NUTRITIONAL EVALUATION OF CACTUS CLADODES AND OTHER SELECTED BROWSE SPECIES AND THE EFFECT OF SUPPLEMENTATION OF *ACACIA SALIGNA* AND CACTUS CLADODES ON PERFORMANCE OF GOATS IN EASTERN ZONE OF TIGRAY, NORTHERN ETHIOPIA

PhD THESIS

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HAWASSA UNIVERSITY

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ABBREVIATIONS AND ACRONYOMS

ADG	Average Daily Weight Gain
ADF	Acid Detergent Fiber
AOAC	Association of Official Analytical Chemist
BW	Body Weight
CF	Crude Fiber
CP	Crude Protein
CT	Condensed Tannins
CTA	Technical Center for Agriculture
CSA	Central Statistical Agency
DM	Dry Matter
DP	Dressing Percentage
EBW	Empty Body Weight
EARO	Ethiopian Agricultural Research Organization
ESA	Ethiopian Standards Agency
FAO	Food and Agricultural Organization of the United Nations
FAOSTAT	Statistical Data Bases of Food and Agricultural Organization of the United Nations
GLM	General Linear Model
HCW	Hot carcass weight
ILCA	International Livestock Center for Africa
IOS	International Organization for Standardization

NDF	Neutral Detergent Fiber
Masl	Meter above sea level
ME	Metabolizable Energy
OM	Organic Matter
OMD	Organic Matter Degradability
PUFA	Polyunsaturated Fatty Acids
REMA	Rib-Eye Muscle Area
SBW	Slaughter Body Weight
SLC	Society of Leather and Chemists

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LIST OF PAPERS

The thesis is based on the following papers referred by their roman numbers in the text

I. Assessment of the goat production system, Availability of browse species and the production and utilization of cactus in the cactus-dominated areas of the eastern zone of Tigray, north Ethiopia.

II. Evaluation of Nutritive Value of Cactus (*Oputinia ficus indica*) Cultivars and other Browse Species in Eastern Zone of Tigray, Ethiopia. *Journal of Science and Development, 12(1) 2024.*

III.To evaluate the effect of supplementation of cactus (*Opuntia ficus-indica*) cladodes, *Acacia saligna*, wheat bran and cottonseed cake on feed intake, digestibility, growth and carcass characteristics of Central Highland goats. *Online Journal of Animal and Feed Research*. 14 (5): PP. 274-286; September 30, 2024.
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IV.To evaluate the influence of the concentrate substitution regime (using *Acacia saligna* and cactus cladodes) on semen quality, the meat composition, the semen quality and the physico-mechanical and chemical characteristics of leather derived from Central Highland goats.

Nutritional Evaluation of Cactus cladodes and Other Selected Browse Species and The Effect of Supplementation of *Acacia saligna* and Cactus cladodes on Performance of Goats in Eastern Zone of Tigray, Northern Ethiopia

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ABSTRACT

This research, conducted across the eastern zone of Tigray, Ethiopia, integrated four interrelated activities to enhance local goat production. The primary objectives were to: (1) assess the goat production system, cactus (Opuntia ficus-indica) production, and its utilization; (2) evaluate the nutritive value of five cactus cultivars (Dekik, Korem, Lematse, Tsaeda, and Keyh) and selected browse species; (3) evaluate the effect of supplementing with cactus cladodes, Acacia saligna, wheat bran, and cottonseed cake on performance goats; and (4) To evaluate the influence of the concentrate substitution regime (using Acacia saligna and cactus cladodes) on semen quality, the meat composition, the semen quality and the physico-mechanical and chemical characteristics of leather derived from Central Highland goats. A survey of 151 households in four districts (Wukro-Kilte-Awlaelo, Atsbi-Womberta, Ganta-Afeshum, and Saesie-Tsaeda-Emba) confirmed that goats are the predominant and most valuable livestock, primarily raised for breeding and subsequently for income generation. The average household kept 12.78 goats and had 15 years of experience. Feed resources varied by season, with natural grasses and browse used in the wet season, and crop residues, cactus cladodes, and browse dominating the dry season. Key browse species included Acacia abyssinica, Carisa edulis, Acacia saligna, and Dodonaea viscosa. Constraints to goat production included land, water, and labor shortages. Cactus is cultivated mainly as a food source, but 68% of households also feed it to their animals, often as a supplement to crop residues. The Keyh cultivar was the most abundant, widely utilized for food and feed, and had the highest fruit production potential. However, bloating from cactus feeding, often treated with dissolved detergent, was a major concern. Nutritive analysis of five browse species and five cactus cultivars showed considerable differences. Among browse, D. viscosa was superior, recording the highest crude protein (CP) content (17.73\%) and highest in vitro dry matter digestibility (IVDMD) (70.47\%) during the wet season. Among cactus, the Keyh cultivar showed the highest IVDMD (70.59\%), while Lematse had the highest CP (11.17\%) in the wet season. A feeding trial with 24 goats tested the replacement of concentrate (cottonseed cake, CSC) with cactus and Acacia saligna (AS); Goats on Treatment 4 (T4), which involved a partial replacement of 35 gDM CSC with 40 gDM AS and 80 gDM cactus cladodes (CC), showed the highest dry matter intake, average daily body weight gain, feed conversion efficiency, hot carcass weight, and dressing percentage. In the final experiment, goats supplemented with Treatment 3 (T3) (45 gDM CSC + 80 gDM AS) produced the highest quality semen, characterized by larger testicle size, higher progressive and mass motility, and higher semen concentration. T3 also resulted in higher goat meat fat content. Regarding leather, partially replacing CSC with either Acacia saligna or a combination of AS and CC produced leathers with physico-mechanical and chemical properties (e.g., tensile strength and tear resistance) comparable to those of goats supplemented with sole concentrate(containing 80 gDM/dayCSC) in terms of meat composition and leather characteristics.

Key words: Nutritive value, *Acacia saligna*, cactus cultivars, meat compsotion, leather, fat content, wheat bran, carcass characteristics

1. GENERAL INTRODUCTION

Livestock are generally recognized as vital tools for alleviating poverty among rural populations.Worldwide, about 800 million poor smallholder farmers own livestock and depend on them for their livelihoods. Livestock are living assets contributing to food security and are an important source of protein and minerals for nutritional security (Herrero *et al*., 2013). Ethiopia has a huge livestock resource in a variety of production systems ranging from pastoral to mixed crop–livestock systems with different levels of intensification. Goats, kept in all agroecological zones, are the major livestock species in Ethiopia with a population estimated at 52.5 million heads (CSA, 2021). For developing countries like Ethiopia where the demand for animal products continues to rise owing to a growing human population and economic growth, this livestock species, if properly managed, has great potential to raise food outputs, facilitate economic growth and enhance environmental benefits (Vanlauwe *et al*., 2014). In Ethiopia, goat meat is in high demand for domestic consumption as well as for the export market mainly to the Middle East countries (Teklewold *et al*., 2009). At the national level, they are important sources of foreign currency through live animal and meat export (FAOSTAT, 2019).

The major factors that affect the productivity of small ruminants are feed supply, genotype, animal management, policy and institutional constraints (Haile et al., 2018; Sheriff and Alemayehu, 2018). Almost all goats in Ethiopia are maintained by smallholder farmers and pastoralists who depend exclusively on grazing native pastures and utilizing crop residues as their only source of feed (Gezahegn, 2006; Birhan and Adugna, 2014).The low nutritional quality; the low crude protein) (<7%) and high fiber contents of native pastures and crop residues (Gashaw and Defar, 2017). These feedstuffs are insufficient to provide year-round supply of adequate quantity and quality of nutrients beyond maintenance and should be supplemented to enhance their nutritive value. Concentrates are also not affordable and inaccessible to most farmers and pastoralists in the country (Balehegn *et al*., 2020). Therefore, supplementation with browse foliage could be a viable alternative in smallholder livestock-crop mixed production systems.

