *et al.* (2020) in Moyale district. The largest land size (0.84 ± 0.48 ha) was allocated for crop cultivation while the average land allocated for improved forage legumes (0.009 ± 0.003 ha) was the lowest. The average land allocated for private grazing in all agro ecologies was 0.09 ± 0.04 ha. It was significantly smaller in high land (0.169 ± 0.02) as compared to the low (0.05 ± 0.09) and mid (0.05 ± 0.01) lands. In agreement to this finding Tefera *et al.* (2019) reported that, land allocated for private grazing in Farta was too small (0.23 ± 0.04). The discrepancy in land allocation

among agro-ecologies might be due to the difference in farming systems. The average land allocated for crop cultivation is similar with the findings of Tefera *et al.* (2019) who reported that 1.1 ± 0.04 ha of land allocated for crop production in Farta district, Ethiopia.

Table 4.2 Land ownership and land use pattern in the study area

Variables (ha)	Low Land N=79 Mean $\pm$ SD	Midland N=86 Mean $\pm$ SD	Highland N=81 Mean $\pm$ SD	Total Mean Mean $\pm$ SD	P value
Crop cultivation	$1.0^a \pm 0.59$	$0.80^b \pm 0.42$	$0.73^b \pm 0.37$	0.8452 ± 0.48	0.0067
Private grazing	$0.05^b \pm 0.09$	$0.05^b \pm 0.01$	$0.169^a \pm 0.02$	0.09 ± 0.04	0.001
Browse fodder	$0.01^b \pm 0.003$	0.002^b	$0.04^a \pm 0.008$	0.02 ± 0.004	0.000
Improved forage	0.0^b	0.0^b	$0.028^a \pm 0.01$	0.009 ± 0.003	0.001
Total land	$1.06^a \pm 0.05$	$1.02^a \pm 0.17$	$0.97^b \pm 0.10$	1.01 ± 0.1	0.05

^{a, b}, means in a row with the same category that have different supper scripts differ ($P < 0.05$); ha =hectare, N= number of respondents and SD= standard deviation

4.3.3 Livestock holding of respondents (TLU)

The average number of livestock holding per household in the study area is presented in Table 4.3. Except for the number of donkeys, the average number of livestock holding per household significantly varied ($p < 0.05$). Cattle holding were higher in midland 3.15 TLU/HH (tropical livestock unit) as compare to low and highland areas. On the other hand, the average livestock holding for goats in lowland 0.5 TLU/HH was greater than in midland and highland areas. However, sheep holding were higher in mid and highland areas. This indicates that sheep are more adapted and suitable species in highlands compared to goats which are more adapted in lowlands (Henry *et al.*, 2018).

The current result is in agreement with the result of Ahmed *et al.* (2010) who reported that higher average sheep holding number is observed in the high-altitude zone of Basona Worena district, Amhara region. The total livestock holding of this study is higher than the reports of Addisu *et al.* (2016) who reported that cattle, sheep and goat holding was 2.48, 0.12 and 0.10, respectively in Enebsie Sar Midr district, Ethiopia. However, the result is lower than 5.8 TLU/HH, reported by Tefera *et al.* (2019) in Farta district, Ethiopia. On average, cattle are the predominant livestock species reared in the

study area. This may be due to the fact that cattle are multipurpose animals; farmers used for traction, provide milk and are means of cash income.

Table 4.3. Livestock holding in the study area (TLU)

Livestock Species	Lowland N=79 Mean $\pm$ SD	Midland N=86 Mean $\pm$ SD	Highland N=81 Mean $\pm$ SD	Overall Mean $\pm$ SD	P value
Cattle	2.49 ^b $\pm$ 1.22	3.15 ^a $\pm$ 1.22	2.15 ^b $\pm$ 1.04	2.61 $\pm$ 1.23	0.004
Sheep	0.23 ^b $\pm$ 0.03	0.24 ^a $\pm$ 0.05	0.24 ^a $\pm$ 0.04	0.23 $\pm$ 0.04	0.007
Goat	0.5 ^a $\pm$ 0.05	0.19 ^b $\pm$ 0.04	0.11 ^b $\pm$ 0.02	0.26 $\pm$ 0.03	0.001
Equine	0.67 $\pm$ 0.13	0.66 $\pm$ 0.60	0.52 $\pm$ 0.07	0.67 $\pm$ 0.26	0.09
Poultry	0.08 ^a $\pm$ 0.05	0.05 ^b $\pm$ 0.03	0.05 ^b $\pm$ 0.05	0.06 $\pm$ 0.04	0.004
Bee colony	2.29 $\pm$ 0.32	2.63 $\pm$ 1.08	3.9 $\pm$ 0.69	2.94 $\pm$ 0.67	0.308

^{a, b}, means in a row with the same category having different super scripts differ (P<0.05);

TLU = Tropical Livestock Unit

4.3.4 Identified major indigenous browse species

In the study areas, 44 indigenous browse fodder species were identified, of which 32 and 12 were fodder trees and shrubs, respectively. It was observed that farmers preferred browse species based on the criteria they set. From the total identified 44 indigenous browse species, the top 12 species from each agro-ecology, which were prioritized and frequently used with their scientific and vernacular name are presented in Table 4.4.

From the current list of available browse fodder species *Albezia amara*, *Ficus vasta*, *Terminalia brownii*, *Acacia abyssinica*, *Acacia brevispica*, *Ficus sycomorus*, *Cordia Africana*, *Ficus thonningii*, were found to be commonly grown in the lowlands. *Ficus vasta*, *Acacia abyssinica*, *Dodonaea viscosa*, *Cordia Africana*, *Ficus thonningii*, *Ficus sycomorus*, *syzygium giuneens* and *Stereospermum kunthianum* were common in the midland. *Vernonia amygdalina*, *Ficus thonningii*, *Acacia abyssinica*, *Cordia Africana*, *Myrica salicifolia*, *syzygium giuneens*, *Olea Africana*, *Ficus vasta* were identified as animal feed resources in the highland areas.

Acacia seyal, *Albezia malacophylla*, *Cordia Africana*, *Ficus sycomorus*, *Vernonia amygdalina*, *Ficus thonningii*, *Piliostigma thonningii*, *Steteospermum kanthianum*, *Rothmannia urcelliformis* were identified in Metekel and Awi zone, north western Ethiopia (Ayenew *et al.*, 2021). Belachew *et al.* (2020) noticed that *Rhus natalensis*, *B. aegyptiaca*, *A. tortilis*, *A. mellifera*, *T. brownii*, *Ziziphus mucronata* and *Tamarindus*

indica were present on the grazing areas of selected districts of Gamo Gofa and Wolayta zones, Ethiopia. *Ficus thonningii*, *Cordia Africana*, *Vernonia amygdalina*, *Grewa bicolar*, *Dombeya bruceana* and *Ehretia cymosa* were identified by (Mekoya, 2008) in Lay Armacho and Sidama districts whereas, *Acacia mollifiers*, *Acacia tortilis*, *Celtis Africana*, *Cordials Africana*, *Grewa bicolour* and *Olea europaea* were mentioned by Shenkut *et al.* (2012) in rift valley of Ethiopia.

Table 4.4. The most preferred browse species in the study district

Agro ecology	Botanical name	Vernacular name	Family name	Plant habit	Plant part used for livestock feed
Low land	<i>Albezia amara</i>	Sibkana	<i>Fabaceae</i>	Tree	Leaves & pods
	<i>Ficus vasta</i>	Warka	<i>Moraceae</i>	Tree	Leaves & pods
	<i>Terminalia brownii</i>	Ekima	<i>Combretaceae</i>	Tree	Leaves & pods
	<i>Acacia abyssinica</i>	Girar(bazra)	<i>Mimosaceae</i>	Tree	Leaves & pods
	<i>Acacia brevispica</i>	Gigirkana	<i>Mimosaceae</i>	Tree	Leaves
	<i>Ficus sycomorus</i>	Bamba	<i>Moraceae</i>	Tree	Leaves
	<i>Rhus glutinosa</i>	Ekimo	<i>Anacardiaceae</i>	Tree	Leaves & fruit
	<i>Carissa spinarum</i>	Agam	<i>Apocynaceae</i>	Shrubs	Leaves & fruit
	<i>Capparis tomentosa</i>	Gimero	<i>Capparaceae</i>	Shrubs	Leaves
	<i>Eupharbia spinarum</i>	Kinchib	<i>Euphorobiaceae</i>	Tree	Leaves
	<i>Cordia africana</i>	Wanza	<i>Boraginaceae</i>	Tree	Leaves & pods
	<i>Ficus thonningii</i>	Chibha	<i>Moraceae</i>	Tree	Leaves & pods
Mid land	<i>Ficus vasta</i>	Warka	<i>Moraceae</i>	Tree	Leaves & fruit
	<i>Stereospermum kunthianum</i>	Kotemisa	---	Tree	Leaves
	<i>Acacia abyssinica</i>	Girar (Bazira)	<i>Mimosaceae</i>	Tree	Leaves & pods
	<i>Dodonaea viscosa</i>	Kitkita	<i>Sapindaceae</i>	Shrubs	Leaves
	<i>Cordia africana</i>	Wanza	<i>Boraginaceae</i>	Tree	Leaves & pods
	<i>Ficus thonningii</i>	Chibha	<i>Moraceae</i>	Tree	Leaves & pods
	<i>Carissa spinarum</i>	Agam	<i>Apocynaceae</i>	Shrubs	Leaves & fruit
	<i>Olea Africana</i>	Woyira	<i>Oleaceae</i>	Tree	Leaves
	<i>Rhus glutinosa</i>	Qamo	<i>Anacardiaceae</i>	Tree	Leaves & seeds
	<i>Acanthus sennii</i>	Kosheshele	<i>Acanthaceae</i>	Shrubs	Leaves & flowers
	<i>Ficus sycomorus</i>	Bamba	<i>Moraceae</i>	Tree	Leaves
	<i>Syzygium giuneens</i>	Dokima	<i>Myricaceae</i>	Tree	Leaves

Continued...

High land	<i>Vernonia amygdalina</i>	Girawa	<i>Asteraceae</i>	Tree	Leaves
	<i>Ficus thonningii</i>	Chibha	<i>Moraceae</i>	Tree	Leaves & pods
	<i>Grewia ferruginea</i>	Lenguata	<i>Tiliaceae</i>	Shrubs	Leaves
	<i>Buddleia polystachya</i>	Anfar	<i>Buddlejaceae</i>	Tree	Leaves
	<i>Syzygium giuneens</i>	Dokima	<i>Myrtaceae</i>	Tree	Leaves & fruits
	<i>Rosa abyssinica</i>	Kega	<i>Rosaceae</i>	Shrubs	Leaves & fruit
	<i>Acacia abyssinica</i>	Girar (Bazira)	<i>Mimosaceae</i>	Tree	Leaves & pods
	<i>Cordia africana</i>	Wanza	<i>Boraginaceae</i>	Tree	Leaves & fruit
	<i>Myrica salicifolia</i>	Shinet	<i>Myricaceae</i>	Tree	Leaves
	<i>Olea africana</i>	Woyira	<i>Oleaceae</i>	Tree	Leaves
	<i>Ficus vasta</i>	Warka	<i>Moraceae</i>	Tree	Leaves & fruit

4.3.5 Species diversity and evenness of indigenous browse species

According to Getnet *et al.* (2019), species diversity is a function of the number of species present and how evenly the individuals are distributed across these species. A greater variety of species allowed for greater species interaction, greater system stability and an indication of good environmental condition. Higher species diversity is indicated a more complex and healthier community. Knowing the diversity of native browse species offers farmers the chance to choose, propagate and use browse fodder in the future (Girma *et al.*, 2015).

The highest species richness (15.75), diversity (2.57) and evenness (0.87) were recorded in mid land than all agro-ecologies, which might be associated with environmental differences, such as temperature, moisture, soil characteristics and precipitation of the study area. The result of the current study is contradict with the finding of Abraham *et al.* (2022) who reported that the highest mean species richness (5.6) and diversity indices (1.59) of indigenous legume fodder tree and shrubs were exhibited in lowland area closure which valued 1.2 in Gamo zone land escapes. Similarly, Nemera *et al.* (2018) also reported that the highest diversity index value of shrubs and trees were recorded at lower altitude than mid and high altitudes.

The mean species richness and diversity indices of area closure revealed significant difference compared with open grazing land in all agro-ecologies explained the level of protection while the lower in grazing lands explained the level of exploitation by human being and livestock. According to Etefa *et al.* (2014), forestland in the Tigray region has a higher species richness of fodder trees and bushes. In addition, compared to rangelands, Coulibaly *et al.* (2021) showed that the forest reserve had the highest diversity indices.

Table 4.5. Species richness, diversity and evenness of indigenous browse species

Agro ecology	Diversity index (H')	Richness	Evenness
	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD
Low land	2.35 ^b $\pm$ 0.07	15.00 ^b	0.86 ^b $\pm$ 0.04
Mid land	2.57 ^a $\pm$ 0.03	17.75 ^a	0.88 ^a $\pm$ 0.02
High land	2.31 ^b $\pm$ 0.10	14.00 ^c	0.87 ^b $\pm$ 0.06
P value	0.003	0.00	0.00
Land use type			
Area enclosure	2.87 ^a $\pm$ 0.05	21.5 ^a $\pm$ 4.35	2.05 $\pm$ 0.04
Free grazing	2.46 ^b $\pm$ 0.23	14.75 ^b $\pm$ 2.98	1.89 $\pm$ 0.17
P value	0.01	0.0004	0.12

^{a, b}, means in a column with the same category having different supper scripts differ (P<0.05)

4.3.6 Farmer's selection criteria of indigenous browse species

Farmer's agreed criteria to select a specific plant for animal feed are presented in Table 4.6. In this study, farmer's criteria for evaluating indigenous browse species are important in order to satisfy various farming goals and agronomic requirements. The criteria of the farmers to select the fodder trees and shrubs are not dependent on the specific characteristics of indigenous tree species. The species evaluation was made based on plant characteristics and the perceived animal preference. Among the selection criteria listed by households, palatability (0.213 and 0.186) was the most important criteria to select browse fodder as feed for livestock in low and midland areas respectively. Multifunctionality (0.230) of browse species was mentioned as first important selection criteria in highland. In addition, fast growth and regrowth, adaptability and biomass yield were listed from plant related criteria.

The criteria were also used in previous studies Horamo *et al.* (2021) who showed that palatability was the main farmer's criteria to characterize browse fodder in their farmlands. Ayenew *et al.* (2021) also reported that biomass yield, availability, feed value and palatability were the most important criteria for ranking the multipurpose browse species. Correspondingly, Begashaw (2018) also reported that farmer's preference to select indigenous browse fodder is mostly based on the availability, palatability and adaptability of plants.

Table 4.6 Farmer's selection criteria and rank used to evaluate browse species

Evaluation criteria	Lowland									
	No of farmers									Rank
	1 st	2 nd	3 rd	4 th	5 th	6 th	7 th	8 th	Index	
Palatability	33	23	0	0	0	0	0	0	0.213	1
Feeding value	8	14	14	5	12	0	0	3	0.161	3
Improve milk production	1	8	9	10	3	0	0	7	0.094	5
Relieve hunger	11	4	16	17	6	4	0	0	0.167	2
Growth and regrowth	0	1	10	10	12	11	4	6	0.106	4
Adaptability	0	5	4	4	11	11	13	3	0.093	6
Multifunctionality	0	1	0	8	6	22	11	4	0.082	8
Biomass yield	5	3	4	2	4	4	19	11	0.086	7
Midland										
Palatability	24	15	7	11	3	1	0	0	0.186	1
Feeding value	3	12	14	9	9	9	3	2	0.140	3
Improve milk production	2	6	2	4	1	5	7	30	0.069	8
Relieve hunger	7	1	6	5	1	12	24	6	0.099	7
Growth and regrowth	0	2	10	9	20	7	7	6	0.109	5
Adaptability	3	10	8	14	11	5	7	3	0.131	4
Multifunctionality	17	13	11	5	6	6	3	0	0.166	2
Biomass yield	6	2	3	5	10	16	10	9	0.101	6
Highland										
Palatability	4	12	21	4	3	3	0	0	0.178	2
Feeding value	0	0	4	4	5	10	3	5	0.066	8
Improve milk production	1	4	3	8	11	5	3	3	0.102	5
Relieve hunger	0	4	4	6	6	2	11	1	0.085	7
Growth and regrowth	1	11	7	6	3	7	7	3	0.130	3
Adaptability	5	1	5	6	9	2	1	3	0.096	6
Multifunctionality	37	9	1	0	0	0	0	2	0.230	1
Biomass yield	5	7	4	10	0	3	2	7	0.115	4

4.3.7 Farmers' ranking of indigenous browse species

Evaluation of indigenous browse species on the stated criteria by the local farmers is shown in Table 4.7. The purpose of ranking browse species is to determine which species, farmers prioritized while choosing and rating indigenous browse species (Almaz *et al.*, 2021). Based on farmer's evaluation criteria *Terminalia brownii*, *Albezia amara*, *Cordia Africana*, *Ficus sycomorus*, *Acacia brevispica* and *Ficus thonnigii* were the most preferred species feed resource in lowland area. *Cordia Africana*, *Ficus vasta*, *Acacia abyssinica*, *Ficus thonnigii*, *Stereospermum kunthianum*, *Ficus sycomorus*, *Dodonaea viscosa* and *Syzygium giuneens* were ranked as the top preferred species in midland. *Cordia abyssinica*, *Ficus thonnigii*, *Vernonia amygdalina*, *Acacia abyssinica*, *Myrica salicifolia*, *Olea Africana*, *Ficus vasta* and *Dodonaea viscosa* were ranked as the top preferred species in the highland.