The use of browse species as fodder for ruminants is increasingly becoming important in many parts of the tropics. Browse refers to leaf and twig growth of shrubs, woody vines, trees, cacti and other non-herbaceous plants that can be ingested by herbivores (Allen *et al*., 2011). Generally, browse fodder is richer in crude protein, minerals and digestible nutrients than grasses or cereal straws (Melagu *et al*, 2003; Kumara *et al*., 2009; Ogunbosoye *et al*., 2015). The use of browse fodder as a supplement has improved intake, digestibility and animal performance (Norton, 1994; Uguru *et al*., 2014; Bekele *et al*., 2022). Many browse species are important feed resources in dry areas of Ethiopia, especially for goats (Georgis, 2010; Abebe, 2010). In line with this, Yayneshet et al. (2008), reported that more than two-thirds of the feed ingested by goats in northern Ethiopia was composed of various browse species. Several important browse species, which are tolerant to drought and can survive over a wide altitude range, such as cactus (*Opuntia ficu-indica*), *Eculea schimperi*, *Dodoneae viscosa*, *Olea europea*, and the genus Acacia are widely grown in many dryland areas of northern Ethiopia (notably the Tigray region) and form a significant portion of the diet consumed by ruminants.

Among these, the exotic cactus is one most widespread and useful browse species of increasing importance that has been introduced in the region to combat feed and food insecurity, to support household income, and prevent land degradation (Georgis *et al*. 2010; Tegegne, 2007). Farmers use cactus extensively as an emergency forage that is harvested from both wild and cultivated stands to escape the consequences of feed shortage during the dry seasons and drought periods. In the Tigray region alone, wild cactus covered about 32,000 ha of land (Belay *et al*., 2011) and has become an integral part of the people's economy (Shushay, 2014). Cactus is highly valued because of its drought resistance, high biomass yield, palatability and ability to grow in poor soils. It is rich in energy and thus could partly help to solve the shortage of energy feedstuffs during the dry season and supplement low-quality forages grazed by ruminants (Salem and Smith, 2008; Desta, 2010;Gebretsadik et al., 2013;Ferreira et al., 2021; Ângulo, 2022).

The use of cactus fodder as supplementary feed has shown to improve intake, digestibility and performance when fed to sheep (Tegegne *et al*., 2007; Gebremariam *et al*., 2006 ; Costa *et al*., 2012; Alhanafi *et al*., 2019) goats (Costa *et al*., 2009 ; Taddesse *et al*., 2014; Gusha *et al*., 2015; da Silva *et al*., 2024) and dairy cows (Vilela *et al*., 2010; Pérez-Sánchez et al., 2015; dos Santos *et al*., 2022; De Lima *et al*., 2023). However, it is low to moderate in crude protein (Tegene, 2007) suggesting the need for finding potential fodder plants that can be combined with this plant. As such the use of native trees and shrubs (notably of tree legumes such as Acacia species that are abundantly available and whose pods and leaves are widely used as an important feed resource in the region) could partly help solve the shortage of protein in cactus and supplement low quality feeds grazed by ruminant livestock. Most acacia species can remain green and maintain their nutritive value throughout the dry period. They are rich in crude protein, energy, and digestible nutrients (Kandie, 2022) and thus are considered as important supplements to low-quality feeds like mature grasses or crop residues. Combining foliage from these trees with cactus can increase the utilization potential of the diet as a supplement. Acacia species remain one of the most valuable plants that provide a source of browse to ruminants during the dry season in the pastoral and agro-pastoral areas when grass becomes scarce and low in nutritive value (Ahn *et al.,* 1989; Bayssa *et al*., 2016; Retta *et al*., 2022). The combination of leaf and pod supplements enhances dietary intake, digestibility, and overall performance (Hashim, 1994). Therefore, offering a mix of tree fodder, such as *Acacia saligna*, along with cactus cladodes might result in superior animal performance compared to feeding either tree fodder or cactus cladodes individually.

Eastern Tigray experiences recurrent seasonal feed deficits and prolonged dry periods that reduce goat productivity (reduced growth, reproduction, and increased mortality). Farmers commonly rely on low-quality crop residues and communal grazing with limited access to protein-rich supplements. Although *Opuntia ficus-indica* is widely present in Tigray and other northern Ethiopian regions and several indigenous browse species are used by goats, quantitative information is limited on (i) the nutritional composition of locally available cactus and high-priority browse species in Eastern Tigray, and (ii) how inclusion of cactus and selected browse mixes affects feed intake, nutrient digestibility, growth performance, and carcass traits of growing goats under local management. Although *Opuntia ficus-indica* and many browse species have been studied in different Ethiopian regions, local variations in species composition, cultivar differences, soil/mineral status, and management practices mean that site-specific nutritive profiling and feeding trials in Eastern Tigray are needed. This will allow robust, practical recommendations adapted to local breeds and farmer systems. The evidence is also useful for the adoption of cactus-browse feeding strategies that could reduce the dry-season productivity gap.Therefore, the objective of this study was Nutritional Evaluation of Cactus cladodes and Other Selected Browse Species and The Effect of Supplementation of *Acacia saligna* and Cactus cladodes on Performance of Goats in Eastern Zone of Tigray, Northern Ethiopia with the following specific objectives;

- To conduct an assessment of the goat production system, browse species availability and the production and utilization of cactus in the cactus-dominated areas of the eastern zone of Tigray, north Ethiopia.
- To evaluate the nutritional value of cactus and other browse species from the Eastern zone of Tigray region.
- To evaluate the effect of supplementation of cactus (*Opuntia ficus-indica*) cladodes, *Acacia saligna*, wheat bran and cotton seed cake on feed intake, digestibility, growth and carcass characteristics of Central Highland goats
- To evaluate the influence of the concentrate substitution regime (using *Acacia saligna* and cactus cladodes) on semen quality, the meat composition, the semen quality and the physico-mechanical and chemical characteristics of leather derived from Central Highland goats.

2. GENERAL BACKGROUND

2.1. Goat Production in Ethiopia

Goats are among the major economically important livestock in Ethiopia. Ethiopia‘s large goat flock size was estimated to be 52.4 million (CSA, 2021), playing an important role in the livelihood of resource-poor farmers and the country’s economy. They provide nutritious food sources (meat, milk), provide additional income (through sale of skin and live animals) to the household and serve as a way to store capital and meet social obligations of the farmer. According to earlier estimates, nearly 2 million goats are exported yearly and 1.1 million goats are supplied to the domestic market in Ethiopia (ESGPIP, 2008). Goat meat is also becoming more and more popular in the Middle East and several African nations. A growing human population and economic shifts are also contributing to the rise in domestic meat demand (Legese and Fadiga, 2014). Goats also provide a significant contribution to the country's foreign exchange earnings through the export of hides and skins (Grumiller and Raza, 2019). The increased domestic and international demand for goats presents poor livestock producers with significant opportunities to increase benefits from their goats and raise income through livestock markets. In Ethiopia, goats exhibit remarkable adaptability to various climates and are present across all agro ecological zones and production systems. Their smaller body size results in reduced feed and space requirements compared to cattle. Additionally, the goat species do better under the adverse effects of climate change. Because of their unique characteristics, they are more resilient to the possible effects of climate change than other farm animals. Another benefit is that goats are preferred by small-scale, landless farmers in rural areas since they are a system that will increase productivity with less effort and infrastructure. (ESGPIP, 2008; Koluman, 2023).

Goats in Ethiopia are kept under extensive traditional systems of mixed crop-livestock in the highlands and pastoral and agro-pastoral production systems in the lowlands (Gebregziabhear et al., 2019). These extensive farming systems are characterized by limited use of purchased inputs (such as concentrate feeds) and low productivity per animal (Abate et al., 2012; Birhan and Adugna, 2014). The low productivity is manifested, among others, through stunted growth of young animals and longer time taken to reach market weight and reproductive age. The average carcass weight of Ethiopian goats, for example, is 10 kg, which is the second lowest in sub-Saharan Africa (Hirpa and Abebe, 2008). The human population growth and the associated demand for food crops in Ethiopia are forcing the conversion of many grazing lands into croplands (Mengistu et al., 2017). Under such circumstances raising small ruminants such as goats instead of large ruminants could match the limited available feed resources.