Ababu *et al.* (2021) stated that tree *lucerne*, *Buddleja polystachya fresen* and *Hypericum quartinianum* were the most preferred species for livestock feed in Baso whereas, *Celtics Africana*, *Acacia abyssinica* and *Justicia schimperiana hochest* were ranked as the top preferred species in Tarmaber districts. Belachew *et al.* (2020) also revealed that, *A. tortilis* was the first favored browse fodder consumed by in Gamo Gofa and Wolayita zone, Ethiopia. Likewise, Kindu (2009) reported that in the highlands of central Ethiopia from 29 identified tree fodder and shrub species, farmers prefer four most selected tree fodder and shrub. Among these four trees, *Buddleja polystachya fresen* was preferred as the best based on its ability to improve soil fertility, palatability and fast to intermediate growth.

Table 4.7. Farmers' ranking of indigenous browse species in the study area

Low land			Mid land			High land		
	Index	Rank		Index	Rank		Index	Rank
<i>Terminalia brownii</i>	0.162	1	<i>Cordia Africana</i>	0.144	1	<i>Cordia abyssinica</i>	0.211	1
<i>Albezia amara</i>	0.138	2	<i>Ficus vasta</i>	0.124	2	<i>Ficus thonniigii</i>	0.153	2
<i>Cordia Africana</i>	0.111	3	<i>Acacia abyssinica</i>	0.121	3	<i>Vernonia amygdalina</i>	0.124	3
<i>Ficus sycomorus</i>	0.09	4	<i>Ficus thonniigii</i>	0.119	4	<i>Acacia abyssinica</i>	0.119	4
<i>Acacia brevispica</i>	0.084	5	<i>Stereospermum kunthianum</i>	0.111	5	<i>Myrica salicifolia</i>	0.099	5
<i>Ficus thonningii</i>	0.083	6	<i>Ficus sycomorus</i>	0.092	6	<i>Olea Africana</i>	0.065	6
<i>Ficus vasta</i>	0.081	7	<i>Dodonaea viscosa</i>	0.069	7	<i>Ficus vasta</i>	0.065	7
<i>Acacia abyssinica</i>	0.074	8	<i>syzygium giuneens</i>	0.065	8	<i>Dodonaea viscosa</i>	0.053	8
<i>Rhus glutinosa</i>	0.065	9	<i>Carissa spinarum</i>	0.046	9	<i>Grewia ferruginea</i>	0.042	9
<i>Euphorbia spinarum</i>	0.057	10	<i>Olea Africana</i>	0.040	10	<i>Buddleia polystachya</i>	0.033	10
<i>Carissa spinarum</i>	0.033	11	<i>Rhus glutinosa</i>	0.035	11	<i>Syzygium giuneens</i>	0.029	11
<i>Capparis tomentosa</i>	0.020	12	<i>Acanthusn sennii</i>	0.031	12	<i>Rosa abyssinica</i>	0.004	12

4.3.8 Planting practice of indigenous browse species

About 85.4% of households practiced planting of indigenous browse species for different purposes in land use systems while, the rest 14.6 % of households used only naturally grown indigenous browse species (Table 4.8). About 93.4 % of the respondents in midland reported planting of browse species followed by 91.4 % in highland and 71.4% in lowland areas. This variation could be due to the relatively higher availability of browse species in the lowlands, which aspires the farmers in the lowland to use naturally grown fodder rather than planting. For many species, particularly in lowland areas, protection of natural regrowth may in fact be a more effective and cheaper way to ensure long-term survival (Azene, 2007).

The majority of households in the study areas planted browse species in home garden (45.13%), within the home compounds and boundaries of farmland (34.19%), home garden and forestland (9.64%), boundaries of farmland (5.14%). The majority of respondents in lowland and highland areas planted fodder in home compound and soil and water conservation areas and midland area respondents planted on home garden and boundaries of farmland. Several studies have shown that the niches of trees and shrubs across the landscapes were homesteads, farm boundary, cropland, hedge, gullies, hillsides and grazing lands (Alemie and Gebremedhin, 2019).

Table 4.8. Planting practice of indigenous browse species

Variables	Description of result	Agroecology						
		Lowland N=79		Midland N=86		Highland N=81		Overall Mean
		N	%	N	%	N	%	%
Planting of indigenous browse fodder	Yes	57	71.7	80	93.4	74	91.1	85.4
	No naturally grown	22	28.3	6	6.6	7	8.9	14.6
If yes where you propagate?	Home garden	40	51.43	28	32.73	41	51.22	45.13
	Boundaries of farm land	5	5.71	6	7.28	2	2.44	5.14
	Soil and water conservation land	5	5.71	-	-	-	-	1.9
	Scattered with in grazing land	2	2.86	-	-	-	-	0.96
	Home garden and boundaries of farm land	16	20	50	58.18	20	24.4	34.19
	Back yard and conservation land	11	14.29	-	-	12	14.63	9.64
	Back yard and scattered with in grazing land	-	-	2	1.81	-	-	0.6
	Forest land and scattered land	-	-	-	-	2	2.44	0.81
	All the above locations	-	-	-	-	4	4.88	1.63

Note: N= number of respondents

4.3.9 Propagation technique of indigenous browse species

The majority of households (31.8%) planted browse species using seedling and cutting with higher (51%) proportion from highland area (Table 4.9.). This result was supported by Begashaw (2018) who reported that the major propagation techniques of browse trees and shrubs were practiced by seedling and direct sowing. Kebede *et al.* (2017) showed that cutting directly in the field and seedling propagation technique are used for *Ficus Thonninigii* propagation. Similarly, Getachew *et al.* (2022) also indicated

that seed, seedling and stem cutting were the prominent propagation methods of indigenous legume tree and shrubs fodder in Gamo landscape. In another study by Meaza and Demssie (2015), it has also noted that natural seedlings from soil seed banks and home nurseries are the main sources of seedlings of fodder trees across the communities in the northern highlands of Ethiopia.

Table 4.9. Propagation technique of browse species in the study area

Variables	Description results	Proportion (%)			
		Lowland	Midland	Highland	Overall mean
Propagation Technique	Seedling	25.6	33.3	19.7	26.2
	Direct sowing	18.6	5.2	2.0	8.63
	Cutting	27.9	5.2	21.5	18.2
	Seedling and sowing	7.0	8.8	4.0	6.6
	Seedling and cutting	16.3	28.1	51	31.8
	Sowing and cutting	0	14.0	0	4.67
	Seedling, sowing and cutting	4.7	5.4	1.8	3.96
Total		100	100	100	100

4.3.10 Feeding method of indigenous browse species

From the total respondents, 56.6% of the respondent fed browse fodder species based on animal preference followed by 42.33% based on farmers' perceived quality of fodder, and the rest (1.1%) feed based on both animal and farmers' perceived quality of fodder. About 82.1% respondents in highland area feed livestock based on animal preference, while 46.6% and 41% of the respondents in lowland and midland feed based on animal preference, respectively. Especially during the dry season, when feed scarcity occurs, animals were obliged to consume the available fodder tree and shrub to survive. This was supported by Alemie and Gebremedhin (2019) who reported that the dry season progress less palatable species are also browsed by livestock.

The majority of respondents (42.27%) were feeding livestock by using partially cut and carry and partially browsing. This result agreed with the report of Getachew *et al.* (2017) who reported that leaves of browse trees were fed to livestock by cut and carry system. In the contrary, Belachew *et al.* (2020) stated that most of the farmers (66%) in Gamo Gofa and Wolayta zones, Ethiopia were directly let their goats to browse in the

grazing areas. This may be due to variation in the type of the plant and the type of animals available in the study area.

Table 4.10. Feeding system of indigenous browse species in the study area

Variables	Description results	Agroecology						
		Lowland N=79		Midland N=86		Highland N=81		Overall Mean
		N	%	N	%	N	%	%
Preferred method of feeding	Based on farmers' perceived quality of fodder	41	51.7	49	57.4	14	17.9	42.33
	Based on animal preference	37	46.7	36	41	67	82.1	56.6
	Both preferred method	1	1.7	1	1.6	0		1.1
Feeding system	Cut and carry	26	33.3	14	16.4	15	18	22.56
	Browsing	22	28.3	24	27.9	40	49.2	35.13
	Both cut and carry and, browsing	31	38.3	48	55.7	26	32.8	42.27

Note: N =number of respondents

4.3.11 Fodder conservation method and form of feeding

About 56.8%, of respondents fed animals with indigenous browse fodder in fresh form and 12.3% fed in dry forms (Table 4.11). Forage conservation could be one possible solution in areas where feed shortage is severe during the dry seasons (Tefera *et al.*, 2019). Javed *et al.* (2008) also found that, fodder tree leaves are harvested during summer, fed to livestock, and stored as hay. However, in the current study the practice of conservation system for browse fodder were very low. In the study area, only 12.07% of respondents used conservation of browse fodders. This showed that the practice of browse fodder conservation was not practicable more in the study area. In line with the current result, Tefera *et al.* (2019) showed that 4% and 8% in the highland and midland use forage conservation for dry period respectively.

In the highlands of northern Ethiopia, farmers harvest green leaves of Chinese banyan (*Ficus macrocarpa*) plant and store it as a hay for use in the dry season (Balehegn *et al.*, 2015). Fodder harvested from browse trees has also been ensiled, usually in combination with grains (Mbatha and Bakare, 2018). Phiri *et al.* (2007) also demonstrated that browse fodder from tree legumes *Leucaena leucocephala* and

Vachellia boliviana ensiled with maize used to replace dairy concentrate diets while sustaining intake and body weight gain.

Table 4.11. Conservation method and form of feeding of indigenous browse species

Variables	Description results	Proportion (%)			Overall mean
		Lowland N=79	Midland N=86	Highland N=81	
Do you conserve browse fodder?	Yes	11.7	6.6	17.9	12.07
	No	88.3	93.4	82.1	87.9
If yes conservation method	Hay making	10	6.6	14.3	10.3
	Silage making	1.7	0	3.6	1.8
Form of feeding	Fresh form	58.3	83.6	28.6	56.8
	Dry form	17.7	4.9	14.3	12.3
	Both fresh & dry form	24	11.5	57.2	30.9

Note: N= number of respondents

4.4 Conclusion

The study revealed that there are different species of indigenous browse fodder resources found in the three agro ecologies of the study area. IBFS improved productivity by enhancing the ecosystem functioning and allowing resource utilization; however, its diversity and species richness varied with land use and agroecological zone. The highest species richness and diversity were recorded in mid land agro-ecologies and area closure land use system. Farmers' preference criteria in selection of browse fodder encompasses palatability, multifunctionality and feeding value were the most important criteria to select browse species in three agro ecologies. The majority of farmers planted indigenous browse fodder on their farm boundaries, home compound and soil and, water conservation areas. Partially cut and carry and partially browsing systems were the preferred feeding system in the study areas. It is possible to conclude that when incorporating locally available feed resources, farmer's indigenous knowledge and experience-based choice of browse fodder species is vital for efficient utilization of available browse species to tackle feed shortage in different agro-ecological zones. Therefore, further research is required to verify the nutritional value of indigenous browse fodder and evaluate the effect of these plants on the production performance of animals.

CHAPTER 5

NUTRIENT CONTENT, *IN VITRO* GAS PRODUCTION AND POST INCUBATION PARAMETERS OF INDIGENOUS BROWSE FODDERS IN DIFFERENT AGRO-ECOLOGICAL ZONES OF NORTHWEST ETHIOPIA

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NUTRIENT CONTENT, *IN VITRO* GAS PRODUCTION AND POST INCUBATION PARAMETERS OF INDIGENOUS BROWSE FODDERS IN DIFFERENT AGRO-ECOLOGICAL ZONES OF NORTHWEST ETHIOPIA†

[CONTENIDO DE NUTRIENTES, PRODUCCIÓN DE GAS *IN VITRO* Y PARÁMETROS POST-INCUBACIÓN DE FORRAJES NATIVOS EN DIFERENTES ZONAS AGROECOLÓGICAS DEL NOROESTE DE ETIOPÍA]

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Abstract

In Ethiopia, indigenous browse species have the potential to serve as a sustainable supplement for poor quality feeds and enhance ruminant livestock production. The aim of the study was analyze the nutrient content, *in vitro* gas production, and post incubation parameters of indigenous browse species in northwestern Ethiopia. Eight indigenous browse fodder plants were collected from each agroecology for this experiment. Leaf and pod samples of the fodder trees were collected, dried and ground for laboratory analysis. Analysis of variance was carried out for nutrient content, *in vitro* gas and CH₄ production of the samples within agro-ecologies using standard analytical procedures for each agro-ecological zone due to the difference in the types of available browse species. The statistical design used to analyze the data was Completely Randomized Design (CRD). The highest CP content was recorded from *V. amygdalina* (223.4 g/kg DM), *Dodonaea viscosa* (207.7 g/kg DM), and *Acacia abyssinica* (216.0 g/kg DM) in the highland, midland and lowland agro-ecology respectively. In lowland area, NDF, ADF and ADL contents were highest for *Albezia amara* leaves (773.7, 330.5 and 101.4 g/kg DM) and lowest for *Acacia brevispica* (218.8, 95.9 and 26.4 g/kg DM) respectively. *Vernonia amygdalina* (40.66 ml/200mg), *Stereospermum kunthianum* (47.61 ml/200mg DM) and *Ficus vasta* (36.95 ml/200mg DM) had the highest gas volume at 24 hr incubation time in high, mid and lowland, respectively. The estimated OMD, ME and SCFA at 24 hr of incubation was the highest for *Vernonia amygdalina* (68.48%, 9.01 MJ/ kg DM and 0.91 mmol/L), *Stereospermum kunthianum* (68.88%, 9.46 MJ/kg DM and 1.07 mmol/L) and *Ficus vasta* (63.33%, 8.26 MJ/kg DM and 0.82 mmol/L) in high, mid and lowland agro ecologies, respectively. *Albezia amara* leaves (0.33 ml/200mg DM), *Ficus sycomorus* (0.23 ml/200mg DM) and *Myrica salicifolia* (2.66 ml/200mg DM) had the lowest CH₄ production among the species in the low, mid and highland study areas, respectively. The present study provides a valuable resource for selecting suitable feed options for livestock in different agro-ecological zones. High CP and digestible browse species like the one *Vernonia amygdalina*, *Stereospermum kunthianum*, and *Ficus vasta* could be prioritized for livestock feed. Low CH₄ producing species like *Ficus sycomorus* and *Myrica salicifolia* could be incorporated into diets to reduce enteric CH₄ emission. The study

suggest that these indigenous browse species have a potential as feed supplements to improve feed quality and reduce rumen enteric CH₄ production in ruminant animals.

Key words: Browse species; Digestibility; Gas production; Nutrient content; Methane

5.1 Introduction

Poor animal nutrition is one of the main constraint to enhance livestock productivity in Sub-Saharan region (Balehegn *et al.*, 2020; Matovu and Alçiçek 2023). In Ethiopia, ruminant animals depend mainly on natural pastures and crop residues feed resources. However, the utilization of natural pasture and crop residues for enhancing livestock performance is constrained by their inherent low nutritional value such as protein, mineral, carbohydrates and vitamins (Mengistu *et al.*, 2017). This suggests that improving the performance of ruminant livestock that are fed low-quality feed resources requires the application of various mechanisms to enhance feed quality.

Indigenous browse species have the potential to serve as a sustainable supplement for poor quality feeds and enhance ruminant livestock production (Shenkute *et al.*, 2012). For livestock production in the Sub-Saharan areas, including Ethiopia, indigenous fodder species have long been considered essential for livestock nutrition, particularly where the quantity and quality of feedstuff is low for long period (Derero and Kitaw 2018; Humbelani *et al.*, 2021). Browse fodder produces a considerable quantity of forage biomass as leaves, pods and fruits that are rich in nutrients (Abraham *et al.*, 2023). However, their nutritional quality differs among species due to the variation in chemical composition and associated characteristics (Sebolai, 2018; Ravetto *et al.*, 2020; Dereje *et al.*, 2021) .

Poor forage digestibility in ruminants is a concern, as it compromises animal productivity and contributes to greenhouse gas emissions (GHG) (Palangi *et al.*, 2022; Abraham *et al.*, 2023). According to the report of Gerber *et al.* (2013), the contribution of livestock to the anthropogenic GHG emissions is about 14.5% considering the emission report of IPCC (2006). CH₄ gas from livestock production activities is a significant source of greenhouse gas emissions which have been shown to influence climate change (Kumar *et al.*, 2018; Min *et al.*, 2020). Ruminant production systems contribute between 18% and 33% of CH₄ emissions (Canulsolis *et al.*, 2020). Enteric CH₄

emissions, which represent energy loss from ruminant animals, are problematic due to their significant impact on animal performance and their contribution to climate change. According to FAO (2022), 12% of a ruminant's energy intake is usually lost as CH₄ through the enteric fermentation process. Due to this, there has been growing interest in searching of feeds that could help mitigating CH₄ production in the rumen. There are reports which claim the inclusion of browse fodder parts in poor-quality fiber-based diets significantly enhanced the digestibility and hence mitigated enteric CH₄ emissions (Bayssa *et al.*, 2016; Berhanu *et al.*, 2019; Abraham *et al.*, 2023; Badgery *et al.*, 2022). However, there is no adequate information on *in vitro* gas production and methane mitigation potential of indigenous browse species in northwest Ethiopia, particularly in the south Gondar zone where many indigenous browse species potentially exist but not fully exploited as livestock feed. Therefore, this study investigated to evaluate the nutrient content, kinetics of gas production, and CH₄ production potential of indigenous browse species.

5.2 Material and Methods

5.2.1 Description and selection of the study area

Indigenous browse samples were collected from south Gondar zone of Amhara National Regional State, Northwestern Ethiopia. The three districts were selected purposively based on accessibility and representativeness of different agro-ecologies. The districts were *Ebinat* (representing lowland), *Libo Kemkem* (midland) and *Farta* (highland).

Ebinat district is located between 11° and 12° north latitude, and 37° and 38° east longitude. It is located 122 km from Bahir Dar the capital of the region and 714 km from Addis Ababa. Annual temperature and rainfall ranges from 25°C to 30°C and from 500 to 900mm respectively. The district has a total livestock population of 562,040 of these, 131,505 are indigenous goats. Ebinat has three agroecological zones with 50% kolla (lowland), 35% Woyina Dega (midland) and 15% Dega (highland) which is suitable for sorghum and other low land crop production (Ayanaw, 2021). Two kebeles (the lowest administrative area) from kolla (lowland) agroecology category of the district were selected purposively based on agroecological zone and potential of indigenous browse

species since the rural kebeles of Ebinat district are 50% Kolla (lowland) agro- ecological zones. From these Balarib and Burkoch kebeles were selected to represent the study area supported the agroecology conditions.

Libo Kemkem district separates from Fogera woreda on the west by Lake Tana, on the North by the Central Gondar Zone and, on the East by Ebinat Woreda. It covers an area of 9,514 km². It located at 120 04.351°N - 120 10.926°N and 370 44.266°E - 370 50.057°E. The district far from Bahir Dar and Addis Ababa is 88.71km and 656 km respectively. Due to the effect of altitudinal variations, there are three agro-climatic Zones in Libo Kemkem. The area coverage of the agro-climatic zone of the district is 18% Dega (Highland), 43% Weyna Dega (Midland), and 39% Kolla (lowland). The total population of the district are 226, 958 of which, 116,954 are males and 110,004 are females. Crop production is mostly rained though in some areas irrigation is practiced around the river. The major crop types grown in the area include cereals, pulses, as well as oilseeds and from vegetable and root and tuber, garlic and red onion are highly produced and marketed. Two kebeles (the lowest administrative area) from Weyna dega (midland) agroecology category of the district were selected purposively based on agroecological zone and potential of indigenous browse species since the rural kebeles of Libo Kemkem district are 43% Weyna dega (midland) agro- ecological zones (LKAACO, 2019). From these Shehochu Tehara and Estifanos kebeles were selected to represent the study area supported the midland agroecology conditions.

The *Farta* district is located at 11°40' N latitude and 38° E longitude and located at about 97 km north east of Bahir Dar and 667 km from Addis Ababa. It lies within an altitude range of 1920-4135 above sea levels. The district receives an average annual rain fall of 900-1099 mm and a mean temperature in the range of 9-25°C. The livestock population of the district is estimated to be 168,307 cattle, 80,792 sheep, 32,667 goats, 28,849 equines and 186,861 poultry. Agroforestry is the common practice in which trees and shrubs are an integral component of the farming system that complements the function of livestock feed uses and improve productivity.

5.2.2 Foliage sample collection and preparation

The samples of the indigenous browse species were collected from sampling sites in Ebinat, Libo Kemkem and Farta districts of the south Gondar zone from August to September 2022. Eight (8) indigenous browse fodder plants were collected from each agroecology for laboratory analysis. Samples were randomly harvested and bulked. Representative samples from 10 plants of each species, collected from each agroecology. Samples were oven-dried at 65°C for 72 hr for constant weight to determine the dry matter (DM) and ground using a Wiley mill to pass through a 1mm sieve size. The ground feed samples were kept in airtight plastic containers until the chemical composition analysis and *in vitro* gas production was measured.

5.2.3 Chemical analysis of selected indigenous browse plants

The chemical analyses of the forage samples were determined using standard analytical methods. The dry matter and ash content of the sample were determined according to the procedures of AOAC (1990). The Kjeldahl method was used to determine total nitrogen (N) and crude protein (CP) was calculated as $N \times 6.25$ (AOAC, 1990). The neutral detergent fiber (NDF) was analyzed using the detergent extraction method as described by Van Soest *et al.* (1991) and acid detergent fiber (ADF) and acid detergent lignin (ADL) were analyzed according to Van Soest and Robertson (1985).

5.2.4 *In vitro* DM Digestibility

The *in vitro* dry matter digestibility (IVDMD) was determined according to Tilley and Terry (1963) as modified by Van Soest and Robertson (1985), in which the second stage (pepsin digestion) is substituted with a neutral detergent solution. This treatment removes all indigestible microbial matter and leaves as a residue of the undigested plant cell wall, and the values represent true digestibility.

5.2.5 *In vitro* gas production

The *in vitro* gas production was carried out by using the gas production technique of Menke and Stengass (1988). Rumen fluid was obtained from three rumen cannulated Arsi-Bale sheep by suction tube fed natural pasture hay as a basal feed and supplemented with 200g of concentrate mixture (64% wheat bran, 35% noug seed cake, and 1% salt) per sheep/day. The animals had free access to clean drinking water and mineral licks.

Rumen fluid was collected before morning feeding and then prepared and purged with CO₂ to maintain anaerobic conditions (Makkar, 2003).

The incubation of sampled species was carried out according to Menke and Stengass (1988) 120 ml in calibrated syringes in three batches at 39 °C. Each sample weighing about 200 mg was placed in the syringe and 30 ml of inoculum was added that contained cheese cloth strained rumen liquor and buffer solution under continuous flushing with CO₂. The volume of gas production was measured at 3, 6, 12, 24, 48 and 72 hr.

The gas production characteristics were estimated using the equation

$$Y = a + b (1 - e^{ct}) \text{ (Orskov and McDonald, 1979).}$$

Where

Y = volume of gas produced at time 't',

a = intercept (gas produced from the fermentable fraction),

b = gas production from the non-fermentable fraction,

(a+b) = total gas production,

c = gas production rate constant for the non-fermentable fraction (b), t = incubation time

5.2.6 Post-incubation parameters

Post-incubation parameters such as metabolizable energy (ME, MJ/ Kg DM), organic matter digestibility (OMD%) and short-chain fatty acids (SCFA, mmol/L) were estimated at 24 hr of incubation time Menke and Stengass (1988). At the end of 24 hr of incubation, 4 ml of 1N Na (OH)₂ was added to the substrate in each syringe to determine the production of CH₄ (Fievez *et al.*, 2005).

In vitro organic matter digestibility (IVOMD) was calculated from the equation: IVOMD (%) = 18.53 + 0.9239GP (at 24hr) + 0.0540 CP. Where: IVOMD = *in vitro* organic matter digestibility at 24 hours and CP = crude protein (%). Metabolizable energy (ME) was calculated from the equation:

ME (MJ/g DM) = 2.20 + 0.136 GP + 0.0057CP. Where: GP=Gas production over 24 hr of incubation; CP=Crude protein content of feed samples. Short-chain fatty acids

(SCFA) were calculated from the equation: SCFA = 0.0239*GP – 0.0601.

5.2.7 Statistical analysis

Analysis of variance (ANOVA) was carried out on chemical composition, volume of *in vitro* gas production, *in vitro* gas production characteristics, and post-incubation parameters using the General linear model (GLM) procedure of Statistical Package for Social Science (SPSS version 26). The statistical design used to analyze the data was Completely Randomized Design (CRD). Means were separated using Tukey's comparison test.

The Model was;

$$Y_{ij} = \mu + A_i + e_{ij}$$

Where, Y_{ij} = response variable, μ = overall mean, A_i = species effect and e_{ij} = random error

5.3 Results

5.3.1 Nutrient content of indigenous browse species

The nutrient content of selected indigenous browse species is presented in table 5.1. The DM content of the browse fodder in the lowland area ranged between 878.9 g/kg DM and 921.1 g/kg DM whereas in the midland between 899.7 g/kg DM and 926.4 g/kg DM. In the lowlands, *Ficus vasta* and *Albezia amara* pods had the highest DM content among the leaves and pods of indigenous browse fodder species, whereas the leaves of *Albezia amara* and *Ficus sycomorus* had the lowest, respectively. *Cordia africana* had the highest DM in the midland whereas; *Ficus sycomorus* leaves had the lowest.

The crude protein (CP) content of indigenous browse species (IBFS) for the highland, midland, and lowland ranged from 89.0 to 223.4 g/kg DM, 130.3 to 207.7 g/kg DM and 102.1 to 216.0 g/kg DM, respectively. In the highlands, the highest CP content was recorded from *V. amygdalina* followed by *Cordia africana* and the lowest was recorded *Syzygium giuneens*. In the midlands, *Dodonaea viscosa* had the highest CP content followed by *Acacia abyssinica*. In the lowlands, the highest CP content was recorded for *Acacia abyssinica*.

The ash content of indigenous browse species in the highlands ranged from 44.7 to 157.7 g/kg DM, where *Syzygium giuneens* and *Myrica salicifolia* exhibited the lowest while *Cordia africana* exhibited the highest. The ash content of IBFS varied from 62.7 to

138.6 g/kg DM, where *Albezia amara* pods and *Ficus sycomorus* revealed the lowest and the highest value in the lowland respectively.

The NDF and ADF content of indigenous browse species ranged from 378.6 to 582.0 g/kg DM and 132.5 to 299.6 g/kg DM in the highlands, respectively. In the midlands, the NDF content ranged from 277.4 to 638.6 g/kg of DM and the ADF content from 137.1 to 243.3 g/kg DM. *Syzygium giuneens* had the highest NDF and ADF content, and *V. amygdalina* had the lowest NDF in highland agroecology. While, *Cordia africana* had the highest NDF and ADF content in the midlands. In the lowlands, *Albezia amara* pod and *Cordia africana* had the highest NDF content, *Albezia amara* leaves had the highest and *Acacia brevispica* had the lowest ADF content in the lowlands, respectively.

In the highlands, the ADL content of indigenous browse species ranged between 44.5 and 69.9 g/kg of DM. *Olea africana* contained the lowest, whereas *Myrica salicifolia* had the highest ADL content. The ADL content of indigenous browse species in the midlands ranged from 28.7 to 81.1 g/kg DM. The lowest ADL content was found in *Acacia abyssinica* and the highest was in *Cordia africana*. In the lowland, the ADL content ranged from 26.4 to 101.1 g/kg of DM. The leaves of *Albezia amara* had the highest ADL, while *Acacia brevispica* had the lowest in lowland agroecology.

Table 5.1. The nutrient compositions of selected indigenous browse species (g/kg DM)

Browse species	DM	Ash	CP	NDF	ADF	ADL	IVDMD
Lowland							
<i>Ficus vasta</i>	921.1	114.2	181.5	411.2	182.0	44.4	619.4
<i>Acacia abyssinica</i>	911.5	74.3	216	449.4	184.5	58.9	566.6
<i>Acacia brevispica</i>	904	72.9	102.1	218.8	95.9	26.4	553.1
<i>Ficus sycomorus</i>	897.5	138.6	166.4	390	185.3	47.8	536.5
<i>Cordia africana</i>	910.7	128.9	208.1	534.1	234.0	72.6	547.6
<i>Terminalia brownii</i>	916.3	77.4	150.8	386.3	169.6	33.5	561.4
<i>Albezia amara</i> (pod)	916.5	62.7	154.6	589.2	228.1	63.6	563.1
<i>Albezia amara</i> (leaves)	878.9	71.5	198.1	773.7	330.5	101.4	505.1
Midland							
<i>Ficus vasta</i>	907.8	128.7	139.6	438.6	186.3	59.2	570.5
<i>Acacia abyssinica</i>	914.8	59.5	178.5	356.8	148.7	28.7	594.0
<i>Cordia africana</i>	926.4	147.2	151.3	638.6	243.3	81.1	513.1
<i>Ficus sycomorus</i>	899.7	183.9	130.3	413.7	204.7	49.9	523.3
<i>Ficus thonningii</i>	902.6	153.1	160.5	476.0	191.2	49.0	546.1
<i>Dodonaea viscosa</i>	919.9	77.0	207.7	359.2	137.1	30.1	677.2
<i>Syzygium giuneens</i>	916.4	82.9	135.4	489.3	238.2	75.5	518.5
<i>Stereospermum kunthianum</i>	917	84.1	137.9	277.4	142.8	33.1	638.8
Highland							
<i>Ficus vasta</i>	898.1	145.4	123.1	460.3	209.0	48.2	522.8
<i>Acacia abyssinica</i>	909.2	60.6	209.3	436.4	132.5	50.2	577.2
<i>Ficus thonningii</i>	905.9	157.2	197.3	402.0	150.4	50.7	582.6
<i>Cordia africana</i>	909.2	157.7	219.9	503.5	200.7	52.7	558.3
<i>Vernonia amygdalina</i>	913.3	113.8	223.4	378.6	177.1	47.1	664.5
<i>Olea africana</i>	940.5	66.5	187.3	454.2	207.6	44.5	610.9
<i>Syzygium giuneens</i>	903.5	44.7	89.0	582.0	299.6	45.2	484.3
<i>Myrica salicifolia</i>	898	58.2	139.4	479.7	201.6	69.9	540.3

Note: AEZ = Agroecological zone; DM = Dry matter; CP = Crude protein; NDF = Neutral detergent fiber; ADF = Acid detergent fiber; ADL = Acid detergent lignin; IVDMD = In vitro dry matter digestibility

5.3.2 In vitro DM digestibility of indigenous browse species

The *in vitro* DM digestibility (IVDMD) contents varied among the studied indigenous browse species. The IVDMD of IBFS in the highland ranged between 484.3 and 664.5 g/kg DM. *Vernonia amygdalina* had the highest IVDMD, whereas *Syzygium giuneens* had the lowest IVDMD. In the midland, the IVDMD of IBFS ranged from 513.1 to 677.2 g/kg DM. The lowest IVDMD was found in *Cordia africana* and the highest values of IVDMD were recorded for *Dodonaea viscosa*. In the lowland area *Ficus vasta* (619.4 g/kg) DM had the highest while the lowest values were obtained in *Albezia amara* leaves (505.1 g/Kg) DM.

5.3.3 *In vitro* gas production of indigenous browse species

In vitro gas productions of IBFS from the study area are presented in Table 5.2. The browse species samples showed variability in the total volume of gas produced. The volume of gas released from fermented samples increased with increasing incubation time throughout 72 hr incubation time. Among the samples from the highland area, the lowest gas volume was recorded for *Syzygium giuneens* (12.99 ml/200 mg) while *Vernonia amygdalina* (40.66 ml/200 mg) produced a higher gas volume than the other species at 24 hr of the fermentation period. At 24 hr of incubation, the gas production volume ranged from 12.32 ml/200mg (*Syzygium giuneens*) to 47.61 ml/200 mg (*Stereospermum kunthianum*) in the midland area. All the *in vitro* gas volume production of the IBFS exhibited significant differences among species in the lowland. At 24 hr of incubation, *Albezia amara* leaves produced lowest (3.33 ml/200 mg) and *Ficus vasta* (36.95 ml/200 mg) were higher gas volume.

Table 5.2. *In vitro* gas production (ml/200 mg DM) of indigenous browse species

Species	Incubation period						
	3hr	6hr	9hr	12hr	24hr	48hr	72hr
Lowland							
<i>Ficus vasta</i>	4.96 ^{ab}	9.32 ^{ab}	15.65 ^a	23.98 ^a	36.95 ^a	44.94 ^a	46.94 ^b
<i>Acacia abyssinica</i>	1.65 ^{de}	3.00 ^{ef}	5.00 ^d	6.33 ^e	11.99 ^e	16.99 ^g	19.49 ^f
<i>Acacia brevispica</i>	7.32 ^a	11.33 ^a	14.65 ^a	17.99 ^b	32.97 ^b	41.47 ^b	50.46 ^a
<i>Ficus sycomorus</i>	3.99 ^{bc}	5.99 ^{cd}	7.99 ^c	10.98 ^d	17.97 ^d	29.47 ^e	33.47 ^d
<i>Cordia africana</i>	3.56 ^{bcd}	5.32 ^{de}	8.32 ^c	12.31 ^d	26.28 ^c	34.97 ^c	36.47 ^c
<i>Terminalia brownii</i>	3.66 ^{bcd}	5.66 ^{cd}	8.33 ^c	10.99 ^d	16.65 ^d	26.48 ^f	28.48 ^e
<i>Albezia amara</i> (leaves)	1.33 ^e	1.96 ^f	1.33 ^e	1.67 ^f	3.33 ^f	5.49 ^h	6.49 ^g
<i>Albezia amara</i> (pods)	4.99 ^{ab}	7.97 ^{bc}	10.64 ^b	14.64 ^c	23.62 ^c	31.42 ^d	33.41 ^d
Mean	3.93	6.32	8.98	12.36	21.22	28.9	31.9
SD	0.78	0.68	0.68	0.61	0.8	12.28	13.56
Midland							
<i>Ficus vasta</i>	6.66 ^b	8.99 ^{bc}	7.99 ^c	12.32 ^c	17.98 ^{de}	29.47 ^c	32.46 ^c
<i>Acacia abyssinica</i>	6.00 ^b	11.99 ^b	15.66 ^b	18.99 ^b	26.98 ^b	37.98 ^b	39.98 ^b
<i>Ficus sycomorus</i>	3.33 ^b	3.66 ^c	5.66 ^c	7.99 ^c	15.31 ^{de}	26.95 ^{cd}	29.95 ^d
<i>Cordia africana</i>	5.00 ^b	6.99 ^{bc}	8.99 ^c	11.66 ^c	20.31 ^{cd}	28.47 ^d	30.97 ^{cd}
<i>Ficus thonningii</i>	4.00 ^b	5.33 ^c	6.33 ^c	8.32 ^c	16.32 ^{de}	24.48 ^d	27.47 ^e
<i>Dodonaea viscosa</i>	5.65 ^b	7.98 ^{bc}	9.65 ^{bc}	12.64 ^c	22.62 ^{bc}	39.39 ^b	41.39 ^b
<i>Syzygium giuneens</i>	5.66 ^b	6.99 ^{bc}	7.99 ^c	9.99 ^c	12.32 ^e	15.48 ^e	16.48 ^f
<i>Stereospermum kunthianum</i>	12.32 ^a	22.97 ^a	31.96 ^a	40.61 ^a	47.61 ^a	57.93 ^a	59.93 ^a
Mean	6.07	9.36	11.78	15.31	22.43	32.52	34.83

SD	1.69	1.84	2.14	1.68	2.46	0.82	0.76
Highland							
<i>Ficus vasta</i>	3.00 ^d	5.00 ^e	6.99 ^c	8.99 ^d	16.65 ^{de}	23.48 ^{de}	24.98 ^e
<i>Acacia abyssinica</i>	5.66 ^{bc}	9.98 ^{bc}	13.99 ^b	16.65 ^{bc}	24.31 ^{bc}	31.97 ^{bc}	34.47 ^c
<i>Cordia africana</i>	3.66 ^{cd}	6.33 ^{de}	9.66 ^c	12.99 ^{cd}	22.64 ^{cd}	26.98 ^{bc}	29.47 ^d
<i>Ficus thonningii</i>	3.66 ^{cd}	8.33 ^{cd}	13.99 ^b	19.65 ^b	26.64 ^{bc}	34.97 ^{bc}	34.97 ^c
<i>Vernonia amygdalina</i>	8.32 ^a	16.65 ^a	25.64 ^a	33.30 ^a	40.66 ^a	50.44 ^a	52.94 ^a
<i>Olea africana</i>	5.99 ^b	10.99 ^b	16.65 ^b	20.98 ^b	30.97 ^b	36.96 ^b	38.96 ^b
<i>Syzygium giuneens</i>	3.00 ^d	5.33 ^e	6.99 ^c	9.33 ^d	12.99 ^e	20.48 ^e	21.48 ^f
<i>Myrica salicifolia</i>	2.66 ^d	4.99 ^e	7.99 ^c	10.99 ^{cd}	13.65 ^e	18.98 ^e	16.53 ^g
Mean	4.5	8.45	12.73	16.6	23.56	30.53	31.72
SD	0.56	0.94	1.29	2.09	2.36	1.86	0.63

Note: Superscripted ^{a, b, c, d, e}; Means in the same column with different superscript differ significantly ($P < 0.05$) ($P < 0.05$). Abbreviation: SD = standard deviation; CV = Coefficient of variation.