2.2. Feed Resources and livestock feeding system in Ethiopia

Livestock feed resources are natural pasture/grazing land, crop residue, improved pasture and forage, browse species, agro-industrial by product and other by-products like food and vegetable refusal, of which the first two contribute the largest feed types (Alemayehu, 2003; Abdirahin et al., 2015; Mulushewa et al., 2018; Abebaye et al., 2019; Boloche and Wato, 2022). In most highland areas of the country, the grazing land availability and its productivity become declining due to crop land expansion, inadequate technical support, and lack of appropriate management and sufficient input supply particularly forage seed production (Mengistu, 2004; Teshome, 2014). In Soro district of Hadiya zone, Southern Ethiopia during the dry season, (85.6%) of the respondents have used crop residues as the number one feed resource followed by hay (82.2 %) and industrial byproduct (65%). The results revealed that the majority of the respondents indicated that crop residues (wheat straw, teff straw, maize stover, barley straw, bean, and peas residues) were the important feed sources, especially during the dry season when the availability of pasture was low. But in the wet season, the respondents used natural pasture (88.9%), fodder trees (75%), and improved forages (71.7%) (Boloche and Wato, 2022). In Derashe district southern western Ethiopia the dominant livestock feed resources; (73%) is generated from the crop-residues, but small amount (23%) is contributed from the natural-pasture and only about (4%) of the livestock feed come from the improved-forage-crops (Chufa et al., 2022). In Sankura district, Silte Zone, Southern Ethiopia during the dry season, 90.9% of the respondents in the study district use crop residues as number one feed resource followed by hay (73.5%) and 56% of them use agro-industrial by product. In wet seasons, all the respondents (100%) use natural pasture followed by improved forage, pasture and fodder tree to feed their animals (Ahmednur Negash Juhar, 2023).

In different agro ecologies of Tigray, Northern Ethiopia the contribution of the major feed resources to the overall feed supply for ruminants varied. From the ranking of the available feed resources by the local farmers, weeds, crop residue, indigenous browse species and natural pasture stood first to fourth in the highlands during the wet season. During the dry season crop residue was the first in its contribution followed by indigenous browse species, hay and crop residues. Weeds were the first in its contribution during wet season followed by crop residue, indigenous browse species and natural pasture (Kibrom Gebremeskel et al., 2019). Livestock production dependent on crop residues, natural grazing, hay from grasses, indigenous browse species, and agro-industrial by products (Yayneshet, 2010). In Tanqua-Abergelle district of Tigray, Northern Ethiopia crop residues, natural pastures, and stubble grazing are ranked as the major cattle feed resources based on their priority. During the wet season, natural pastures are the main feed resources for cattle and followed by crop residues and green herbages. Sheep and goats are made to graze on the natural pastures. Crop residues are not offered usually for small ruminants in the wet season. The farmers do not concern more about small ruminant feeding, as they can graze/browse themselves in the hillside, riverside, and around homesteads. However, during dry season, limited amount of crop residues and hay is supplemented to the small ruminants. Sampled farmers ranked crop residues (82%) to be the first most important feed resources during the dry season while about 10% ranked the same feed as the second most important feed for their animals (Gebremariam and Belay, 2016).

2.2.1. Natural pasture

Animals depend mainly on natural pastures for their feed requirements. Natural pastures that provide more than 90% of the livestock feed are generally very poorly managed (Bikila and Tigist, 2016).Many researchers agreed that natural pasture comprises the largest share from livestock feed, but estimates of the contribution of this feed resource vary greatly. In highland natural pasture account as 49% of all feed resources (Yami et al., 2012). The distribution of such natural vegetation varies from place to place depending on climatic variation. The study in central highlands of Ethiopia also the contribution of natural pasture was 56.5% (Worku, 2017). Natural pasture lands/ rangelands become degraded because of expansion of cultivation, conflict, water pond development and settlement. Generally, dry land ecosystems are subject to increasing land use changes as human need for food and natural resources rise, which eventually contributes to climate change (Grover et al., 2011). A significant proportion of grazing lands in pastoral areas have been encroached due to crop cultivation, ranching, year round grazing, settlement and shortage of rainfall (Angassa and Oba, 2008). The CP content of natural pasture ranges from 6.25% to 7.9% in dry season and 9.2%-10.4% in wet season and NDF content of natural pasture ranges from 67.2%-70.5% in dry season and 54.4% o 57.1% in wet or rainy season. The *in vitro* DM digestibility content of dry season grasses ranged from 53.7% to 55.7%. Similarly, the *in vitro* DM digestibility content of rainy season grasses ranged from 62.3% to 66.9% (Geremew et al., 2017; Mamo et al., 2023). The metabolizable energy content of grasses in dry season ranged from 8.1 to 8.3. Likewise, metabolizable energy content of rainy season grasses ranged from 9.3% to 10.0% (Mamo et al., 2023).

2.2.2. Crop Residues

Crop residues are abundantly produced in almost all parts of the world where there is crop production is produced. Cereal straws such as Teff, barley, wheat and pulse crop residues are stalked after threshing and fed to animals during the dry season when the quality and quantity of available feed from natural pasture declines drastically in different parts of the Ethiopia (Ketema, 2014). The sizes of farm holdings for crop production were highly variable, ranging from 0.5 hectare to 5 hectare. Crop residues (cereal straws or stovers and grain legume haulms) are becoming increasingly important as sources of roughage feeds for ruminants. The actual quantities of crop residues available for livestock feeding depends on costs of collection, transport, storage and processing, seasonal availability, other alternative uses and wastage. The nutritive value of crop residues is variable depending, among others, on the species and variety of the crops, time of harvest, handling and storage conditions and other factors. Cereal straws and stovers generally have relatively low nutrient content, high fiber content, low digestibility, and low voluntary intake. Most cereal straws and stovers have lower nutritive value than the haulms from grain legumes and/or vines from root crops such as sweet potato. Thus, without supplementation, crop residues cannot satisfy even maintenance requirements of animals primarily because of low N and high cell wall contents and slow digestion (Adugna, 2012; Gashaw and Defar, 2017).

In Guji Zone of Southern Oromia, Ethiopia during the rainy season, crop residues were used to augment the limited nutrients acquired from communal grazing areas. According to the information acquired from group conversations, crop residue feeding begins in February and continues until July shortly after crop threshing, primarily in highland areas. Crop residue is the second (2^{nd}) most common source of livestock feed for 40.6% of crop producers in the study areas, including 40.6% from the highlands, 39.9% from the midlands, and 15.5% from the lowlands. Crop residue from different crops (tef, maize, wheat, barley) was fed to livestock by 40.6% and 39.6% of highland and midland respondents, respectively (Jabessa, 2024). In general, crop residues and natural pasture are the major feed resources of the study area which was agreed with the result of (Feyisa and Dejen, 2017; Chufa et al., 2022). The CP contents of crop residues ranged from 2.1% to 6.7%. The NDF contents of crop residues ranged from 58.1%-77.5%. The crop residue IVDMD ranges from 41.92%- 59.42 (Geremew et al., 2017; Gashaw and Defar, 2017). The crop residues of the IVDOMD content ranged from 43.7% to 57.0 %. The metabolizable energy content of crop residues ranged from 7.2 % to 8.5% (Mamo et al., 2023).

2.2.3. Improved Fodder Plants

Improved pasture and forages play varying role in different livestock production systems. In general, they are important as adjuncts to crop residues and natural pastures and may be used to fill the feed gaps during periods of inadequate crop residues and natural pasture supply. Even in the presence of abundant crop residues, which are often free fed to ruminants, improved forage crops especially legumes are needed to improve the nutritional values of crop residues (Yami et al., 2012). Use of improved forages represents less than 1% of the total livestock diet (CSA, 2017).

Cultivated forage crops growing in the Eastern zone of Ethiopia are sesbania, leucaena, Napier grass, alfalfa, tree lucerne, vetch, cowpea, lablab and pigeon pea.(Tesfay et al., 2016). However, in southern Tigray Ethiopia, the type of improved fodder crops introduced were oat-vetch, tree lucerne, elephant grass and Falaries grass. The common local feed resources were hay, cereal crop residue, vegetable residues and atela (liquid left over after preparing a local drinking from sorghum, maize, barley, finger millet crops). All farmers feed introduced forage plants to their animals in some way or another. The ways of feeding, however, varied among the farmers. Majority of the farmers (65%) fed oat-vetch to their cow. The other 22.5% and 12.5% of the respondents fed oat-vetch to their oxen and sheep respectively. Tree lucerne (77.8%) and elephant grass (70%) were mainly provided to oxen. This also might be due to the fact that oxen are usually used for draught power hence they need more energy and these two feeds have high energy content and supply oxen with more energy to perform better on draught power. Separate feeding by the function or purpose of animal is a common practice and has production and reproduction benefits. Phalaris grass is introduced by a few farmers and all of them (100%) provide to their cow. Improved fodder crops including oat-vetch, tree lucerne and elephant grass were the principal supplementary feed resources mainly for cows and oxen in both dry and wet season. However, feeding sheep with these fodder crops was practiced by a few of the interviewed farmers in the study area. As reported by most of the respondents, oat-vetch, and tree lucerne and elephant grass were predominantly used as supplements of green feeds in dry season; because natural pastures are dried and lose their nutrient content in this season. However, for a considerable number of farmers these fodder crops were year round source of green (supplementary) feed sources. Oat-vetch was the most accessible fodder crop year round in most of the interviewed farmers as compared to the others and most of them fed for cows. This might be due to the interest of the farmers to collect more milk and produce more butter to sell for disposable cash incomes (Hailesilassie, 2016). Improved forages also provide benefits such as soil fertility through their nitrogen fixing ability and reducing soil erosion (Yami et al., 2012). Due to its positive biological impact on degraded lands the government of Ethiopia has given due attention in stock exclusion and watershed areas.