5.3.4 *In vitro* gas production characteristics of indigenous browse species

The *in vitro* gas production characteristics of IBFS are presented in Table 5.3. In the lowland, the immediate fermented values (“a”) of browse species ranged from 30.8% for *Albezia amara* leaves to 35.7% for *Ficus vasta*. The lowest slowly degradable fraction (“b”) was obtained from *Albezia amara* leaves (31.4%) and highest in *Acacia abyssinica* (62.9%). Potential gas production (a + b) ranged from 62.2% for *Albezia amara* leaves to 98.7% for *Acacia abyssinica*. The rate of gas production (“c”) ranged from 0.004 /hr for *Albezia amara* leaves to 0.025 /hr for *Ficus vasta*.

Among the browse species in the midland, the gas production from immediately soluble portion “a” value ranged from 29.6% (*Stereospermum kunthianum*) to 37.5% in (*Acacia abyssinica*). The gas production from water-insoluble but degradable portion “b” fraction was highest in *Stereospermum kunthianum* (70.1%) and lowest 32.5% in *Syzygium giuneens*. The rate of gas production “c” ranged from 0.006 /hr in *Syzygium giuneens* to 0.761/hr in *Stereospermum kunthianum* leaves. The potential gas production (a+b) values ranged from 67.3% in *Ficus thonningii* to 99.7% in *Stereospermum kunthianum* leaves.

In the highland species, the rapidly soluble fraction (“a”) value varied from 26.9% for *Vernonia amygdalina* to 38.8% for *Olea africana*. Slowly degradable fraction (“b”) value ranged from 26.4% for *Myrica salicifolia* to 65.6% for *Vernonia amygdalina*. Potential gas production (a + b) ranged from 62% for *Myrica salicifolia* to 92.5% for *Vernonia amygdalina*. The rate of gas production (“c”) ranged from 0.013/hr for *Myrica*

salicifolia to 0.073/hr for *Vernonia amygdalina*. The difference in values of “a”, “b” and “c” between species might be attributed to the concentration of carbohydrates in each browse species.

Table 5.3. *In vitro* gas production characteristics of indigenous browse species

Gas production characteristics						
Species of browse plants	a (%)	b (%)	a + b (%)	c (hr ⁻¹)	LT (hr)	RSD
Lowland						
<i>Ficus vasta</i>	35.7	51.8	87.5	0.025	0.47	5.768
<i>Acacia abyssinica</i>	35.8	62.9	98.7	0.018	0.50	2.643
<i>Acacia brevispica</i>	32.5	35.7	68.2	0.017	2.94	1.635
<i>Ficus sycomorus</i>	33.5	50.1	83.6	0.015	0.99	1.386
<i>Cordia africana</i>	33.4	47.8	81.2	0.019	0.80	3.937
<i>Terminalia brownii</i>	34.1	44.9	79	0.013	1.32	2.11
<i>Albezia amara (leaves)</i>	30.8	31.4	62.2	0.004	0	0.787
<i>Albezia amara (pods)</i>	35.1	43.4	78.5	0.016	1.06	3.252
Midland						
<i>Ficus vasta</i>	33.8	40.8	74.6	0.018	1.15	1.788
<i>Acacia abyssinica</i>	37.5	53.6	91.1	0.024	0.44	3.712
<i>Ficus sycomorus</i>	30.5	51.4	81.9	0.012	1.31	1.875
<i>Cordia africana</i>	34.3	46.4	80.7	0.014	1.14	2.447
<i>Ficus thonningii</i>	30.9	36.4	67.3	0.019	1.78	1.364
<i>Dodonaea viscosa</i>	32.2	58.9	91.1	0.016	0.74	2.671
<i>Syzygium giuneens</i>	36.4	32.5	68.9	0.006	5.02	1.678
<i>Stereospermum kunthianum</i>	29.6	70.1	99.7	0.761	0.14	1.636
Highland						
<i>Ficus vasta</i>	33.5	41.7	75.2	0.014	1.40	1.935
<i>Acacia abyssinica</i>	37.7	44.9	82.6	0.017	0.80	2.752
<i>Cordia africana</i>	34.9	44.1	79	0.016	1.06	3.239
<i>Ficus thonningii</i>	36.9	55.2	92.1	0.019	0.54	6.115
<i>Vernonia amygdalina</i>	26.9	65.6	92.5	0.073	0.18	1.693
<i>Olea africana</i>	38.8	52.2	91	0.016	0.62	4.808
<i>Syzygium giuneens</i>	34.6	43.3	77.9	0.015	1.13	2.826
<i>Myrica salicifolia</i>	35.6	26.4	62	0.013	0	2.463

Note: a = gas production from the soluble fraction; b = gas production from the insoluble but degradable fraction; a + b = potential gas production; c = the rate constant of gas production of b; RSD= residual standard deviation.

5.3.5 The post incubation parameters of indigenous browse species

The OMD, SCFA, ME and CH₄ production of selected browse species are shown in Table 5.4. The post-incubation parameters OMD, ME, SCFA and CH₄ production of IBFS exhibited significant differences among the three agroecologies. In highland area,

OMD at 24 hr incubation time ranged from 33.34% in *Syzygium giuneens* to 68.48% in *Vernonia amygdalina*. The OMD values of browse species in the midland of the study area at 24hr ranged between 37.32% in *Syzygium giuneens* to 68.88% in *Stereospermum kunthianum*. At 24 hr incubation time, the OMD of *Ficus vasta* (63.33%) was highest and the value of *Albezia amara* (31.41%) was lowest in lowland agroecology of the study area. Low OMD in this study may be due to the high NDF content of the species. The NDF value has a negative effect on OMD.

The SCFA values (mmol/L) in the highland area ranged from 0.25 mmol/L for *Syzygium giuneens* to 0.91 mmol/L for *Vernonia amygdalina*. *Stereospermum kunthianum* (1.07 mmol/L) has the highest while *Syzygium giuneens* (0.23 mmol/L) recorded the lowest SCFA production amongst the studied browse species in the midland area. In lowland browse species, SCFA was the highest in *Ficus vasta* (0.82 mmol/L) and the lowest in *Albezia amara* leaves (0.02 mmol/L). The ME value of browse species in the highland ranged from 4.48 MJ/kg in *Syzygium giuneens* to 9.01 MJ/kg DM in *Vernonia amygdalina*. The metabolizable energy content of browse species observed in the midland ranged from 4.65 MJ/kg DM for *Syzygium giuneens* to 9.46 MJ/kg DM for *Stereospermum kunthianum*.

CH₄ production among indigenous browse species showed significant differences in the lowland, midland and highland study areas. Among all species *Ficus vasta* (4.67 ml/200 mg), *Stereospermum kunthianum* (8.66 ml/200 mg) and *Vernonia amygdalina* (9.6 ml/200 mg) had the highest CH₄ production, whereas *Albezia amara* (0.33 ml/200 mg), *Ficus sycomorus* (0.23 ml/200 mg) and *Myrica salicifolia* (2.66 ml/200 mg) produced the least in the low, mid and highland study areas respectively.

Table 5.4. Post incubation parameters of selected indigenous browse species

Post incubation parameters					
Species name	OMD (%)	ME(MJ/k g) DM	SCFA (mmol/L)	CH ₄ (ml/200mg)	CH ₄ /GP at 24 hr
Lowland					
<i>Ficus vasta</i>	63.33 ^a	8.26 ^a	0.82 ^a	4.67 ^a	0.07 ^{ab}
<i>Acacia abyssinica</i>	40.09 ^d	5.06 ^d	0.23 ^e	1.33 ^{cd}	0.03 ^{bc}
<i>Acacia brevispica</i>	53.53 ^b	7.27 ^b	0.73 ^b	2.66 ^{bc}	0.04 ^{ab}
<i>Ficus sycomorus</i>	47.37 ^c	5.59 ^c	0.37 ^d	0.67 ^d	0.02 ^c
<i>Cordia africana</i>	55.99 ^b	6.96 ^b	0.57 ^c	2.67 ^{bc}	0.05 ^{ab}
<i>Terminalia brownii</i>	41.50 ^d	5.32 ^c	0.34 ^d	2.66 ^{bc}	0.05 ^{ab}
<i>Albezia amara leaf</i>	31.41 ^e	3.78 ^e	0.02 ^f	0.33 ^d	0.01 ^c
<i>Albezia amara pod</i>	46.92 ^c	6.29 ^{cd}	0.50 ^c	3.66 ^{ab}	0.07 ^a
Mean	47.52	6.07	0.45	2.33	0.042
SD	0.95	0.11	0.07	0.58	0.01
Midland					
<i>Ficus vasta</i>	45.52 ^c	5.44 ^b	0.37 ^{cd}	2.66 ^{cd}	0.05 ^{abc}
<i>Acacia abyssinica</i>	50.77 ^b	6.89 ^{ab}	0.59 ^b	6.66 ^b	0.10 ^a
<i>Ficus sycomorus</i>	46.32 ^c	5.02 ^b	0.31 ^{cd}	0.23 ^e	0.01 ^d
<i>Cordia africana</i>	49.33 ^c	5.83 ^b	0.43 ^{bc}	3.66 ^c	0.07 ^{abc}
<i>Ficus thonningii</i>	46.58 ^c	6.91 ^{ab}	0.33 ^{cd}	3.67 ^c	0.08 ^{ab}
<i>Dodonaea viscosa</i>	49.34 ^c	6.46 ^b	0.48 ^{bc}	3.67 ^c	0.07 ^{abc}
<i>Syzygium giuneens</i>	37.32 ^d	4.65 ^b	0.23 ^d	1.67 ^d	0.04 ^d
<i>Stereospermum kunthianum</i>	68.88 ^a	9.46 ^a	1.07 ^a	8.66 ^a	0.10 ^a
Mean	49.26	6.33	0.476	3.79	0.065
SD	2.19	0.66	0.06	0.57	0.012
Highland					
<i>Ficus vasta</i>	44.69 ^{de}	5.17 ^c	0.34 ^{cd}	3.67 ^{cd}	0.08 ^{bc}
<i>Acacia abyssinica</i>	49.85 ^{cd}	6.69 ^b	0.52 ^{bc}	6.67 ^b	0.12 ^a
<i>Cordia africana</i>	55.17 ^{bc}	6.53 ^b	0.48 ^{bc}	6.66 ^b	0.13 ^a
<i>Ficus thonningii</i>	57.68 ^b	6.95 ^b	0.58 ^b	7.66 ^b	0.12 ^a
<i>Vernonia amygdalina</i>	68.48 ^a	9.01 ^a	0.91 ^a	9.66 ^a	0.12 ^a
<i>Olea africana</i>	55.17 ^{bc}	7.48 ^b	0.68 ^b	6.68 ^b	0.11 ^{ab}
<i>Syzygium giuneens</i>	33.34 ^f	4.48 ^c	0.25 ^e	4.65 ^c	0.09 ^{abc}
<i>Myrica salicifolia</i>	37.08 ^{ef}	4.85 ^c	0.27 ^e	2.66 ^d	0.06 ^c
Mean	47.52	6.39	0.50	6.04	0.103
SD	0.72	0.12	0.02	0.58	0.011

Means in the same column with different superscript differ significantly ($P < 0.05$). Note: ME = metabolizable energy; OMD = organic matter digestibility; SCFA = Short Chain Fatty Acids; MT/GP = methane to gas ratio; SD = standard deviation.

5.4 DISCUSSION

5.4.1 Nutrient content of indigenous browse species

The nutritive values of indigenous browse fodder in the present finding are within the range reported for most browse species in the tropics (Yisehak and Janssens, 2013). The value of CP (89 g/kg DM to 223.4 g/kg DM) contents of the browses in the current study is in line with the findings of Shenkute *et al.* (2012) who reported that the CP contents of the browse species ranged from 89 to 209 g/kg DM in mid rift valley of Ethiopia. Similarly, Desalegn *et al.* (2016) reported that the CP content of indigenous browse fodder varied between 105.3 and 233.4 g/kg DM in northwestern Ethiopia. The CP content of all selected indigenous browse fodder species in the study areas was above the minimum critical levels of CP content (80 g/kg DM) required for normal function of rumen microorganisms (NRC, 2001). It has been indicated that most tropical browses are high in CP and can be used to supplement poor quality roughages to increase the productivity of ruminant livestock (Derero and Kitaw, 2018; Aynalem *et al.*, 2020; Njidda *et al.*, 2022; Abraham *et al.*, 2023) which is consistent with the results obtained in the current experiment.

The NDF and ADF of browse fodder varied from 218.8 to 773.7 g/kg DM and 95.9 to 330.5. The above result were comparable with the findings of Ayenew *et al.* (2021) who showed that NDF and ADF content of multipurpose browse species ranged from 226 to 497.5 and 185 to 282 g/kg DM respectively in the highland of Awi zone northwest Ethiopia. According to the report of Sisay *et al.* (2018), the NDF, ADF and ADL were highest for *Cordia africana*.

DM digestibility is dependent on the cell wall constituents (fiber components) of the forages. In current study the NDF content except *Syzygium giuneens* in the highland, all species have an NDF of less than 55%, which was lower than the concentration suggested as a limit which could affect intake and digestibility in ruminants (Van Soest and Robertson, 1985). On the other hand, all the browse species in all agro-ecologies had ADF content < 40% which is believed to have high quality feed (Kellems and Church, 1998). Browse fodder species that have high content of ADF might have lower digestibility since the digestibility of feeds and ADF content is negatively correlated (Sisay *et al.*, 2018; Mokoboki *et al.*, 2019). The fiber composition of the species was

variable among the browse species and varied between low to moderate categories. Since that forages are the main source of ruminant animals (Chebli *et al.*, 2021). Variability in the nutrient content of browse species might be due to plant species, soil types and locations. These factors influence chemical composition, digestibility and nutrient utilization by animals.

The *in vitro* dry matter digestibility in the current study varied from 484.3 g/kg DM in *Syzygium giuneens* to 677.2 g/kg DM in *Dodonaea viscosa*. This variation could be attributed to factors like species type and location (Melaku *et al.*, 2010; Cheema *et al.*, 2014). The current finding is in agreement with a previous report (Misrak *et al.*, 2023) who investigated that the IVDMD value varied between 639.2 g/kg DM in *Olea africana* to 462.8 g/kg DM in *Cordia africana*. The result reported by Bayssa *et al.* (2016); Ravetto *et al.* (2020) and Feyisa *et al.* (2022) also indicated that indigenous browse species in various locations had high digestibility percentage.

5.4.2 *In vitro* gas volume and production characteristics

The study found significant differences in the volume of gas production and gas production characteristics among the browse species. In this investigation, *Vernonia amygdalina* (40.66 ml/200 mg, *Stereospermum kunthianum* (47.61 ml/200 mg and *Ficus vasta* (36.9 ml/200 mg) had the highest gas in highland. *Syzygium giuneens* (12.99 ml/200 mg and 12.32 ml/200 mg), and *Albezia amara* (3.33 ml/200 mg) had the lowest gas volume at 24 hr after incubation of the feed samples in mid and lowland respectively. Gas production after 72 hr of incubation ranged between 6.49 and 56.9 ml/200 mg DM and this was comparable with the finding of Sisay *et al.* (2018) who showed that a range between 11.85 and 53.73 ml/ 200 mg DM of different indigenous browse species from Ethiopia rift valley. On the other hand the above result was lower than the report of Abraham *et al.* (2023), who stated a range between 23 and 71 ml/200 mg DM of indigenous legume trees and shrubs in the semi-humid condition of southern Ethiopia. The highest gas volume at 24 hr of incubation had positive effects on the concentration of SCFA and ME production from the browse species. The variation in OMD and gas production among browse species is the reflection of the chemical composition of the forage species especially the amount of NDF in the browse species. It was reported by

Terrill *et al.* (1992) that the presence of high NDF levels negatively affects OMD of the feed samples.