2.2.4. Browse species or fodder and their Chemical composition

Fodder forage for ruminant feeding are generally defined as the plant materials, primarily leave and stems, wild or grown for either direct consumption by ruminant or preserved for feeding of such animals (Heady, 1975). Fodder and shrubs are important components of ruminant diet and they have been found to play important roles in the nutrition of grazing animals in areas where few or no alternatives are available (Van et al., 2005). Trees and shrubs have long been considered as important sources of nutrition for grazing animals especially in areas with a pronounced dry season. The wealth of potential tree fodder is enormous and they are an effective insurance against seasonal feed shortages, supplementing the quantity and quality of pasture compounds (Lefroy et al., 1992). Fodder trees, which are one of the benefits of agroforestry, are less affected by seasonal dry conditions because of their more extensive root systems and longer life spans (Abel et al., 1997). As a major source of animal feeds in Africa, fodder trees and shrubs are highly valued by farmers. These forage species contain appreciable amounts of nutrients that are deficient in other feed resources such as grasses during dry seasons and dry periods. They have deep root systems enabling the extraction of water and nutrients from deep in the soil profile (Aregawi et al., 2008).

The leaves of all browse plants were more preferred than the other plant parts. Feeding leaves and twigs of indigenous trees for livestock, especially during the dry season, is a coarse pattern in southern Ethiopia (Deribe, 2015). Certain browse species retained leaves late in the dry season, whereas others shed leaves early in the dry season. According to the group discussion, livestock herders in the district (especially lowland area) preferred those browse species, which could retain leaves late in the dry season so that more feed may be provided at critical times of the year when there is less fresh vegetative biomass available for feeding to stock (Atsbha and Wayu, 2020). In southern Tigray the overall contribution of browse species surpasses 20-60% (dry season) and 22.8-65% (wet season) of the animals feeds presently utilized by smallholder farmers (Atsbha and Wayu, 2020). The result showed that 97.8% of respondents used browse fodder trees and shrubs as feed resources from trees and shrubs planted at their backyard, farmland, and naturally grown plants in the study areas. The sample farmers indicated that they gave priority in feeding of fodder trees and shrubs for fattening beef and goats, weak animals, draft animals and lactating cows. The study in Daro Labu district, Western Hararghe Zone assessment shows that 83.3% of the respondents use green fodder tree and shrub leaves during dry season, 14.4% use during both dry and wet seasons, and only 2.2% of the respondents feed these plants during wet season (Debela et al., 2017). Leaves, pods, twigs and fruits were the plant parts utilized by domesticated animals. In conclusion, browse species have a major role within the feeding of animals and alternative commendable typical uses. More farmers should be urged to develop these trees and shrub fodder species to keep away from the eradication of acceptable trees for reasonable use (Atsbha and Wayu, 2020). The mean CP content of the indigenous browse species 16.4% DM; ranged from 8.13% DM to 24.34% of their leaves. Most of the browse species had high CP content and the majority containing above 15% in DM basis. The NDF content of indigenous browse species ranged from 12.9% DM to 45.89% DM (Gemiyo et al., 2013).Indigenous browses species have higher CP content compared to grasses and crop residues sampled in this study. This confirms previous reports that indicated higher CP contents of indigenous browses in Ethiopia (Getnet, 2003; Bogale et al., 2008; Mekonnen et al., 2009; Melaku et al., 2010) and other tropical countries(Njidda and Ikhimioya, 2010; Boufennara et al., 2012). Aynalem and Taye (2008) have shown that the levels of CP ranged from 18.62 to 24.44% among indigenous browses. The use of browse species as a fodder for ruminants can overcome the protein deficiency in the basal diet, complement crop production and improve overall productivity system (including the crop sector) from the same land (Mekoya, 2008; Balehegn et al., 2020).Most browse plants have high crude protein content, ranging from 7.8% to more than 25% on a dry matter basis (Moleele, 1998; Fentahun *et al*., 2020; Belete *et al*., 2024). This reliable protein resource can be used to develop a sustainable feeding system and increase livestock productivity, because its protein content is above the maintaenance requirement of ruminant animals.

Table 1 displays the chemical compositions of the various tree and shrub species. *Acacia saligna* had an NDF content of 41.1–51.44% and a CP content of 12.1–16.8% (Meneses R *et al*., 2013; Taddesse *et al*., 2014; Yirdaw *et al*., 2017). The CP content of *Olea europea* ranges from 8.84-12.9% and its NDF content ranges from 36.2-41.46% (Shenkute *et al*., 2012; Girma *et al*., 2015; Ibrahim *et al*., 2016; Altop *et al*.,2018; Ali *et al*., 2020; Lee *et al*., 2021; Abrham *et al*., 2023) and twigs and leaves of Olea europea contains 65% DM, 92% OM, 4.2% CP, 3% EE, 48% NDF, 4.5MJ/kgDM ME(Alkhtib et al., 2021). According to these values, *Olea europea's* CP content is higher than the maintenance requirement (more than 7%), its NDF content falls between medium and high quality feeds (Singh and Oosting, 1992), and its energy content is comparable to what is needed for a goat weighing 15 kg and gaining 50g per day (Kearl, 1982). *Carisa edulis* has an NDF content of 44.25–60.7% and a CP content of 9.3–13.27% (Girma et al., 2015; Ali et al., 2020; Fantahun et al., 2020; Desta, 2024). According to these findings, *Carisa edulis's* CP content was more than what ruminant animals needed for maintenance, much like *Olea europea*. *Dodoneae viscosa* has an NDF content of 29.76–35.015% and a CP content of 8.28–18.46% (Riaz and Chaudhry, 2016; Mengistu *et al*., 2017; Ali *et al*., 2020). Based on its NDF content, *Dodoneae vicosa* was classified as a high-quality feed since its CP content was significantly higher than the maintenance requirements of ruminant animals and could maintain development and lactation (Singh and Oosting, 1992). *Eculea racemosa* (*schimperi)* has a CP level of 6.9–7.61% and an NDF content of 56–56.34 percent (Mengistu et al., 2017; Ali et al., 2020). According to these values, *Eculea racemosa's* CP content satisfies ruminant animals' minimum maintenance requirements, and its NDF content places it in the category of medium-quality feeds. All the browse species had a CP concentration higher than what ruminant animals needed for maintenance, as shown in Table 1.

Table 1. Chemical composition of tree/shrub species

Tree /shrub species	DM %	Chemical Composition(%DM)						Source
		Ash	CP	EE	CF	NDF	ADF	
	91.9	9	16.8			40.1	28.6	Meneses R et al. (2013)
Acacia saligna	90.3	15.74	12.1			51.44	38.96	Taddesse et al. (2014)
	93	14.5	14.2			44.29	32.02	Yirdaw et al. (2017)
	91.8	6.53	11.9			41.2	28.8	Girma et al. (2015)
	91.26	5.22	10.1			39.9	25.8	Abrham et al.(2023)
Olea europea		8.28	10.8			38.82	27.5	Lee et al. (2021)
		6.4	12.9	2.4	27.8	38.8	26.9	Altop et al.(2018)
	96	5.2	8.8			41.46	31.25	Ali et al. (2020)
	49.5	6.8	10.6	7.9	14.5			Ibrahim et al. (2016)
	93.4	7.4	8.9			36.2	29.5	Shenkute et al. (2012)
	92.6	9.06	9.47			44.25	27.7	Girma et al. (2015)
Carisa edulis	96	7.3	9.3			55.52	42.72	Ali et al. (2020)
	92.4	6.7	10.9			60.7	40.95	Fantahun et al. (2020)
	93	7.78	13.2			51.77	37.63	Desta, 2024
	92.17	5.35	10.78			29.76	21.62	Mengistu et al.(2017)
Dodoneae vicosa								
	92.24	5.78	8.28	1.71		31.10	21.04	Riaz and Chaudhry (2016)
	95.5	5.75	18.4			35.015	25.13	Ali et al 2020
Eculea racemosa(schimperi)	90.86	5.31	6.9			56	50	Mengistu et al. (2017)
	96	6.25	7.6			56.31	45.83	Ali et al. (2020