The highest insoluble but rumen degradable ('b') fraction was observed for *Vernonia amygdalina*, *Stereospermum kunthianum* and *Acacia abyssinica* species in high, mid and lowland respectively. These reflected a superior index of microbial degradation of the browse and high fermentation rates of the feed samples in the rumen. On the other hand, the highest lag time (LT) in *Ficus vasta*, *Syzygium giuneens* and *Acacia brevispica* reflected the delay in the fermentation rate of these species. This was an implication of the effect of either high tannin rumen microbial fermentation or high level of fiber fraction (NDF) in the species that would hinder the penetration of rumen microorganisms to the soluble carbohydrate fraction for rapid fermentation rate. Yisehak *et al.* (2014) and Mutai *et al.* (2022) investigated that, *Acacia brevispica* (16.474mg/kg DM) and *Syzygium giuneens* (172g/kg DM) leaves contained high levels of condensed tannins which might be resulted in lower gas production due to reduced rumen microbial activity

5.4.3 The post incubation parameters of indigenous browse species

The estimated OMD, ME and SCFA from the gas volume at 24 hr of incubation was the highest for *Vernonia amygdalina*, *Stereospermum kunthianum* and *Ficus vasta* in high, mid and lowland respectively. The least was *Syzygium giunees* in the highland and midland and, *Albezia amara* species in the lowlands. The amount of gas released when browses were incubated has been reported to be closely related to digestibility of feeds for ruminants (Krishnamoorthy *et al.*, 1995). Thus, gas volume can be considered a good reflection of substrate fermented to VFA and an estimate of potential digestibility in the rumen (Getachew *et al.*, 2000). The OMD, ME and SCFA values of the studied browse species estimated in the experiments were within the range reported for most browse trees and shrub species native to the tropics (Bayssa *et al.*, 2016; Sisay *et al.*, 2018; Amanzougarene and Fondevila, 2020; Abraham *et al.*, 2023).

CH₄ fermentation was observed to be high in *Ficus vasta*, *Albezia amara* pods, *Stereospermum kunthianum* and *Acacia abyssinica* species. However, a lower volume of methane gas was produced from *Albezia amara* leaves and *Ficus sycomorus* species. This showed high conversion rate of carbohydrate fermentation products to propionate instead

of CH₄. The presence of a high concentration of polyphenolics might be the cause of the browse species indicated lower CH₄ production. Depending on the chemical makeup of the phenolic compounds found in different browse species, the effect of phenolic compounds on methanogenesis might be attributed to the direct suppression of methanogenic archaea (Patra and Saxena, 2010).

Hassan *et al.* (2010) suggested that the CH₄ reduction potential of any feedstuff can be estimated from the percentage of *in vitro* CH₄ gas production and the feedstuff can be arbitrarily classified in three categories. Low reduction potential of CH₄ in gas (11-14%); medium potential (6-11%) and high potential (0-6%) with respect to standard grass hay. In the current study, the browse fodder under investigation were classified as low to high methane reduction potential since the percent of CH₄ production in the current study ranged from 1% to 13% of the total gas. The differences in CH₄ among the species reflect the observed variations in fiber fraction.

5.5 Conclusions

In this experiment, the indigenous browse species yielded moderate to high CP values. Leaves of *Acacia abyssinica*, *Dodonaea viscosa*, *Vernonia amygdalina* in lowland, midlands and highland respectively have been identified as alternative sources of protein, suggesting their potential in supplementing low quality forages. NDF, ADF and ADL content also varied among different species, *Albezia amara*, *Cordia Africana* and *Syzygium giuneens* species showing higher fiber content compared to others. Based on the above result, *Vernonia amygdalina*, *Stereospermum kunthianum* and *Ficus vasta* in high, mid and lowland agro ecologies, respectively produced substantial gas volume, OMD, ME and SCFA and CH₄. The study also found that certain browse species such as *Albezia amara*, *Ficus sycomorus* and *Myrica salicifolia* from lowland, midlands and highlands respectively were identified as potential candidates in mitigating CH₄ production. This indicates that these browse species have a higher conversion rate of carbohydrate fermentation products to propionate instead of methane. The classification of the browse fodder species into low to high methane reduction potential categories based on their CH₄ production percentages provides valuable information for livestock producers looking to reduce CH₄ emissions from ruminant. In conclusion, all browse

species had moderate to high CP contents that can be used as a supplement for low-quality roughages to improve feed quality and reduce CH₄ production. Further research on minerals and phenolic contents in browse species could help in promoting the use of browse species with improving poor quality feeds and lower methane emission from goat production.

CHAPTER 6

GROWTH PERFORMANCE, HAEMATOBIOCHEMICAL PROFILE AND ENTERIC METHANE EMISSION OF GOATS SUPPLEMENTED WITH *TERMINALIA BROWNII* DRIED LEAVES

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Abstract

This study aimed to evaluate the effect of supplementing *Terminalia brownii* tree leaves on growth performance, hematobiochemical profile and CH₄ emission of goats. Twenty-five male goats with an average initial weight of 19.1 ± 1.6 kg were randomly assigned to five dietary treatments, each with five replicates. The treatments included a control group fed 100% concentrate mix (T1), 85% CM + 15% *Terminalia brownii* (T2), 70% CM + 30% *Terminalia brownii* (T3), 55% CM + 45% *Terminalia brownii* (T4) and 40% CM + 60% *Terminalia brownii* (T5). All goats were provided with natural pasture hay as a basal diet. After 90 days of feeding, a seven-day digestibility trial was conducted to assess nutrient digestibility. CH₄ emission was measured by laser methane detector tool. The data of nutrient content, nutrient intake, digestibility, body weight gain, FCE, blood profile and CH₄ emission were recorded. Data were analyzed using SAS (version 9.4) software. The result showed that goats that received the T5 treatment consumed significantly more DM (779.24 g) and CP (181.06 g) than other treatment groups. Interestingly, the digestibility of NDF and ADF was not statistically different among the treatments. The final body weight of goats reared in T4 (24.56 kg) and T5 (24.78 kg) were higher than T1, T2 and T3. Goats fed T5 recorded the highest count of lymphocyte (61%) followed by animals fed T3 (28.17%) while the least (36.5%) was observed in T4 treatment. Besides, goats fed T4 diet had the highest neutrophil count (56.9). Goats fed on T5 diet had the highest hemoglobin levels as compared to other treatments. CH₄ value was comparable between goats fed the *Terminalia brownii* leaves treatment and those fed a concentrate mix, as it suggests that *Terminalia brownii* leaves might serve as an effective substitute for concentrate feeds without increasing methane emissions. This suggests that the T4 and T5 treatments effectively promoted both growth and feed intake in the goats. Additionally, substituting *Terminalia brownii* leaves with concentrate had no adverse effect on the blood profile of goats.

Key words: Average daily gain, Digestibility, Supplementation, *Terminalia brownii*

6.1 Introduction

In Ethiopia, low-quality roughages, such as natural pastures and crop residues, are the primary sources of livestock feed (Gashaw and Defar, 2017; Yigzaw *et al.*, 2018). However, these feed resources are low in nutrients with poor digestibility. Of these limitations, the most prevalent is protein deficit, from such feeds and this deficit can be compensated with a straightforward source of nitrogen supplements (Chen *et al.*, 2022). Besides, low-quality feed contributes substantially to CH₄ emissions from livestock digestive systems (Vargas *et al.*, 2022). Ruminant animals lose between 2% to 12% of their consumed energy through CH₄ gas production, negatively impacting their overall productivity (Johnson and Johnson, 1995). This energetic loss is particularly relevant in the tropics, where native grasses are the main source of ruminant diets. Dietary supplementation of poor quality diets is known to improve intake by increasing nitrogen supply to rumen microorganisms (Karimi *et al.*, 2021; Morales *et al.*, 2021). This in turn has a positive effect on increasing the microbial population and digestion rate of feed. As the rate of breakdown of digested feed increases, intake is accordingly increased (Cammack *et al.*, 2018; Liu *et al.*, 2019).

Conventional concentrate supplements are accessible at a high price in developing countries (Dey *et al.*, 2022; Melesse *et al.*, 2023). Among these, by-product feeds such as oil seed meals, sugarcane bagasse and brans from the edible oil, sugar and flour processing units could help to address the feed challenges in Ethiopia (Begna *et al.*, 2023). However, those concentrate feeds are expensive and not reasonable for smallholder farmers of the tropics. Trees and shrubs foliage appear to be sustainable alternatives to supply economically affordable supplements for small holder farmers without negatively affect the health and environment (Kholif *et al.*, 2022). Browse species have been reported to increase protein supply in roughage feeds and improve digestibility by optimizing rumen fermentation (Ebrahim and Negussie, 2020; Singh *et al.*, 2023). Besides, improving nutritive values of low quality feeds the inclusion of trees and shrubs leaf meal may help reduce CH₄ gas emission. CH₄ gas emission from ruminants is a global concern. Subsequently, the browse species is recommended for supplementing low quality roughages. Furthermore, haematobiochemical examination is among the methods, which may contribute to the detection of some changes in health

status, which may not be apparent during physical examination but which affect the fitness of the animal (Daramola *et al.*, 2015). For instance, fodder trees and shrubs have been found to have a good crude protein content and are used as supplements for ruminant animals in different parts of the world (Mekuriaw and Asmare, 2018; Sisay *et al.*, 2018; Ayenew *et al.*, 2021; Abraham *et al.*, 2023).

One of the browse fodders used as a protein source is *Terminalia brownii*. It is a native tree to tropical Africa. The leaves of the tree are a good source of protein for livestock production. Its leaves are rich in protein, with levels ranging from 12.27 % (Adane *et al.*, 2023) to 16.94 % (Milkias and Derrebe, 2022). This substantial amount of CP makes valuable feed resource for animal production. In line with this, in the current study area typically in the lowlands of Ebinat district, Northwest Ethiopia, *Terminalia brownii* tree is widely available and found to be source of succulent fodder especially in the dry season when pastures and crop residues are depleted their nutritive values. However, there was no documented information on *Terminalia brownii* leaves for ruminant nutrition and influence of *Terminalia brownii* diets on the hematobiochemical indices of small ruminants. Therefore, the objective of this experiment was to evaluate the effect of replacing the concentrate mixture with *Terminalia brownii* leaves on the growth performance, blood profile and CH₄ emission of goats.

6.2 Material and Methods

6.2.1 Description of the Experimental Site

The experiment was conducted in Bahir Dar University, College of Agriculture and Environmental Science animal farm. The site is situated at an elevation of 1912 meters above sea level and is positioned between latitude 11°37'N and longitude 37°28'E. The average daily maximum and minimum temperature was 29°C and 7°C respectively. The average annual rainfall is 1445 mm. The main rainy season is from June to September.

6.2.2 Experimental animals and their management

Twenty-five male goats with an average age of one year were bought from Ebinat town, South Gondar zone, Ethiopia. Dentition and information from the owners were used to estimate the age of the experimental animals. For identification, the experimental

animals were given ear tags. The experimental goats were kept for fifteen days to adapt the experimental feeds. All experimental goats were received treatments (albendazole and Ivermectin 1%, 1ml/50 kg single dose) against for internal and external parasites. Throughout the trial, the prevalence of illnesses and abnormalities on the animals was regularly monitored.

Randomized complete block design (RCBD) was used in the experiment. Based on their initial body weight, the experimental goats were grouped into five blocks of five goats each. The experimental goats from each block were randomly assigned to each treatment feed. The results of nutrient content data of feed ingredients were used to formulate the five experimental feeds that are presented in Table 6.1. In T1, T2, T3, T4 and T5, *Terminalia brownii* was used as a replacement for 0, 15, 30, 45 and 60% of the concentrate mixture (wheat bran, nouge seed cake and maize grain) respectively. Soon after the formulation, representative samples were taken from each of the treatment feeds for chemical analysis. The five treatment diets used for the experiment are detailed in Table 6.1.

Table 6.1. Allocation of experimental treatments

Feed ingredients	T1	T2	T3	T4	T5
Natural pasture hay	<i>Ad libitum</i>	<i>Ad libitum</i>	<i>Ad libitum</i>	<i>Ad libitum</i>	<i>Ad libitum</i>
Composition of concentrate mix (% of DM)					
Noug seed cake	21	17	14	12.5	9.75
Wheat bran	60	52	42	30	19.5
Ground maize grain	18	15	13	11.5	9.75
<i>Terminalia brownii</i>	0	15	30	45	60
Common salt	1	1	1	1	1
Nutrient concentration of concentrate mix					
CP, % of DM	17.94	17.4	16.9	16.65	16.22
ME, MJ/kg DM	8.88	8.2	7.8	7.22	6.62

6.2.3 Feeds and feeding management

The basal feed used in this study was natural pasture hay consisting of grasses and some herbaceous legumes. Leaves of *Terminalia brownii* was collected from backyard area of Ebinat district in South Gondar zone, Ethiopia. The *Terminalia brownii* leaves were transported to the experimental site and air-dried under a shed. After drying, the leaves were thoroughly mixed and chopped by hand to prevent the goats from selectively eating only certain parts. Similarly, the pasture hay was also chopped to encourage the

goats to consume all parts of the feed. Maize grain purchased from local market and, nouge seedcake and wheat bran were bought from oil extraction and floor meal factories in Bahir Dar town. The basal diet was offered *ad libitum* along with free access to drinking water. The proportion of concentrate supplements that is maize grain, noug seedcake and wheat bran based on the iso-nitrogen calculation. Manually chopped *Terminalia brownii* leaves were mix with the basal diet and provided to the experimental animals.

6.2.4 Dry matter and nutrient intakes

The researchers carefully monitored the goats' feed consumption daily, recording both the amount of feed offered and refused. The daily feed intake was determined by subtracting the refused feed from the offered amount for each goat. The total dry matter and nutrient intakes were determined by multiplying the total daily feed consumed by the nutrient composition of the diet.

6.2.5 Dry matter and nutrient digestibility

The digestibility of treatment feed was done after the 90 days feeding trial for seven days. Experimental goats were harnessed with fecal collection bags. Faeces were collected every morning, 20% of representative samples were taken and frozen at - 20 ° C and pooled during the collection period for each goat. At the end of the collection period, each sample was mixed and dried at 65 °C for 72 hrs for laboratory analysis. The apparent digestibility of nutrients was determined as the proportion of the difference between the nutrient consumed and the nutrient in the faeces.

$$\text{Apparent DM digestibility} = \frac{\text{DMI} - \text{Faecal DM output}}{\text{DMI}}$$

$$\text{Apparent nutrient digestibility} = \frac{\text{Nutrient intake} - \text{faecal nutrient output}}{\text{nutrient intake}}$$

6.2.6 Body weight change

The initial body weight of goats was measured by taking the body weights during the start of the experiment. Their weight was taken every two weeks interval before their

morning meal. The final weight was measured at the end of the experiment. The average daily gain (ADG) was determined as the change between the final and initial weights divided by the number of days of feeding. FCE was estimated as a ratio of feed intake to weight gain.

6.2.7 Chemical composition analysis of feeds and feces

The representative samples of feed offer, refusals and feces were taken for chemical analysis. The DM, ash and CP contents of feed offered, refusals and feces were analyzed according to methods suggested by (AOAC, 1990). The dry matter content was determined by drying the samples at 105 ° C. The nitrogen content of the feed and feces samples was determined using Kjeldahl procedure. The crude protein (CP) content was determined by using the calculation $N \times 6.25$. Ash was determined by igniting the samples in muffle furnaces at 550 ° C overnight (AOAC, 1990). Neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) content was investigated following recommendation (Van Soest *et al.*, 1991).

6.2.8 Blood sample collection and analysis

Blood samples were collected from all goats using blood collection needle. Blood sample was collected in a purple top 5 ml vacuum tubes containing 10% anticoagulant ethylene diamine tetra-acetic (EDTA). The blood samples were taken from the jugular vein at the morning before the daily feed offer. All the blood samples were taken immediately to the laboratory. The blood hematological tests were read (analyzed) by automated hematology analyzer. The hematological parameters tested were packed cell volume (PCV), hemoglobin (Hgb), white blood cells (WBC), differential white blood cells (neutrophil, lymphocyte and monocytes), red blood cells (RBC), mean corpuscular volume (MCV) and mean corpuscular hemoglobin concentration (MCHC).

The blood samples for the serum biochemical analysis were also taken from goats in red top vacuum tubes of 5 ml with no anticoagulant, that allow for clotting. The blood samples were taken to biotechnology laboratory and centrifuged at 3000 rpm with a centrifugation force of 1620 g for 15 minutes. Then after, the serum and plasma samples were transferred into labeled grass vials and stored at a temperature of -20 °C pending analysis. The blood chemistry tests were done by an automated biochemical analyzer

using a commercial kit. The separated serum and plasma samples were then analyzed for biochemical parameters include: glucose, cholesterol and total protein.

6.2.9 Measurements of enteric CH₄ emissions

CH₄ gas emission was measured on all goats using hand-held portable laser CH₄ gas detector (LMD). We held the LMD at a fixed distance of 1 m from each goat while measuring. The CH₄ emitted was recorded by pointing the green laser beam on the LMD at the muzzle of each goat in ppm per minute (Sorg, 2021). The CH₄ measurements were taken three times, that is at the morning after feeding, midday, and in the afternoon to account for any significant effect on CH₄ emissions because of rumen fill effects. The enteric CH₄ emission was read on the LMD from each goat for three minutes over a period of five consecutive days.

6.2.10 Data analysis

The data were analyzed using the General Linear Model (GLM) procedures of SAS (version 9.4). Means that showed significant difference among them were separated using the Tukey's Multiple Range test. Differences were considered statistically significant at the 0.05% level of significance. The analysis model was as follows.

$$Y_{ij} = \mu + T_i + B_j + e_{ij}$$

Where,

Y_{ij} is the response variable (the observation in j^{th} block and i^{th} treatment)

μ is the overall mean.

T_i is a treatment effect.

B_j is a blocking effect and e_{ij} is a random error.

6.3 Results

6.3.1 Chemical composition of treatment feeds

The chemical composition of experimental feeds and refusals are shown in Table 6.2. In the current study, the CP content of *Terminalia brownii* (15.80%) had a higher content as compared to the CP content of offered natural pasture hay (7.64%). Likewise, *Terminalia brownii* showed lower NDF, ADF and ADL (38.63%, 16.96% and 3.35%) contents respectively than natural pasture hay. In terms of crude protein content, *Terminal*

brownii dried leaves (15.8% CP) was comparable with wheat bran (16%). However, noug seed cake (31.15%) had better value of CP as compared to *Terminalia brownii* leaves. Ash content varied throughout the diets from 5.28% to 14.14% having lower and higher contents of ash in wheat bran and noug seed cake respectively. The crude protein value of feed refusals decreased while the content of NDF, ADF and ADL increased as compared to the offered treatment.

Table 6.2. Chemical composition (%) of the feeds offered and refused

Feed offered	DM	OM	Ash	CP	NDF	ADF	ADL
Natural pasture hay	91.59	88.24	11.76	7.64	71.12	49.46	13.75
<i>Terminalia brownii</i>	91.63	92.30	7.74	15.80	38.63	16.96	3.35
Noug seed cake	92.26	91.26	14.14	31.15	38.10	31.74	10.74
Wheat bran	91.15	94.70	5.28	16	49.24	15.56	5.68
Ground maize grain	88.9	91.8	8.8	10	41.54	21.87	4.17
Concentrate mix	93.30	85.85	8.76	23.15	29.50	20.55	8.75
Feed refusal							
T1	92.45	87.70	12.32	5.60	42.25	37.0	10.80
T2	93.10	91.30	8.70	5.95	64.40	46.55	15.75
T3	94.45	92.20	7.80	7.0	59.95	40.40	12.55
T4	94.55	89.50	10.50	6.50	50.05	41.55	15.25
T5	94.80	91.85	8.13	7.20	60.35	48.80	15.25

DM= Dry Matter; CP = Crude Protein; NDF= Neutral Detergent Fiber; ADF = Acid Detergent Fiber; ADL = Acid Detergent Lignin; OM= Organic Matter.

6.3.2. DM and nutrient intake

The daily DM and nutrients intake of experimental goats supplemented with *Terminalia brownii* leaves are shown in Table 6.3. There was a statistically difference for both DM and OM intake among treatments. The inclusion level of *Terminalia brownii* leaves increased, the DM and OM intakes were increased. On the other hand, lowest DM (608.58g/day) and OM (563.56 g/day) intake were investigated in sole concentrated mixture supplemented group while the highest for T5 (779.24 and 763.68 g/day) group respectively. Correspondingly, NDF, ADF and ADL intakes also meaningfully different among treatments and increased as the inclusion of *Terminalia brownii* increased. The result showed that supplementation of *Terminalia brownii* increased crude protein intake and there was an increasing trend as the level of inclusion increased, the highest being in T5 (181.06 g/day). As compared to the groups supplemented with concentrate mixture, T4 and T5 treatment groups had the highest intake of ash.

Table 6.3. Nutrient intake of goat supplemented with different levels of *Terminalia brownii*.

Intake (g/day)	Treatment					Sig.
	T1	T2	T3	T4	T5	
DMI	608.58 ^b	631.62 ^b	627.84 ^b	686.42 ^{ab}	779.24 ^a	**
OMI	563.56 ^b	617.24 ^b	616.40 ^b	711.78 ^a	763.68 ^a	***
AshI	48.68 ^d	54.22 ^c	57.96 ^c	67.84 ^b	76.44 ^a	***
CPI	128.3 ^b	135.88 ^b	142.22 ^a	174.24 ^a	181.06 ^a	***
NDFI	246.02 ^c	265.84 ^{bc}	287 ^b	343.2 ^a	362.52 ^a	***
ADFI	174.22 ^c	189.44 ^c	227.02 ^b	270.94 ^a	280.3 ^a	***
ADLI	52.82 ^c	67.84 ^b	69.42 ^b	72.7 ^b	87.38 ^a	***

^{abc} Means in the same row with different superscript differ significantly; DMI = Dry matter intake; AshI = ash intake; OMI= Organic matter intake; CPI = Crude protein intake; NDFI =Neutral detergent fiber intake; ADFI = Acid detergent fiber intake; ADLI = Acid detergent lignin intake; T1 = Hay + 100% CM; T2 = Hay + 85%g CM + 15% *Terminalia brownii*; T3 = Hay + 70% CM + 30% *Terminalia brownii*; T4 = Hay + 55% CM + 45% *Terminalia brownii*; T5 = 40% CM + 60% *Terminalia brownii*; ** = (P < 0.01); *** = (P < 0.001).

6.3.3 Apparent DM and nutrients digestibility

In table 6.4 the apparent dry matter and nutrient digestibility of the treatment feeds are shown. There were notable variations (P <0.005) in crude protein and acid detergent lignin digestibility values among treatments. The groups treated with T4 had a higher crude protein digestibility (73.96%) than the groups supplemented with T1, T2, T3, and T5. There were no statistical variations in OM, NDF and ADF values among the treatments.

Table 6.4. Apparent digestibility (%) of DM and nutrients in goats

Parameters	Treatments					SEM	Sig.
	T1	T2	T3	T4	T5		
DMD	60.97	63.07	64.17	72.15	59.9	4.39	NS
OMD	63.67	65.03	66.21	73.41	60.1	4.82	NS
CPD	52.36 ^b	61.82 ^{ab}	64.98 ^{ab}	73.96 ^a	65.69 ^{ab}	6.43	***
NDFD	59.09	58.41	60.64	69.32	61.57	8.21	NS
ADFD	60.87	56.03	59.61	67.73	60.33	8.45	NS

^{ab} Means in the same row with different superscripts differ significantly; SEM = standard error of mean; DMD= Dry matter digestibility; CPD = Crude protein digestibility; NDFD= Neutral detergent fiber digestibility; ADFD = Acid detergent fiber digestibility; OMD= Organic matter digestibility; SL = Significant level; T1 = Hay + 100% CM; T2 = Hay + 85%g CM + 15% *Terminalia brownii*; T3 = Hay + 70% CM + 30% *Terminalia brownii*; T4 = Hay + 55% CM + 45% *Terminalia brownii*; T5 = 40% CM + 60% *Terminalia brownii*; *** = (P < 0.001); NS=non-significant.

6.3.4 Body weight change and FCE

Table 6.5 shows the body weight gain and FCE of goats fed *Terminalia brownii* leaves. The initial body weight did not differ statistically ($p>0.05$) among treatments. As the inclusion of *Terminalia brownii* leaves increased to 60%, there was a noticeable increase of final body weight in the experimental goats. The daily weight gains of goats increased as their substitution level of *Terminalia brownii* increased. The daily weight gain was higher in the goats supplemented with high level of *Terminalia brownii* leaves. Additionally, the data showed that the FCE of the experimental diets did not differ significantly among treatments. T1 and T2 exhibited the lowest FCE values among the groups supplemented with *Terminalia brownii*.

Table 6.5. Body weight change and FCE of goats supplemented with *Terminalia brownii* leaves.

Parameters	Treatment					SEM	Sig.
	T1	T2	T3	T4	T5		
Initial BW (kg)	18.96	18.8	19.2	19.24	19.08	0.03	NS
Final BW (kg)	22.24 ^b	21.86 ^b	22.88 ^{ab}	24.56 ^a	24.78 ^a	1.43	***
BW change (kg)	3.28 ^b	3.06 ^b	3.68 ^{ab}	5.32 ^a	5.7 ^a	1.52	*
ADG (g/day)	36.6 ^{bc}	34.0 ^c	41.0 ^{abc}	59.0 ^{ab}	63.4 ^a	17.1	*
FCE	0.054	0.052	0.06	0.076	0.074	0.03	NS

^{abc} Means in the same row with different superscript differ significantly; BW = body weight; ADG= Average Daily Gain; SEM = Standard Error of Mean; FCE = Feed conversion efficiency; T1(Control) = Hay + 100% CM; T2 = Hay + 85%g CM + 15% *Terminalia brownii*; T3 = Hay + 70% CM + 30% *Terminalia brownii*; T4 = Hay + 55% CM + 45% *Terminalia brownii*; T5 = 40% CM + 60% *Terminalia brownii*; * = ($P < 0.05$); *** = ($P < 0.001$); NS = non-significant ($P > 0.05$).

6.3.5 Hematological and serum chemistry parameters of goats

The hematological profiles of goat fed varying levels of *Terminalia brownii* leaves are presented in Table 6.6. There were no variations ($P>0.05$) in the hematological parameters except for white blood differentials (lymphocytes, monocytes and neutrophils) and hemoglobin as the inclusion level of *Terminalia brownii* leaves increased in the diet. The differences had found to be statistically significant ($P < 0.05$) for lymphocytes (LYM), monocytes and neutrophils concentration among the treatment groups. Animals fed T5 recorded significant $P (< 0.05)$ highest value of LYM (61%) followed by animals fed T3 (28.17%) while the least LYM value (36.5%) had observed in animal fed T4 treatment. Besides, the highest neutrophils' value (56.9%) had obtained in

T4 (with diet containing 55% concentrate mix with 45% *Terminalia brownii*). Likewise, the results revealed a significant variation in hemoglobin (g/dL) among the treatment groups. Goats fed diet with 60% *Terminalia brownii* (T5) leaves meal had the highest hemoglobin concentration (10.74g/dL) compared with other treatments. Furthermore, there were no significant differences in MCV, MCH and MCHC observed among the treatment groups. However, the value of MCV (25.95 - 33.75 (fL)), MCH (8.40 - 25.10 (pg)) and MCHC (32.75 - 76.90 (g/dL)) were higher than the laboratory reference values of health goats.

The effects of feeding different inclusion rate of *Terminalia brownii* on serum biochemical profiles of goats are presented in Table 6.6. Among serum biochemical parameters, cholesterol significantly varied between treatments ($P < 0.05$). The control group had significantly ($P < 0.05$) higher values of cholesterol (75.0) than other treatment groups. Other indicators, such as total protein and glucose levels, demonstrated statistically insignificant differences among treatments.

Table 6.6. The hematobiochemical profiles of goat fed *Terminalia brownii* leaves

Parameters	T1	T2	T3	T4	T5	SEM	Sig.	Ref.
Hematology								
WBC ($10^3/\mu\text{L}$)	11.21	9.45	10.53	9.64	10.78	2.89	0.962	4-13 ¹
Neutrophils (%)	46.1 ^{ab}	39.09 ^b	37.84 ^b	56.9 ^a	36.92 ^b	4.08	0.019	30-40 ¹
Lymphocytes (%)	46 ^{ab}	57.41 ^a	58.1 ^a	36.5 ^b	61 ^a	4.97	0.018	50-70 ¹
Monocytes (%)	9.2 ^a	3.06 ^c	4.65 ^{bc}	5.65 ^{bc}	6.9 ^{ab}	0.75	0.003	0-4 ¹
Eosinophils (%)	0.43	0.44	0.33	0.3	1.25	0.29	0.095	1-8 ¹
Basophils (%)	0.4	0.45	0.45	0.3	0.4	0.22	0.955	0-1 ¹
RBC ($10^6/\mu\text{L}$)	11.19	7.52	9.61	4.26	6.89	2.32	0.160	8-18 ¹
HGB (g/dL)	9.9 ^{bc}	10.35 ^a	8.10 ^c	10.4 ^a	10.74 ^a	0.47	0.014	8-12 ¹
MCV (fL)	28.13	31.9	25.95	31.12	33.75	2.17	0.077	16-25 ¹
MCH (pg)	9.48	16.65	8.40	25.10	10.26	4.84	0.074	5.2-8 ¹
MCHC (g/dL)	33.86	63.40	32.75	76.90	48.28	13.01	0.071	30-36 ¹
PCV (%)	24.25	27.50	27.45	28.82	28.87	4.54	0.840	10-30 ¹

Blood chemistry								
Glucose, mmol/L	1.0	3.0	3.5	4.0	3.0	2.98	0.132	2.4–4 ¹
Protein, g/dL	8.0	8.0	7.90	8.65	8.25	0.32	0.266	6.2–7.9 ¹
Cholesterol, mmol/L	1.94 ^a	1.11 ^b	1.55 ^{ab}	1.60 ^{ab}	1.56 ^{ab}	0.15	0.026	1.5–1.9 ¹

^{ab} Means with different superscripts in the same row are significantly different (P < 0.05); PCV = packed cell volume; RBC = red blood cell; MCV = mean corpuscular value; HGB = hemoglobin; MCH = mean corpuscular hemoglobin; MCHC = mean corpuscular hemoglobin concentration; WBC = white blood cell; ¹= (Jackson *et al.*, 2002).

6.3.6 CH₄ emission of goats supplemented with *Terminalia brownii* leaves

CH₄ is a greenhouse gas (GHG) produced and released by eructation to the atmosphere in large volumes by ruminants. In this experiment, there was no statistically significant difference in CH₄ gas emission of goats with the inclusion of *Terminalia brownii* leaf meal. However numerically, goats fed a diet with concentrate mix (T3) had the lowest (34.83-ppm) CH₄ gas emissions while the highest CH₄ gas emission had observed in goats fed 60% T5 (40.28 ppm) supplement diet.

Table 6.7. CH₄ emission of goats supplemented with *Terminalia Brownii* leaves

Measurement time	Treatments					Sig.
	T1	T2	T3	T4	T5	
Morning	30.53 ^{cd}	33.63 ^{bcd}	30.29 ^{cd}	28.02 ^d	36.15 ^{abcd}	0.049
Midday	33.82 ^{bcd}	32.83 ^{bcd}	43.04 ^{ab}	44.02 ^{ab}	39.13 ^{abcd}	
Evening	40.86 ^{abc}	40.44 ^{abc}	31.15 ^{cd}	37.91 ^{abcd}	45.56 ^a	
Time * treatment						
Overall mean	35.07	35.63	34.83	36.65	40.28	

^{abc} Means in the same row with different superscript differ significantly; T1(Control) = Hay + 100% CM; T2 = Hay + 85%g CM + 15% *Terminalia brownii*; T3 = Hay + 70% CM + 30% *Terminalia brownii*; T4 = Hay + 55% CM + 45% *Terminalia brownii*; T5 = 40% CM + 60% *Terminalia brownii*; NS = non-significant (P > 0.05).

6.4 Discussion

6.4.1 Chemical composition of treatment feeds

In this experiment, natural pasture hay had a low CP content (7.64%). Yet, CP content of the pasture measured in this research, was higher than the 3.68 -5.9% values investigated by Chalew *et al.* (2016) and Desta and Teferi (2017), and it is comparable to the value stated by Abrha *et al.* (2019). While lower than the values testified by Yeshambel and Bimrew (2018). The NDF, ADF and ADL content of natural pasture hay

in this study were within the ranges for the majority of tropical fiber feedstuffs. The ADF (49.46%) values of natural pasture hay were comparable with 50.70% investigated by Desta *et al.* (2023). The ADL value obtained from this experiment was less than that published by (Abrha *et al.*, 2019) but lower than the values reported by Desta *et al.* (2017); Mekuriaw and Asmare (2018). Differences in soil type, altitude and harvesting stage may be the cause of the variation in fiber content between research investigations (Tamrat *et al.*, 2020; Gobena *et al.*, 2022;). The fiber content of basal diet in the current study was within the range of most tropical forages (Lemus, 2009). The above result demonstrating that the basal diet is poor in quality for optimum rumen condition and supplementation of this natural pasture hay with alternative protein source was recommendable.

The CP content observed in *Terminalia brownii* (15.8%) was alike to 14.67% in *Ziziphus* leaves reported by Abrha *et al.* (2019), but higher than 12.69% values in *Ficus thonningii* reported by Mekuriaw and Asmare (2018). This difference might be season, type of species and age of the plants where samples were collected. The NDF, ADF and ADL contents of *Terminalia brownii* found in the current study were lower than the fiber content of browse leaves studied by Misrak *et al.* (2023) who showed that NDF varied between 43.37% in *Olea africana* and 69.9% in *Cordia africana*, while ADF ranged from 28.56% in *Terminalia brownii* to 53.9% in *Cordia africana*. Also higher value of NDF, ADF and ADL of *Terminalia schimperiana* (50.46%, 23.81% and 15.5%) was investigated by Desalegn *et al.* (2016) respectively in Chilga district north western Ethiopia.

6.4.2 DM and nutrient intakes

As the level of *Terminalia brownii* supplementation increased, the total amount of DM intake also increased. This might be the result of supplementing creating a better rumen environment, which raised microbial protein production and improved DM and nutrient intakes. There was a tendency to increase DM intake with increased levels of *Terminalia brownii*, which attributed to the increase for supplementation. The results also indicated that improving the total intake in the treatments improves the intake of all the nutrients. The total dry matter and organic matter intakes of supplemented goats in the

study ranged from 608.58 to 779.24 and 563.56 to 763.68 g DM/day/head, respectively. The current findings were higher than the findings of Sisay *et al.* (2015) who reported a range of 524 to 601 g/ day/ head for DM intakes of Arsi Bale goats supplemented with *Millettia ferruginea*. The lowest dry matter intake (593.34 g DM/day) of Arsi Bale goats fed *Chloris gayana* hay supplemented with *Acacia tortilis* browse species was also observed by Sisay *et al.* (2022). The total DM intake observed in this study was lower than the 1,015.72 g /day/ head values for Farta sheep fed urea-treated rice straw supplemented with dried *Sesbania sesban* leaves reported by Tekliye *et al.* (2018). In line with the current study Balehegn *et al.* (2014) also investigated that improved DM and nutrient intake was observed when *Ficus thonningii* leaves was substituted by concentrate supplement in highland goats.