DM=dry matter; CP=crude protein; NDF=neutral detergent fiber; ADF=acid detergent fiber; Ether Extract

2.2.4.1 Effect of Supplementation of Browse Species on Performance of Animals

Acacia cyanophylla (Acacia saligna) is a leguminous shrub which provides large amounts of fodder for ruminants in arid and semi-arid regions (Ben Salem et al., 1999; Safinaz et al., 2010;

Gebru and Tesfay, 2017). *Acacia saligna* is one of the introduced browse shrub or tree species, which is widely grown and evergreen in different agro-ecological zones of Tigray (Shumuye and Yayneshet, 2011; Gebremeskel Abraha, 2016). The relatively high crude protein content of *Acacia saligna* (Moujahed *et al*., 2000) makes it a promising supplement to the mostly low-quality fibrous feeds used by smallholder farmers; supplementing *Acacia saligna* with concentrate feed improves the performance of Somali goats (body weight gain of 16.67 g/d and feed conversion efficiency of 0.028 (Taddese *et al*., 2014); supplementing *Acacia saligna* with wheat bran improves the performance of Begait sheep (body weight gain of 59.3 g/d and feed conversion efficiency of 0.08, hot carcass weight of 15 kg (Yirdaw *et al*., 2017); and supplementing *Olea europea* improves the performance of sheep) (average daily weight gain of 37.2-41.8 g/d and feed conversion efficiency of 0.05-0.07, hot carcass weight of 8.5-9.1 kg for sheep) (Abraham, 2023). However, Alkhtib *et al*., (2021) reported higher average daily weight gain (142-144g/d), and lower feed conversion ratio of 6.34-6.45 for Shami goats supplemented urea treated twigs and leaves of *Olea europea*. Supplementation of *Eculea schimperi* to T.swana goats results in higher average DM intake(g) (752g/day) than goats fed on control (Lucerne and Buffel grass) (702.2g/day) and comparable average body weight gain to goats fed on other treatment diets (Aganga and Tshwenyane, 2003).The difference in the performance of small ruminants as reported by different studies might be due to the difference in livestock species (goat, sheep), Breed (Shami, Sidama) type of the browse species (*O.europea*, *E.schimperi*, *A.saligna*), the environmental condition, the amount and type of feed supplement used in the experiment.

2.2.5. Agro-industrial by-products

Agro-industrial by-products have special value in feeding livestock mainly in urban and peri-urban livestock production system, as well as in situations where the productive potential of the animals is relatively high and require high nutrient supply. The major agro-industrial by products commonly used are obtained from flour milling industries (wheat bran, wheat short, wheat middling and rice bran), edible oil extracting plants (nougseed cake, cottonseed cake, peanut cake, linseed cake, sesame cake, sunflower cake etc), breweries and sugar factories (Molasses). The current trends of increasing urban population has a significant effect on the establishment of agro-industries due to the corresponding increasing demand for the edible main products(Shibru, 2012;Chalchissa et al., 2014; Feyisa et al., 2024).

2.2.5.1. Chemical Composition and Supplementary Value of Cotton Seed Cake

Cotton seed cake, like other oil seed meals is obtained after the oil has been extracted from the cotton seed using either of two common methods of extraction, namely, expeller extraction (mechanical) and solvent extraction (chemical). Cotton seed cake contains the range values of 24.51% to 33.8% CP, 34.4% to 60%NDF, and from 5.46% to 9.1% EE (Solomon et al., 2008; Alemu et al., 2010; Barman et al., 2018) and 8.9-9.4 MJ/kg DM ME (Redae et al., 2020 and Makun et al., 2016). Cottonseed meal is one of the richest feeds in phosphorus, containing about 1% or more. In contrast to the high phosphorus content, it has only about 0.2% calcium. Cottonseed meal is used as a source of protein in concentrate mixture, rather than as the only supplement.

Cottonseed has a thick coat or husk, rich in fiber and of low digestibility, which lowers the nutritive value of the diet (McDonald, 2002). It may be completely or partially removed by cracking and riddling, a process known as decortication. Removal of the husk lowers the crude fiber content and has an important effect in improving the apparent digestibility of the other constituents. As a result, the decorticated cake's nutritional value is much higher than the undecorticated cake's. Supplementation of cottonseed cake to Sidama goats' resulted in hot carcass weight of 8.9 kg and average body weight gain of 62.2 g/d (Alemu et al., 2010). Similar to this, supplementation of cottonseed cake to White Borno goats (fed groundnut haulm and guinea grass) improves CP intake (100-140g), feed conversion efficiency (0.0128-0.018), and live weight gain (12.46-12.55g) (Makun et al., 2016). When small ruminants are fed with large amounts of cottonseed meal, there is danger of cottonseed meal injury, unless they are offered plenty of good legume hay or other roughages (Webb-Ware and Hides, 2010; Wachiebene, 2021). A major constraint to the use of cottonseed and cottonseed meal as feedstuff is the presence of toxic constituents of gossypol, a yellowish pigment that occurs in seeds. Although ruminants are more resilient to gossypol, they can nevertheless suffer liver and heart damage from eating whole cotton seed for weeks or months at a time (Rogers et al., 2002; Cope, 2018).

2.2.5.2. Chemical Composition and Its Supplementary Value of Wheat Bran

Wheat bran is an important source of carbohydrates, protein, minerals and vitamins and considered as one of the feeds that can be used for fattening. Wheat bran is usually a cheap agro-industrial by-product that can be used in animal feeding and is readily available (Alemu et al., 1989). The CP content of wheat bran ranges from 15.9% to 19.19% as reported by differrent researchers (Tadesse et al., 2015; Yirdaw et al., 2017; Kumsa et al., 2019; Redae et al., 2020; Mamo et al., 2021; Gebretsadik et al., 2024), which is adequate for lactating and growing animals (Norton, 1982). According to Singh and Oosting (1992), wheat bran could be classified as high quality feeds. Previous research showed that the NDF content of wheat bran ranges from 25.54-44.76% (Tadesse et al., 2015; Yirdaw et al., 2017; Kumsa et al., 2019; Mamo et al., 2021; Gebretsadik et al., 2024). The metabolizable energy (ME) content of wheat bran also ranges from 10 to 11 MJ/kg DM (Redae et al., 2020). This exceeds the Metabolizable Energy needed for a goat weighing 15 kg and an average body weight gain of 50g per day (Kearl, 1982). TDN content of wheat bran ranges from 71.3-72.24% (Redae et al., 2020; Gebretsadik et al., 2024).

Wheat bran supplementation enhances the performance of small ruminants, such as sheep and goats. According to Kumsa et al. (2019), Borena goats supplemented with wheat bran and various protein sources gained an average of 59.71–76.20 g/d of body weight per day. Gebretsadik et al. (2024) found that supplementing sheep with concentrate (66% wheat bran and 34% noug seed cake) instead of cactus meal (from 49-198g/head/d) and fed a basal diet of grass hay resulted in an average daily body weight gain of 58-67.22 g/d. Tadesse et al. (2016) reported daily body gain of 38.7 and 50.9 g/day for Ethiopian goats (Bati, Short ear somali and Hararghe highland) supplemented low and high concentrate (noug seed cake (23%), maize (19%) and wheat bran (57%) mixture at 1-1.5% of their body weight) level respectively and fed on hay basal diet. Similarly Yirdaw *et al*. (2017) reported Begait sheep supplemented with 200 g wheat bran and other protein sources (100 g cotton seed cake, 180 g cow pea, 250 g *Acacia saligna*, and 140 *Sesbania sesban* leaves) and fed grass hay as their basal diet showed an average daily body weight gain of 49.17–70.5. Redae *et al*. (2020) also found that supplementing Abergelle goats with wheat bran and other protein source feeds resulted in an average daily weight gain from 20.56 to 31.3 grams/day and a feed conversion efficiency of 0.03-0.048 (g ADG/g DMI).