The highest DM and OM intake observed in goats fed with *Terminalia brownii* might be attributed to the lowest NDF and ADF values of *Terminalia brownii* leaves. It is commonly acknowledged that the NDF and ADF contents have the greatest impact on fodder intake and degradation. Research has shown that NDF and ADF have a negative link with dry matter intake and digestibility (Mokoboki *et al.*, 2019; Chebli *et al.*, 2021). The values of the CP intake in this experiment were higher than the values that ranged from 54.23 to 111.98 g/day/ head in Kaffa sheep complemented with *Sesbania sesban* leaves reported by Worku *et al.* (2015) and 85.94 to 101.13 g/ day/ head (Sisay *et al.*, 2019). Another investigation reported by Ali *et al.* (2019) also showed that an increased CP intake with increasing levels of sun-dried *Ziziphus spina-christi* leaves substitution for natural pasture hay for Bati goat breeds in Ethiopia which is in agreement with the current finding. The higher intake of NDF and ADF in the inclusion group could mostly be a contribution to the fiber content of supplement.

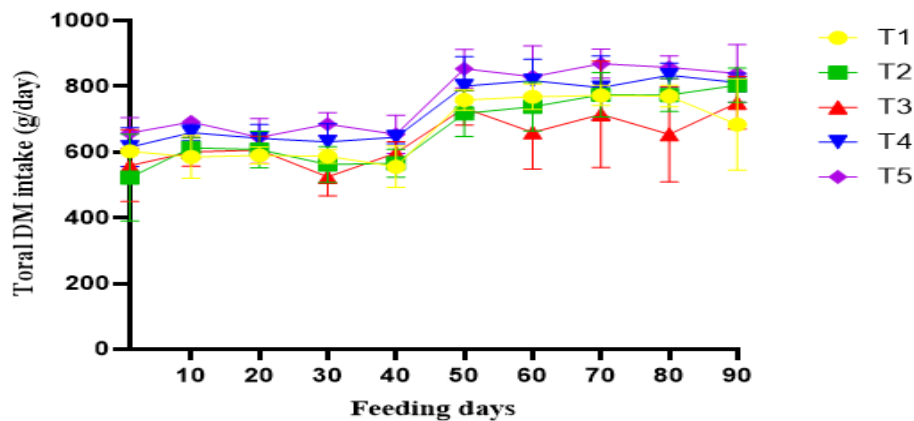


Figure 6.1. Trends of total dry matter intake of local goat fed natural pasture hay supplemented with graded levels of *Terminalia brownii* leaves. T1 = Natural pasture hay + 100% CM; T2 = Natural pasture hay + 85%g CM + 15% *Terminalia brownii*; T3 = Natural pasture hay + 70% CM + 30% *Terminalia brownii*; T4 = Natural pasture hay + 55% CM + 45% *Terminalia brownii*; T5 = Natural pasture hay + 40% CM + 60% *Terminalia brownii*.

6.4.3 Apparent dry matter and nutrient digestibility

The result shown that there were a significant difference in CP and ADL digestibility among the different treatment groups. Specifically, the group supplemented with T₄ revealed higher crude protein digestibility compared to the other treatment groups (T₁, T₂, T₃ and T₅). However, there were no significant differences in the apparent digestibility of dry matter, organic matter, neutral detergent fiber and acid detergent fiber among the treatments.

The above-mentioned result aligns with the findings of several previous studies on the effect of browse species supplements on nutrient digestibility in ruminant animals. Firisa *et al.* (2013) reported that improved digestibility of dry matter, organic matter, crude protein and fiber components in sheep fed a natural pasture hay basal diet supplemented with *Vernonia amygdalina* leaves. Dida *et al.* (2019) found that goats supplemented with 300 g of *Azyhatadirachta indica* leaves had higher nutrient intake and digestibility compared to those supplemented with 300 g of concentrate mix (wheat bran and noug seed cake). Abrha *et al.* (2019) observed that the apparent digestibility of DM and OM was better for sheep supplemented with *Ziziphus spina-christi* (400g) leaves meal, indicating improved nutrient intake. Ephrem *et al.* (2015) also demonstrated that supplementation with sweet blue lupin (*Lupinus angustifolius*) improved the digestibility

of DM, OM and CP, but did not affect NDF and ADF digestibility. The above result also in line with the report of McDonald *et al.* (2011) who noted that addition of dietary protein in the supplement has increased protein availability to rumen microorganisms to speed up the digestion process.

However, some studies have reported contrasting results. Mekuriaw and Asmare (2018) presented that supplementation with higher levels of *Ficus thonningii* leaves meaningfully reduced the digestibility coefficient of nutrients. Kurniawan (2021) also found that incorporating 5-10% *Bauhinia purpurea* leaves meal in concentrate mix had no effect on daily DM intake but decreased dry matter digestibility. The discrepancy of the findings could be attributed to plant species, animal breed and maturity stage of treatment feeds etc.

6.4.4 Body weight change and FCE

The highest average daily gains of goat supplemented with the *Terminalia brownii* in the current experiment could be due to the higher OM and CP intake of *Terminalia brownii* supplemented goats. Similarly, Araya *et al.* (2003) observed higher daily weight gain in goats supplemented with *Acacia tortilis* pods, up to 75% level of inclusion. In line with the present study Tekliye *et al.* (2018) found higher average daily body weight gain in Farta sheep supplemented with different level of *Sesbania sesban* leaves. The average daily gain of supplemented goats obtained in the present study is lower than the finding of Hagos *et al.* (2015) in Tigray highland sheep supplemented with *Ziziphus spina-christi* (90.47 g/day/head)leaves.

The average daily gain measured in the current study was lower than the value reported by Desta *et al.* (2017) in Tigray highland ram fed on mixed grass hay *ad libitum* supplemented with dried mulberry (*Morus indica* L.) leaves. The study by Dida *et al.* (2023) compared average daily gain in sheep trial fed different browse diets, showing higher values for diets supplemented with concentrate mixture compared to *Azadirachita indica*, *Stylosanthes fruticosa* and *Dolichus lablab* leaves.

Different authors are discuss the results of various studies on feed conversion efficiency in small ruminants based on different dietary treatments. The current experiment was in line with Desta *et al.* (2017) who found that no significant difference

in feed conversion efficiency among treatments using dried mulberry leaf meal supplementation for sheep. Dida *et al.* (2019) also showed that FCE was not significantly different among treatments for goats fed different combinations of *Cajanus cajan* and *Azadirachta indica* supplements. Additionally, the study by Sisay *et al.* (2019) found that FCE of Borana goats was not significantly different between concentrate mix and *Vechilla brevispica* and *Vechilla nilotica* leaves supplement.

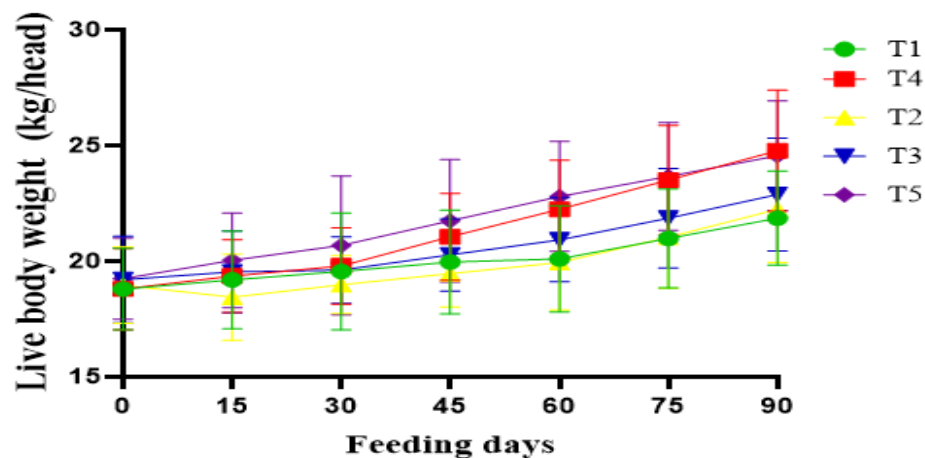


Figure 6.2. Trends of live body weight of local goat fed natural pasture hay supplemented with graded levels of *Terminalia brownii* leaves. T1 = Natural pasture hay + 100% CM; T2 = Natural pasture hay + 85%g CM + 15% *Terminalia brownii*; T3 = Natural pasture hay + 70% CM + 30% *Terminalia brownii*; T4 = Natural pasture hay + 55% CM + 45% *Terminalia brownii*; T5 = Natural pasture hay + 40% CM + 60% *Terminalia brownii*.

6.4.5 The hematobiochemical profiles of goat

Blood profiles offer an important foundation for evaluating the health condition of animals (Stockham and Scott, 2024). The primary functions of white blood cells include producing and distributing antibodies for the immune response as well as protecting the body from foreign organisms (Maddur *et al.*, 2020). According to Jackson *et al.* (2002), the typical range of WBC for a clinically healthy goat is 4.0–13.0 $\times 10^9/L$, which is comparable to the values found in this study (9.45–11.21). A high white blood cell count allows for the production of antibodies and, consequently, a high degree of disease resistance, which is beneficial for adaptability to disease-prevalent places or situations (Essien and Udoh, 2021). A low WBC count exposed animals to a high risk of infection. When compared to the control group, the lymphocyte count was significantly greater in

the 60% *T. brownii* inclusion group. This result was consistent with the findings of Paswan *et al.* (2016), who demonstrated that the lymphocyte count increase as the amount of *A. nilotica* pod meal in the goat diet increased.

According to Farschtschi *et al.* (2022), differing lymphocyte values may indicate varied immune status levels in farm animals, and suggests that low lymphocyte numbers may indicate either a weak immune system or a high neutrophil level in an active infection. Lymphocytes play a key role in the development of acquired immunity, whereas neutrophils are highly effective at trapping and killing invading pathogens. However, the lymphocyte and neutrophil counts obtained in this study are within the physiological ranges of 47–82% and 17–52% respectively for apparently healthy goats (Jackson *et al.*, 2002), implying that inclusion of the implying that inclusion of the *Terminalia brownii* leaf parts were not harmful to the goats.

In this experiment, hemoglobin concentration (8.1-10.74) was differed significantly among treatments but the values were normal for healthy goats (8.0 – 12.0 g/dl) as stated by Radostits *et al.* (2006). This is indicating absence of anemia caused by iron deficiency and improper utilization of iron for the formation of hemoglobin. RBC indices are metrics that are crucial to diagnosing the underlying cause of anemia (Sarma, 1990). MCV, MCH and MCHC are considered RBC indices and give details about average cell size, hemoglobin content and hemoglobin concentration, respectively (Polizopoulou, 2010). The MCV values of goats 25.95 - 33.75 (fL) obtained in this study were higher than the reference range by Jackson and Cockcroft (2002) for healthy goats (16–25 fL). The MCV value obtained in this study implies that the animal might be exposed to macrocytic anemia due to vitamin B₁₂ or folate deficiency (Mohammed *et al.*, 2016). Contrary to expectations, MCH value was ranged from 8.40 - 25.10 (pg), this were higher than the laboratory reference value of healthy goats (5.2–8 pg) (Jackson and Cockcroft, 2002). An elevated MCH might be signify the existence of hemolysis (Polizopoulou, 2010). Similarly, MCHC values recorded in this study ranged from 32.75 - 76.90 (g/dL) was higher than the laboratory reference value (30-36) for goats (Jackson and Cockcroft, 2002).

Serum biochemical parameters are also indicators of the health status of the animals. The current study shows no significant effect of diet on total protein (TP) across all the dietary treatments, however, numerically goats fed on a diet containing *Terminalia brownii* leaves had higher serum TP and more comparable to control diet-fed goats. The concentration of total protein found in the present study were in agreement with the values reported by Kholif *et al.* (2016) who reported that feeding of *Moringa* leaves did not affected serum protein. The blood glucose level (mg/dl) observed in different treatment groups were 1.0, 3.0, 10.5, 4.0 and 3.0 mmol/L in T1, T2, T3, T4 and T5 respectively. The concentration of glucose found in the present study was in agreement with the values reported by Chelopo and Marume (2024). The cholesterol concentration was significantly lower in *Terminalia brownii* leaves fed group as compared to the control groups. Similar to the present findings, Kholif *et al.* (2016) recorded lower serum cholesterol concentrations in goats fed *Moringa* leaves in their diets

6.4.6 CH₄ emission of goats supplemented with *Terminalia brownii* leaves

The above research explores the replacement of concentrate feed with *Terminalia brownii* leaves to assess its impact on CH₄ production in goats. The key finding that CH₄ emissions were comparable between goats fed the *Terminalia brownii* leaves treatment and those fed a concentrate mix is an important result, as it suggests that *Terminalia brownii* leaves might serve as an effective substitute for concentrate feeds without increasing CH₄ emissions.

To interpret and discuss our findings, it is helpful to compare them with similar studies that have investigated the effects of plant-based substitutes, fiber sources, and different feeding strategies on methane emissions in ruminants. High-starch concentrates tend to lead to increased methane emissions because they are rapidly fermented in the rumen, leading to higher hydrogen production, which methanogens utilize to produce methane (Culbertson *et al.*, 2025). On the other hand, browse leaves tend to ferment more slowly and produce less hydrogen, often leading to lower methane emissions (Bonizzi *et al.*, 2025). However, depending on the specific plants used, the presence of secondary metabolites like tannins can either promote or inhibit methane production by affecting the microbial population in the rumen.

The above study found that there was no significant difference in CH₄ emissions between the group of goats fed a concentrate mix and the group fed *Terminalia brownii* leaves. This result suggests that the substitution of concentrate feed with *Terminalia brownii* leaves did not lead to an increase in CH₄ emissions, which is noteworthy for several reasons. It is expected that diets with higher fiber would typically result in lower CH₄ emissions due to slower fermentation and lower hydrogen production. However, the fact that CH₄ emissions were comparable between the concentrate and *Terminalia brownii* treatments suggests that the leaves may have properties (e.g., tannins or other compounds) that offset the potential for higher CH₄ production. The key point from the above result is that *Terminalia brownii* leaves can potentially replace expensive concentrate feeds without exacerbating CH₄ emissions. This has significant implications for sustainable livestock management, particularly in low-resource settings where concentrate feeds are costly and not always affordable.

Several studies have investigated the effects of various forage species, particularly browse plants, on CH₄ emissions. Consistent with our findings on identifying treatment differences using LMD methods, Bekele *et al.* (2025) reported that there was no variations in CH₄ emissions from Menze breed sheep supplemented with different levels of tree leaves. Orzuna-Orzuna *et al.* (2021) found that the supplementation of tannin-rich plants reduced CH₄ emissions in ruminants. However, the effect varied depending on the type of tannin, the amount included in the diet, and the animal's rumen microbiome. This supports the idea that *Terminalia brownii*, if it contains sufficient levels of bioactive compounds, could modulate CH₄ production in a way that makes it comparable to concentrate-fed animals. Leitanthem *et al.* (2022) showed that *Moringa oleifera* leaves were used as a replacement for concentrated mixtures in goat diets, there was a reduction in CH₄ emissions, suggesting that browse species could be a viable alternative without increasing CH₄ output.

6.5 Conclusion

The cost of feed is currently posing a problem for ruminant production in Ethiopia. Therefore, substituting unconventional feed sources with commercial concentrate mixture, which are accessible to smallholder farmers, would help to mitigate feed problem issues and sustain the supply of animal products. Alternative protein sources, such as *Terminalia brownii* tree leaves as a protein supplement feed, could be a solution to halting this situation. Supplementation of local goats with *Terminalia brownii* leaves was increased the dry matter, organic matter, crude protein and fiber intakes. Inclusion of *Terminalia brownii* leaves at a level of 60% was achieved a higher daily weight gain. The study successfully determined that different levels of *Terminalia brownii* dried leaves replaced with concentrate mix in the diets of goats did not have any detrimental effects on their hematological and serum chemistry parameters. While certain parameters such as MCV, MCH and MCHC deviated from the normal range, none of the animals showed any clinical signs of conditions like haemolysis, microcytic hypochromic anemia, or inflammatory response to the treatment diets. *Terminalia brownii* leaves can be a viable alternative to concentrate feeds for ruminant livestock, without exacerbating CH₄ emissions. The comparable CH₄ production between the *Terminalia brownii* and concentrate groups aligns with studies showing that some plant-based substitutes do not negatively affect the health and CH₄ emissions. The study concluded that *Terminalia brownii* leaves could serve as an alternative protein supplement for goats feeding. Future studies could explore the long-term effects of *Terminalia brownii* supplementation, its impact on animal productivity, and the precise mechanisms through which it affects ruminal fermentation and CH₄ production.

CHAPTER 7

GENERAL DISCUSSION

The study encompassed a multifaceted exploration of indigenous browse fodders for livestock feed in Northwest Ethiopia. Shedding light on crucial aspects ranging from identifying and diversity index of major indigenous browse species, farmer's selection criteria and feeding practices, nutrient content and *in vitro* gas and CH₄ production to growth performance, blood profile and enteric CH₄ emission of goats supplemented with *Terminalia brownii* leaves. The interconnected objectives of the study form a cohesive framework aimed at enhancing sustainable ruminant production without an adverse effect on the health of animal and the environment.

A Study on diversity, preference criteria and feeding practice (**Chapter 4**), focuses on understanding how farmers in this area perceive, utilize and manage indigenous browse fodder for livestock feeding. The study also highlights the richness and diversity of indigenous browse species available in northwest Ethiopia. These browse species serve as crucial feed resources, especially during dry seasons when other forage is scarce. The purpose of ranking browse species is to determine which species are prioritized by farmers while choosing and rating browse species (Almaz *et al.*, 2021). Farmers in the study area have a deep indigenous knowledge on the feeding value and benefits of indigenous browse species. They often prefer certain species due to their availability, palatability, multifunctionality, adaptability to the environment, growth and regrowth of the species, biomass yield and ability to improve livestock product and productivity. Farmers select browse species based on specific criteria such as availability, palatability, multifunctionality, growth rate, feeding value and biomass yield of the species. Based on farmers' evaluation criteria, *Terminalia brownii*, *Albezia amara*, *Cordia Africana*, *Ficus sycomorus*, *Acacia brevispica* and *Ficus thonningii* were the most preferred species for livestock feed resource in lowland area. *Cordia Africana*, *Ficus vasta*, *Acacia abyssinica*, *Ficus thonningii*, *Stereospermum kunthianum*, *Ficus sycomorus*, *Dodonaea viscosa* and *Syzygium giuneens* were ranked as the top preferred species in midland. *Cordia abyssinica*, *Ficus thonningii*, *Vernonia amygdalina*, *Acacia abyssinica*, *Myrica salicifolia*, *Olea africana*, *Ficus vasta* and *Dodonaea viscosa* were ranked as the top preferred species in the highland of the study area.

Moreover, the study explores traditional feeding practices, including how browse species is harvested, stored and fed to livestock. The study underscores the importance of indigenous knowledge and the potential of browse fodder in supporting livestock production in resource-limited areas. Overall, the study highlights the need for promoting sustainable management practices, enhancing farmers' knowledge, and conserving indigenous browse species to ensure long-term livestock productivity and environmental health.

The study titled "nutrient content, *in vitro* gas production and post-incubation parameters of indigenous browse fodders in different agro-ecological zones of northwest Ethiopia" (**Chapter 5**) focuses on evaluating the nutrient content, *in vitro* gas volume, fermentation characteristics, SCFA, OMD, ME and CH₄ concentration of indigenous browse species, which are crucial for livestock feeding in Ethiopia. The study covers diverse agro-ecological zones in northwest Ethiopia, including highland, midland and lowland areas. Each zone has unique climatic and soil conditions, influencing the growth and nutrient composition of indigenous browse species.

The study analyzes the nutrient content of indigenous browse fodders, including crude protein (CP), fiber content (NDF, ADF and ADL), ash and dry matter (DM). The identified indigenous browse species are rich in nutrients, particularly CP, making them valuable feed resources for ruminants in resource-limited areas especially during dry season. In the highland, the highest CP content was recorded from *V. amygdalina* followed by *Cordia Africana* and the lowest CP value was recorded from *Syzygium giuneens*. In the midland, *Dodonaea viscosa* had the highest CP content followed by *Acacia abyssinica*. In the lowland, the highest CP content was recorded for *Acacia abyssinica*.

The NDF and ADF content of indigenous browse species ranged from 378.6 to 582.0 g/kg DM and 132.5 to 299.6 g/kg DM in the highland, respectively. In the midland, the NDF content ranged from 277.4 to 638.6 g/kg of DM and the ADF content from 137.1 to 243.3 g/kg DM. *Syzygium giuneens* had the highest NDF and ADF content, and *V. amygdalina* had the lowest NDF in highland agroecology. While, *Cordia africana* had the highest NDF and ADF content in the midland. In the lowland, *Albezia amara* pod and

Cordia africana had the highest NDF content, *Albezia amara* leaves had the highest and *Acacia brevispica* had the lowest ADF content in the lowland, respectively.

In current study except *Syzygium giuneens* in the highland, all species have an NDF of less than 55%, which was lower than the concentration suggested as a limit which could affect intake and digestibility in ruminants (Van Soest and Robertson, 1985). On the other hand, all the browse species in all agro-ecologies had ADF content < 40% which is believed to have high quality feed (Kellems and Church, 1998). Indigenous browse species that have high content of ADF might have lower digestibility since the digestibility of feeds and ADF content is negatively correlated (Sisay *et al.*, 2018; Mokoboki *et al.*, 2019). The fiber composition of the species was variable among the indigenous browse species and varied between low to moderate categories. Since that forages are the main source of ruminant animals (Chebli *et al.*, 2021). Variability in the nutrient content of browse species might be due to plant species, soil types and locations. These factors influence chemical composition, digestibility and nutrient utilization by animals.

In vitro gas production, metabolizable energy, short chain fatty acid and CH₄ production of indigenous browse species in different agro-ecological zones of northwest Ethiopia focuses on evaluating the nutritional value and gas production characteristics of indigenous browse species, which are crucial for livestock feeding in Ethiopia. *In vitro* gas production technique measures the amount of gas produced during the fermentation of feed by rumen microorganisms (Getachew *et al.*, 2004). It helps assess the digestibility and energy availability of feeds.

The study likely compared gas production profiles of different indigenous browse species, highlighting variations in fermentation efficiency. Metabolizable energy represents the energy available to animals after digestion and metabolism (Hervik and Svihus, 2019). The study would have estimated ME from gas production data, providing insights into the energy contribution of these indigenous browse species to livestock diets. Short Chain Fatty Acids are end-products of rumen fermentation and are vital energy sources for ruminants (Lu *et al.*, 2019). The study probably analyzed SCFA production to evaluate the nutritional quality of the indigenous browse species and their potential to support animal growth and productivity. In this finding, the SCFA values in

the highland area ranged from 0.25 mmol/L for *Syzygium giuneens* to 0.91 mmol/L for *Vernonia amygdalina*. *Stereospermum kunthianum* (1.07 mmol/L) has the highest while *Syzygium giuneens* (0.23 mmol/L) recorded the lowest SCFA production amongst the studied browse species in the midland area. In lowland browse species, SCFA was the highest in *Ficus vasta* (0.82 mmol/L) and the lowest in *Albezia amara* leaves (0.02 mmol/L). CH₄ is a byproduct of rumen fermentation and a significant greenhouse gas (Tseten *et al.*, 2022). The study likely measured CH₄ concentration to assess the environmental impact of using these indigenous browse species in livestock systems. This study provides valuable information on the nutritional and environmental aspects of indigenous browse species, supporting their integration into livestock feeding strategies in Ethiopia. It aligns with global efforts to promote sustainable agriculture and climate-smart livestock practices (**Chapter 5**).

Terminalia brownii leaves have been explored as a potential supplement in ruminant diets due to their nutritional profile and bioactive compounds (Bayssa *et al.*, 2016). This experiment examines the effects of supplementing goat diets with *Terminalia brownii* leaves, focusing on growth performance, blood profiles and enteric CH₄ emissions (**Chapter 6**). Supplementing goat with tree leaves rich in nutrients can enhance feed intake and growth rates (Kronqvist *et al.*, 2021). While direct research on the supplementation of goat diets with *Terminalia brownii* leaves is limited, studies on other tannin-rich foliage suggest potential benefits in enhancing growth performance and reducing CH₄ emissions without adversely affecting blood profiles.

The results of the experiment (**Chapter 6**) indicate that increasing the supplementation level of *Terminalia brownii* dried leaves up to 60% in the diet of goats led to significant improvements in final body weight and daily weight gain. The observed increase in final body weight and daily weight gain with higher inclusion levels of *Terminalia brownii* leaves suggests that the leaves provide beneficial nutrients that enhance growth performance. Hematological profiles serve as key indicators of ruminant animal's health, immune response and nutritional status (Motta *et al.*, 2023). The significant differences in lymphocytes, monocytes, neutrophils and hemoglobin levels suggest that *Terminalia brownii* leaves supplementation modifies immune function and oxygen transport efficiency. Lymphocytes are responsible for adaptive immunity,

including the production of antibodies and cellular immune responses (Chapman and Chi, 2022). The increase in lymphocytes in higher *Terminalia brownii* diets suggests that the bioactive compounds in *Terminalia brownii* may have immune-boosting properties. Hemoglobin is a key indicator of oxygen-carrying capacity (Rosove, 2024), and its increase in T5 suggests improved RBC production and iron metabolism. *Terminalia brownii* leaves may contain iron or compounds that enhance iron absorption. The control group had significantly higher cholesterol levels (75.0 mg/dL) compared to *Terminalia brownii* fed groups. This suggests that *Terminalia brownii* supplementation lowers serum cholesterol levels, possibly due to might be tannins and saponins reducing cholesterol absorption in the gut.

CH₄ is a potent greenhouse gas primarily produced by ruminants during enteric fermentation, a process where rumen microbes break down fibrous feed. The study observed no statistically significant differences ($P > 0.05$) in CH₄ emissions among goats supplemented with varying levels of *Terminalia brownii* dried leaves. Although *Terminalia brownii* might contains tannins and bioactive compounds that may influence rumen fermentation, its effect on CH₄ emissions in this study was not statistically significant.

CHAPTER 8

GENERAL CONCLUSION AND RECOMMENDATION

Conclusion

Farmer's preference criteria in selection of browse fodder encompasses palatability, multi-functionality and feeding value were the most important criteria to select browse species in three agroecology. The majority of farmers planted indigenous browse fodder on their farm boundaries, home compound and soil and water conservation areas. Partially cut and carry and partially browsing systems were the preferred feeding system in the study areas. It is possible to conclude that when incorporating locally available feed resources, farmer's indigenous knowledge and experience-based choice of browse fodder species is vital for efficient utilization of available fodder browse species to tackle feed shortage in different agro-ecological zones (**Chapter 4**).

The laboratory result showed that, indigenous browse fodder species yielded moderate to high CP values. Leaves of *Acacia abyssinica*, *Dodonaea viscosa*, *Vernonia amygdalina* in lowland, midlands and highland respectively have been identified as alternative sources of protein, suggesting their potential in supplementing low quality forages. NDF, ADF and ADL content also varied among different species, with some species showing higher fiber content compared to others. Based on the result indigenous browse species produced substantial gas volume, OMD, ME and SCFA and CH₄ however, varied among species. The study also found that certain browse species such as *Albezia amara*, *Ficus sycomorus* and *Myrica salicifolia* from lowland, midlands and highlands respectively were identified as potential candidates in mitigating CH₄ production. The classification of the browse fodder species into low to high CH₄ reduction potential categories based on their CH₄ production percentages provides valuable information for livestock producers looking to reduce CH₄ emissions from ruminants. In conclusion, all browse species had moderate to high CP contents that can be used as a supplement for low-quality roughages to improve feed quality and reduce CH₄ production (**Chapter 5**).

The cost of feed is currently posing a problem for ruminant production in Ethiopia. Therefore, substituting alternative feed sources with commercial concentrate

mixture, which are accessible to smallholder farmers, would help to mitigate feed problem issues and sustain the supply of animal products. Alternative protein sources, such as *Terminalia brownii* tree leaves as a protein supplement feed, could be a solution to halting this situation. Supplementation of goats with *Terminalia brownii* leaves was increased the dry matter, organic matter, crude protein and fiber intakes. Inclusion of *Terminalia brownii* leaves at a level of 60% was achieved a higher daily weight gain. *Terminalia brownii* leaves can be a viable alternative to concentrate feeds for ruminant livestock, without exacerbating CH₄ emissions. The comparable CH₄ production between the *Terminalia brownii* and concentrate groups aligns with studies showing that some browse plant-based substitutes do not negatively affect the health and CH₄ emissions. The study concluded that *Terminalia brownii* leaves could serve as an alternative protein supplement for goats feeding.

Scopes for future work

- Further research in mineral content and secondary metabolites of IBFS could help in promoting the use of browse species for ruminant production
- The biological functions of IBFS secondary metabolites such as anthelmintic, antimicrobial, and antifungal properties should be studied.
- The assessment of seasonal effect on the nutritional value IBFS is open for future work.
- The studied IBFS were contained considerable fiber fraction, some species showed low digestibility. Therefore, a method to increase the digestibility of fiber fractions that could enhance feed value and mitigate methane emissions should be researched.
- Future studies could explore the effects of *Terminalia brownii* supplementation on ruminal fermentation and microflora count.
- Researchers should be studied the effect of *Terminalia brownii* supplementation on the carcass characteristics and meat quality of ruminants.

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APPENDIX

Appendix I. Household Survey Questionnaire

Indigenous Browse Fodder in Different Altitude Area of North Western Ethiopia: Availability, Nutritional and Supplementary Value for Growing Goat

My name is-----, and I am PhD candidate at Bahir Dar university. I am conducting PhD dissertation in your kebeles about fodder tree and shrub species. I would have very much appreciation about your participation in this survey. This interview could take 20 minutes to complete; I hope that you will participate fully in this survey since your views are important. This is just for educational purpose only. Thank you!

1. General information

1. Date of the interview-----
2. District-----
3. Kebele -----
4. House holder's name-----
5. Sex M----- F-----
6. Educational level

1= Illiterate 2. Religious education 3. = read and write only, 4. = elementary,
5. = secondary, 7. = technical education, encircle for each of the house leader

2. Household characteristics

2.1 Family size

Age category		≤5 years	6-15 years	16-64 years	> 64 years	Total
Sex	Male					
	Female					

3. Land holding and Livestock holding

3.1 Do you have private grazing land? a) Yes b) No

3.2. Average land holding under different land use

No	Types of land use	Hectare (ha)
1	Crop cultivation	
2	Forage legume	
3	Fodder tree and shrub	
4	Private grazing	
5	Other (specify)	

3.3. Livestock holding size

1. Do you have domestic animals?

1. Yes

2. No

Type	Cattle	Sheep	Goat	mules	Horse	Poultry	Honey bee colonies
No							

2. If yes, could you tell me what type and number of domestic animals you have?

4. Purpose of livestock keeping

1) Purpose of rearing of cattle

1. For farming 2. For reproduction 3. For sell 4. For milk production only

2) Purpose of rearing small ruminants in the study districts

1. For reproduction 2. For sell only 3. For home consumption only 4. As live bank

5. Types of feed

5.1 What are your major livestock feed resources?

Types of feed	Wet season	Rank	Dry season	Rank
Crop residue				
Agro industrial by products				
Natural Pasture				
Fodder legume				
Fodder tree and shrubs				
Non-conventional feed (Specify)				

6. Name important fodder tree and shrub used as feed for livestock (types of eaten part)

No.	Local Name	Scientific Name	Season of Availability	Eaten by (animals)	Eaten Part
1					
2					
3					
4					
5					

7. Farmers practice on fodder trees and shrubs planting.

7.1. Did you propagate fodder tree and shrubs before?

- a) Yes b) No only naturally established

7.2. if yes, where did you propagate?

- a). within the home compound b). On the boundaries of farm land
c). Scattered within grazing land d). Other (specify)-----

7.3. Natural establishment area?

- a). within the home compound b). Forest land
c). on the boundaries of farm land d). Scattered within grazing land
e). other (specify)

7.4. What is your propagation technique?

- a. Seedling b. direct sowing
c. Cutting

8. Farmers selection criteria (in their order of importance) of fodder trees and shrubs in your districts

Criteria	Rank
Palatability	
Nutritional value	
Improve milk production	
Satisfying hunger	
Fast growth and regrowth	
Adaptability	
Multi functionality	
Biomass yield	
Compatibility	

Ranking exercise

1. Please rank each species based on the criteria

No.	Animal related criteria	List of browse species									
	Palatability										
	Improve animal health										
	Ability to fatten (improve										
	High nutritive values										
	Improve milk production										
	Satisfying the hunger of the animal										
	Plant related criteria										
	Fast growth and regrowth potential										
	Adaptability to the environment										
	Drought resistance										
	Biomass yield										
	Multi functionality										
	Compatibility with other crop										

9. Utilization practice of fodder tree and shrubs

9.1. What method do you prefer to feed your livestock?

- a. Based on your preference
- b. Based on animal preference

9.2. How do you feed fodder trees and shrubs?

- a). only cut and carry
- b). only browsing
- c). partially cut and carry and partially browsing

9.3. How do you harvest fodder tree and shrub (which part you cut) for feeding livestock?

- a). Selective cutting of leave parts, flowers and fruits of shrubs and trees
- b). Cut soft twinges only
- c). Browsing
- d). Coppice at knee height

9.4. Is there any fodder tree and shrub that makes animal sick when they feed?

- a). Yes
- b). No

9.5. If your answer is yes for the above question which fodder tree and shrub and which part of the plant?

9.6. What to do to prevent this problem?

9.7. Do you conserve fodder tree and shrub for the dry season?

- a). Yes
- b). No

9.8. If your answer is yes for the above question which conservation method?

- a). hey preparation
- b) Silage making
- c) Other (specify)_____

9.10. In what form do you feed fodder tree and shrub?

- a). Fresh form b). Drying form
- c). Mixing with other feed d). Chopped
- e). other (specify_____)

10. Which constraint did you face for planting fodder tree and shrub?

- a). Lack of seed and seeding b). Shortage of land
- c). Lack of knowledge d). High price and
- e). low quality f). Problem to adapt the environment

11. Tropical livestock unit conversion factor

Livestock species	Conversion factor	References
Ox	1	(Strock <i>et al.</i> , 1991; Naseri and Kabul, 2005)
Cow	1	
Calf	0.34	(Strock <i>et al.</i> , 1991)
Heifer	0.8	(Naseri and Kabul, 2005)
Bull	0.6	
Sheep	0.13	(Strock <i>et al.</i> , 1991)
Goat	0.13	
Donkey	0.7	(Strock <i>et al.</i> , 1991; Naseri and Kabul, 2005)
Mule	1	(Strock <i>et al.</i> , 1991)
Camel	1.1	
Poultry	0.013	

12. Partial budget analysis the animal experiment

Variables	Treatments				
	T1	T2	T3	T4	T5
Purchasing price of goats	2,900	2,950	2,900	3,000	2,950
Cost of NPH	420	420	420	420	420
Cost of CM	1433	964	670.8	410	252
Cost of Tb	0	21	39	57	78
Cost of labor	640	640	640	640	640
Cost of salt	2.2	2.1	2.1	2.3	2.2
Selling price of goats	6,500	6,450	7,000	7,100	7,050
TVC	2,495.2	2,047.1	1,771.9	1,529.3	1,392.2
Change of TVC	0.00	-448.1	-723.3	-965.9	-1103
TRR	3,600	3,500	4,100	4,100	4,100
Change of TRR	0.00	-1000	500	500	500
NR	1,104.8	1,452.9	2,328.1	2,570.7	2,707.2
Change of NR	0.00	348.1	1,223.3	1,465.9	1,602.4
MRR (%)	0.00	-0.78	-1.69	-1.52	-1.45

CM = Concentrate mix; Tb = Terminalia brownie; TVC = Total variable cost; TRR = Total rate of return;
NR = Net return; MRR = Marginal rate of return

Appendix 2: Pictures associated with dissertation (from left to right the questioner survey, sample collection and feeding trial respectively).