2.2.6. Feed Value of Cactus Cladodes

More than 83% of households that reported cactus as an important feed supplement are from the eastern zone of Tigray. The cladodes/pods of cactus pear are traditionally used as livestock feed during normal dry season and drought periods, and can be included up to 60% level (Firew et al. 2007).Cactus provides excellent palatability and digestibility while minimizing the water requirements for livestock. Nevertheless, it is essential to combine cactus with other feed sources to ensure a balanced daily diet, as it is deficient in protein despite being abundant in carbohydrates and calcium (Nefzaoui and Ben Salem, 2002). Livestock can consume substantial amount of cladodes; for example, cattle may consume between 50 to 70 kg of fresh cladodes daily, while sheep may eat around 6 to 8 kg per day. The energy content of cladodes is approximately 2.28 Mcal (9.53 MJ)/kg DM (Flores-Hernandez et al., 2019). Cladodes can serve as a cost-effective supplement, particularly for the rearing of sheep and goats in rangeland environments. When cladodes are associated with a protein rich feedstuff, they may replace barley grains or maize silage without affecting body weight gains of sheep and cattle (Elsheikh *et al*., 2023). For instance, milk yield for lactating goats supplied with 2.2 kg alfalfa hay/day is actually slightly higher (1.080g/day) when 0.7 kg cladodes replaces an equal mass of alfalfa (Nefzaoui, 2010). Lack of water can negatively affect the feed consumption, digestion, and consequently the weight gain of sheep and goats. Therefore, it is essential to provide livestock with water during dry season and periods of drought in hot arid regions. Animals expend significant energy to access water sources. As a result, the high moisture content found in cladodes serves as an effective solution for raising livestock in arid environments. Indeed, animals that have access to ample supplies of cladodes need minimal to no extra water (Nefzaoui and Ben Salem, 2002).

Soluble carbohydrate-rich feeds like molasses and cactus improve diet palatability and enhance rumen fermentation, usually leading to an increase in TDM intake and/or diet digestibility. Depending on the diet composition, feeding cactus results in increased apparent organic matter (OM) digestibility of the diet or has no effect on this parameter. Research carried out in Ethiopia

(Gebremariam *et al*., 2006; Tegegne *et al*., 2007), Tunisia (Ben Salem *et al*., 2004; Abidi *et al*., 2009a), and Brazil (Costa *et al*., 2012) indicated that the organic matter digestibility of the diet increased by 2-10% in lambs and kids fed with cactus compared to those on cactus-free diets. This enhancement may be attributed to better rumen fermentation.The provision of cactus to Ethiopian lambs fed on teff straw or pasture hay resulted in a decrease in the apparent crude protein digestibility of the diet. Gebremariam *et al*. (2006) claims that the decreased CP apparent digestibility with increased cactus inclusion rate could be explained by the total tannin content of cactus. Indeed, tannins have great affinity with proteins, making them unavailable for rumen microflora and the host animal. However, Costa *et al*. (2012) reported an increase of 13% in the CP digestibility of lamb's diet. Similiarly, Souza *et al*. (2009) also reported high values of CP digestibility (77-80%) in bucks receiving Cynodon hay, cactus and soybean hulls. Ben Salem *et al*. (2002b), Gebremariam *et al*. (2006) and Misra *et al*. (2006) observed no effect of cactus on fiber (NDF) digestibility in the diet. Costa *et al*. (2012) report a positive impact of cactus on NDF digestibility−an increase of 20% in NDF digestibility with a cactus-containing diet, compared with the control (cactus-free) diet given to lamb. Final body weight, hot and cold carcass weight were higher in animals fed cactus pear containing diets (Balduíno da Silva *et al*., 2021). The supplementation of spineless cactus with Leucena hay associated improves performance, weights, and yields of the carcass, commercial cuts of goats grazing in the rangeland (Oliveira *et al*., 2022). Supplementation of cactus cladodes and browse species hay improves performance of goats (Gusha *et al*., 2014). In contrast to this hot carcass yield (%) and cold carcass yield (%) of lambs fed on spineless cactus (42-44%) were lower than lambs fed on ground corn (45-46%). However, average daily body weight gain and DM, CP and NDF intake and feed efficiency, of lambs fed on ground corn are comparable to lambs fed on spineless cactus

(Alves *et al*., 2023). As reported by Gebretsadik *et al*. (2013) the intervieweed farmers in Tigray region (Ethiopia) believed that cactus feeding increase milk yield and body weight gain of animals. In brief, cactus supply has no negative effect on diet digestibility and may even improve it.

2.3. Constraints that Limit Use of Cactus as Livestock Feed

Naturally cactus cladode contains high amount of water and have the potential to save water and it becomes green throught the year and used as source of feed in arid and semi-arid areas. However, presence of high amount of water in cactus cladodes decreases DM intake of sheep especially at 80% of cactus cladodes inclusion (Tegegne *et al*., 2007). There is some evidence that feeds with a particularly high content of water bound within plant tissues promote a lower DMI than comparable feeds of lower water content (McDonald *et al*., 2002; Gebremariam et al., 2006). Having high water content (850-90g/kg fresh cactus) incurred transportation costs /very expensive to transport by the farmers as well as some times result in diarrhea and bloating to animals upon consumption, drying also takes long time as well as it might decrease its nutritional content. A practical drying method will also enable farmers with small cactus pear orchards to store pruned and dried material as a feed for their livestock (De Waal *et al*., 2006). Even though, cactus cladodes had high digestible nutrients (carbohydrate) and minerals (calcium), it is low in crude protein, fiber and minerals (sodium and phosphorus) content (Mokoboki and Sebola, 2017). Hence, animals cannot stay by feeding cactus cladodes as the sole feed without supplementation of other feed resources. Furthermore, if animals fed exclusively with cactus pear, it might result in weight loss, decreased milk fat (Santos *et al*., 1990). Thorny (spiny) dominates over spineless cactus in rangelands of Tigray by 78.7 % to 21.3%, respectively. Both spiny and spineless cacti were used as animal feed at time of critical feed shortage. Farmers burn the spiny cactus plant to remove the spines. This usually consumes the time, energy, and also affects the resource efficiency of the farmers (Desta, 2010). If cactus fruits are available sheep, goat and cattle can consume but the small spines that occur on the fruits can pierce and irritate the membranes of the digestive tract of ruminant animals (cattle, sheep and goat). Small spines can also cause severe inflammation that interferes with digestion and results in loss of condition and death often follows. This has contributed to the reluctance by livestock farmers to use the plant in ruminant feed (Makumbe, 2010).

The majority (75%) of the respondents reported that animals fed spineless cactus were more vulnerable to diarrhea and bloating as compared to those fed the spiny variety. The justification for this, according to respondents, is that during spine burning some of the moisture content of the spiny cladodes might be lost through evaporation (Gebretsadik et al., 2013). However, Abdi et al. (2009) reported that gas production from spineless and spiny cladodes was similar in both the dry and wet seasons. The exclusive use of cactus pear in animal diets can cause nutritional disorders in animals, such as diarrhea, foamy bloat, and ruminal acidosis (Santos et al., 2010). Numerous authors associate these nutritional disorders with diminished levels of physically effective neutral detergent fiber (NDFpe) in cactus pear (Paulino et al., 2021; Pinho et al., 2013). However, the appearance of nutritional disorders in ruminants fed high levels of cactus pear is also related to microbiological factors regarding poor hygienic quality, such as handling and exposure of crushed cactus pear to air for a long time, which can provide a greater intake by animals of certain bacterial groups with pathogenic potential, for example, the order Enterobacteriales, responsible for diarrhea (Paulino et al., 2021). Considering that cactus pear is rich in water, when it is chopped and exposed to air for hours during the animal feeding it could allow microorganisms access to moisture and nutrients, leading to a microbial contamination.Thus, it is important to use fiber rich feed sources like hay or forage in diets based on cactus pear, as it implies in reducing the incidence of nutritional disorders not only by improving the NDFpe of the diet, but possibly also by reducing both moisture and soluble carbohydrate content (Pinho et al., 2013). Eating cactus fruits and cladodes with spines and glochids was reported to result physical injuries and lodging in the gastro intestinal tract, which may lead to bacterial infections (Mengistu 2001; Firew 2007; Nefzaoui et al 2010).

3. SUMMARY OF MATRIALS AND METHODS

The study combined household survey (involving field observation, individual interviews and focus group discussions), laboratory analyses (chemical composition of feed ingredients, meat composition, leather chemical characteristics, nutritional value of cactus cultivars and selected browse species).

3.1. Description of the Study Area

The household survey and forage sampling were conducted in the Eastern zone of Tigray region located in northern Ethiopia (Figure1). The area is located between 13°33′ to 14°40′ N and 39°11′ to 39°59′ E. The total area of the zone is 561,000 ha, which is divided into seven districts: Erob, Hawzen, Wukro, Atsbi-Womberta, Ganta-Afeshum, Gulo-Mekeda, and Saesie-Tsaeda-Emba. The altitude ranges from 1500 to 3280 m above sea level. The study area has three traditional agro-ecological zones: (i) highland, with areas over 2300 m above sea level; (ii) midland, between 1500 and 2300 m above sea level; and (iii) lowland, with areas less than 1500 m above sea level (Meles *et al*., 1997). A large part of the study area is situated in Highland or Dry Dega, followed by Midland or Dry Weinadega. The area has a semi-arid climate and receives a bimodal rainfall: the main rainy season (June–September), locally known as Kiremt and a small rainy season (February–May), locally known as Belg. The rainfall is highly variable due to the complex influences of topography (Meles *et al.* 1997). The mean annual rainfall ranges from 520 to 680 mm, and the mean annual temperature varies between 16 and 20 °C (Kahsay *et al*., 2019).

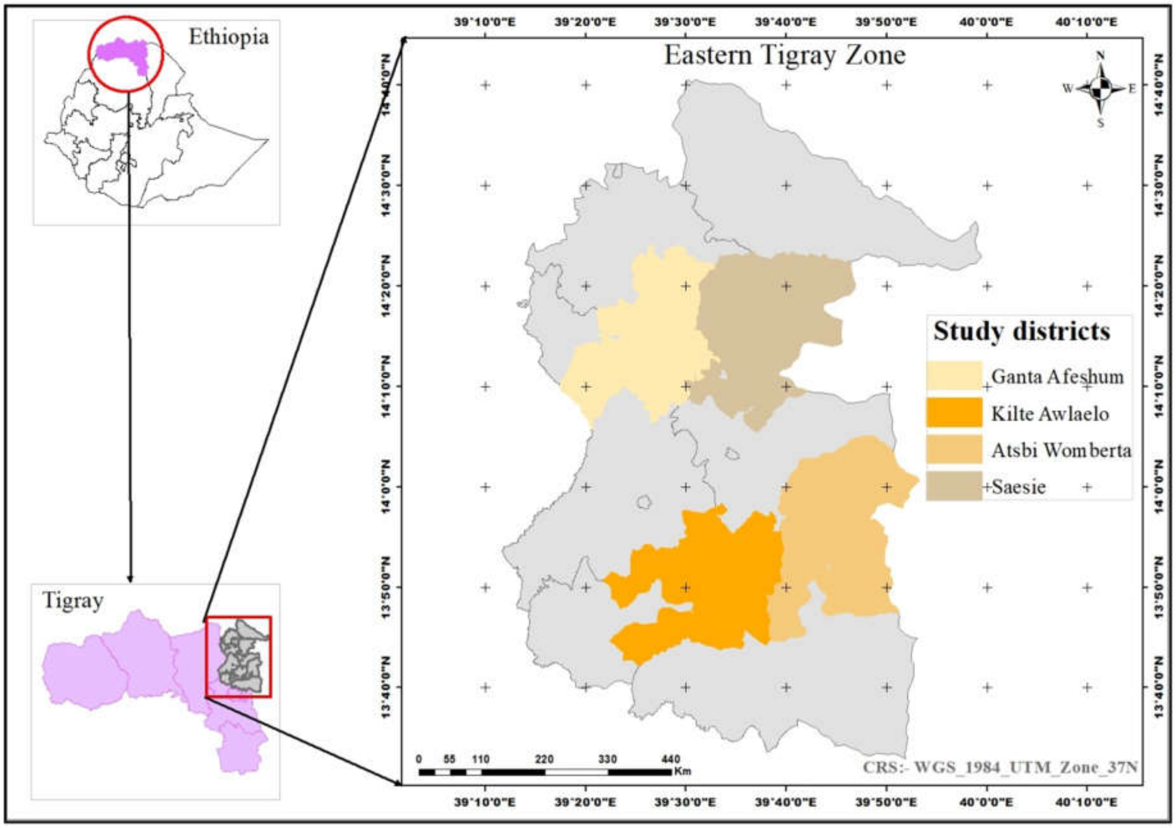

Figure 1: Map of the study area

3.2. Surveying, Forage Sampling and Chemical Analysis

A household survey was conducted in four districts (Wukro-Kilte-Awlaelo, Atsbi-Womberta, Ganta-Afeshum, and Saesie-Tsaeda-Emba) from the eastern zone and these districts were purposively selected based on the goat population, cactus production potential. Again two kebeles from each district a total of eight kebeles; Kokeb Tsibah and Gola-Genahti (Ganta-Afeshum), Adega-Durhara and Emba-Esmeina (Saesie-Tsaeda-Emba), Era and Kelisha (Atsbi-Womberta) and Adikisandid and Sherafo (Wukro-Kilte-Awlaelo) were selected through purposive sampling procedures based on goat population and cactus production potential.

Besides to cactus, there are many tree and shrub species browsed as forage in these areas including the genus Acacia; *Acacia saligna, Acacia Abyssinia* and *Acacia etbaica*, *Carisa edulis*, *Sageretia spiciflora*, *Maytenus obscura*, *Dodonaea viscosa* and *Becium grandiforum*. The sample size for the household interview was determined using the formula recommended by Kothari (2004) and 151 households were interviewed (**Paper I**).

Based on the survey results, the five most abundant and widely used as browse species by the farmers, (*A. saligna*, *C.edulis*, *D.vicosa*, *O.europea* and *E. schimperi)* and five cultivars of cactus were selected to evaluate their nutritional value. Samples of cactus cultivars were collected from two districts; Ganta-Afeshum (i.e. Kokob Tsibah kebele) and Saesie-Tsaeda-Emba (Emba-Esmena kebele) while samples of the leaves tree/shrub species were collected from Atsbi-Womberta district (Kelisha kebele). The samples were collected in the dry and wet seasons in the study area. Cladodes (young leaves) from five cactus cultivars (Dekik, Keyh, Korem, Lematse, and Tsaeda) and leaves from the five tree/shrub species were evaluated for their nutritional value. The samples were dried, ground and analysed for chemical composition, and *in vitro* DM digestibility. The paritial DM of the samples was analyzed at the Animal Science Laboratory of Mekelle University and the chemical composition and *in vitro* dry matter digestibility was analysed at Holleta Agricultural Research Center, Ethiopia (**Paper II).**

3.3. Experiment

Twenty-four yearling male Central Highland goats were used in the experiment. The design of the experiment was randomized complete block design (RCBD). The four treatments included in the experiment were 150 gDM/head/day wheat bran (WB) for all treatments and added (80 gDM of cotton seed cake (CSC) (T1); 45 gDM of CSC + 160 gDM of cactus cladodes (CC) (T2); 45g DM of CSC + 80 gDM of *Acacia saligna* (AS) (T3); and 45 gDM of CSC + 80 gDM of CC + 40 gDM of AS (T4). Feed intake was determined using feed offered minus feed refusal.The average body weight gain was calculated by subtracting the initial body weight from the final body weight divided by number of days (90 days). Digestibility of nutrients was done by subtracting the nutrients excreted in feces from the nutrients ingested. Empty body weight was calculated by subtracting digesta from slaughter body weight and rib eye muscle area was taken after storing the meat for 24 hr at 4 ˚C to cool down. Semen samples were collected by using the Artificial Vagina method. Semen volume was measured by reading the measurements on the calibrated collecting tube. Sperm concentration was determined with the aid of a spectrophotometer. Samples for meat composition were taken from the longissimus dorsi muscle and samples for skin quality were taken from the butt area. The animal experiment was conducted at Wukro town (in rented house) (**Papers III and IV).**

3.4. Laboratory Analysis

Samples of browse species, cactus, wheat bran, cottonseed cake, meat, skin were analyzed for chemical composition and browse species, cactus cultivars for *in vitro* DM digestibility. The ground samples were analyzed for chemical composition on a dry matter basis. Nitrogen analyses was done by (Kjeldahl method AOAC 1990) and CP = N × 6.25.Neutral detergent fiber

(NDF) content was determined by using Van Soest et al. (1991), Acid detergent fiber (ADF), and acid detergent lignin (ADL) were determined according to Van Soest and Robertson (1991).The *in vitro* dry matter digestibility was determined using the two-stage (Tilley & Terry, 1963) method (**Paper II and Paper III**). Meat chemical composition was done at Addis Ababa University Food Science.To determine the meat composition, the samples were incubated in an oven at 100˚C overnight to determine the percentage of dry matter. Ashing was carried out at 600 ˚C for 2h. Total fat was extracted using a Soxhlet apparatus for 6 hours with ethyl ether (boiling point of 34.5˚C), and the dried residue was weighed for fat content. Leather physico-mechanical characteristics were determined using different methods at Sheba tannery and LIDI. Leather thickness was tested in millimeters (mm) using a standard protocol ISO 2589: 2002. Tensile strength and percentage of elongation (the length of the sample at break) were determined using the test method of ISO-3376 :2011. The average tear load and tear resistance were determined using the test methods of the ISO-3377-2: 2011 and ISO-3376:2000, respectively. The leather chemical characteristics include fat content, chromic oxide and moisture content was also done at LIDI. A standard procedure [SLC- 3] was used to determine the moisture content or volatile substances of 5g of dried, chopped skins. The fat content of the moisture-free samples was determined using the standard Soxhlet extraction method [SLC-4]. The chromic oxide content of the leather is determined from the leather ash by oxidizing the leather ash, followed by iodometric titration of hexavalent chromium ions (SLC-8) (**Paper IV).**

3.5. Statistical Analysis

The quantitative data were analyzed using General Linear model (GLM) procedure of SAS version 9.0 (SAS, 2002). Treatment means were separated by Tukey's test. The qualitative data were analyzed using statistical procedures for social science (SPSS) version 16 (SPSS, 2009) and tested by means of crosstabs chi-square test, with significant differences at $P < 0.05$. Ranking method was used to analyse for qualitative data (importance of goat, goat production constraints, cactus production constraints, problems associated when cactus is fed to animals) as employed by Musa et al. (2006) (**Paper I).**

The data on chemical compositions, IVDMD and DMI, DDM, and RFV were analyzed using factorial analysis of variance (ANOVA) using the general linear model procedure of SPSS (version 16.0). In addition, pearson's correlation coefficient (r) was used to decide whether there was relationship between IVDMD, CP, ash, NDF, ADL and ADF. The statistical model included the effects of plant species, season and their interactions. Tukey's significance difference (HSD) was used to compare means $(P < 0.05)$. The significance level was set at 5% (**Paper II).**

The general linear model (GLM) procedure of SAS version 9.0 (SAS, 2002) was used to analyse the data on feed intake, digestibility, body weight gain, and carcass characteristics to the analysis of variance model for randomized complete block design. Tukey's test was used for mean separation and values were considered significant at $P < 0.05$ (**Paper III Paper IV).**

4. SUMMARY OF RESULTS

4.1. Assessment of the goat production system, browse species availability and the production and utilization of cactus in the cactus-dominated areas of the eastern zone of Tigray, northern Ethiopia

In the study area the dominant livestock species owned by the households were goats. About one-third (31%) of the goats were covered by breeding females. On average the households had 15 years of experience in goat farming and the average number of goats per household was 12.8. However, the number of goats kept by the households differed among districts. The households in Wukro Kilte-Awlaelo district had a high number of goats (on average of 17.4) than other districts. The main purpose of raising goats in the study area was for breeding followed by income generation. The major feed resources used by farmers (>74%) during the wet season were natural pasture, browse species, cactus fruit peel and weeds. However, the major feed resources used by farmers (>77%) in the dry season were crop residues, browse species and cactus cladodes. According to the interviewed households the abundant browse species in the study area were Chea/*Acacia abyssinica*, *Carisa edulis*. Hahot/*Sageretia spiciflora*, *A. saligna*, Seraw/*Acacia etibaica*, Atat/*Maytenus obscura*, Atami/*Rhus vulgaris* and *Olea europea, Dodonaea viscosa*, Tebeb/*Becium grandiforum*, and *Eculea schimperi*. There was less tradition of producing and consuming of goat milk in most parts of the study area. Seventy-five percent of the interviewed households in the study area did not practice milking of their goats for household consumption because they believed that goats do not produce sufficient amount of milk and did not have a culture of milking of goats. However, half of the households in Saesie-Tsaeda Emba district practice in milking of goats and they are used by both adults and children as food. The major constraints of goat production were shortage of land, water and labour as first, second and third order.

Regarding production and utilization of cactus, although it was produced for a wide range of functions, cactus in the present study area is produced as food source and feed to animals without any competetion. The cladodes part that did not have fruit and cladodes after the fruit is harvested to give their animals. Most of the households (68%) give cactus to their animals alone or as supplementary to crop residues, while the rest households give after the cactus was mixed with other feeds (like hay, crop residue) especially in Wukro-kilte-Awlaelo district. The cultivar with the greatest potential for fruit production was Keyh, which was followed by Lematse. The most abundant cultivar was Keyh, which was utilized extensively for human food and animal feed. However, bloating was reported by the respondents as a major problem of feeding cactus to animals. The cause of this is when animals feed high amount of green feeds and cactus with higher moisture content forms a foam (gas). Majority of the households mentioned drenching dissolved detergent as the most common way to solve problems of bloating and also most farmers give fiber source feeds (grass hay and crop residue) before giving of cactus to their animals especially for cattle. According to the information gatherd from households in the study area the trend of cactus population/production has been decreasing. While a recurring drought was mentioned by respondents in Ganta-Afeshum and Saesie-Tsaeda-Emba districts a major cause, disease was mentioned by respondents in the other two districts.

4.2. Evaluation of Nutritive Values of Cactus Cultivars and other Browse Species

The nutritive quality of forage species collected from the study area during the dry and wet (rainy) seasons was evaluated on the basis of chemical composition and IVDMD.

4.2.1. Chemical composition and *in vitro* dry matter digestibility of tree/shrub

Among the tree/shrub species, the highest DM content was recorded in *O.europaea* in dry (49.63%) and wet (49.59%) seasons; followed by *C. edulis* and *D.viscosa*. in the dry and wet seasons. The lowest DM content was recorded in *A. saligna* in the wet season (38.52%). The total ash content varied across the tree species ranging from 2.62% in *A. saligna* during the wet season to 9.48% in *C. edulis* during the dry season.

The tree/shrub species demonstrated a range of crude protein (CP) content from moderate (above 7%) to high across both seasons. The CP values varied between 8.2% and 17.73%, with *C. edulis* exhibiting the lowest content. In the wet season, *D. viscosa* recorded the highest CP content, followed by *A. saligna* (15.92%). Conversely, during the dry season, *A. saligna* had the highest CP content (14.25%), followed by *D. viscosa* (12.43%), while *O. europea* showed the lowest CP content. Overall, the CP content of the tree and shrub species was higher in the wet season.

The neutral detergent fiber (NDF) was found to be the lowest in *D. viscosa* during both the wet and dry seasons, while it was highest in *O. europaea* and *E. schimperi* during the dry season. The NDF levels in tree/shrub species were generally lower in the wet season, with except *O. europaea*. The acid detergent fiber (ADF) content was also lowest in *D. viscosa* across both seasons, whereas it was highest in *O. europaea* during the dry season, reflecting a similar trend to that of NDF. The acid detergent lignin (ADL) content was low in *D. viscosa* in both seasons, but high in *C. edulis* and *E. schimperi* during the wet season. In terms of *in vitro* dry matter digestibility (IVDMD), *D. viscosa* exhibited a higher digestibility rate than the other tree/shrub species in the wet season, recorded at 70.47%. (*Dodonaea vicosa* had higher *in vitro* dry matter digestibility (IVDMD), than the other tree/shrub species in the wet season, recorded at 70.47%.) Conversely, the lowest IVDMD was observed in *E. schimperi* during the dry season, at 44.24%.

4.2.2. Chemical composition and *in vitro* dry matter digestibility of cactus cultivars

During the wet season, Lematse cultivar demonstrated the highest crude protein (CP) content, followed by Keyh (10.72%) in the wet season and Dekik (10.26%) in the dry season. The crude protein levels in cactus cultivars were higher in the wet season compared to the dry season. The CP content of cactus in this study is higher because of soil fertility of the area and cladodes part and age of cladodes. In the dry season, Lematse exhibited a significantly higher neutral detergent fiber (NDF) content of 24.86%, followed by Korem and Keyh. The NDF levels in cacti were elevated during the dry season relative to the wet season. Additionally, the acid detergent fiber (ADF) content of Dekik in the dry season was significantly higher than that of the other cactus cultivars, while Lematse had the lowest ADF content across both seasons. The *in vitro* dry matter digestibility (IVDMD) of cacti was significantly higher in Keyh, followed by Lematse and Korem during the wet season. A positive correlation was observed between the CP content and IVDMD of the studied plants; however, both the CP content and IVDMD were negatively correlated with fiber contents, including NDF, ADF, and acid detergent lignin (ADL).

4.3. Effect of Supplementation of Cactus, *Acacia saligna*, and Cottonseed Cake on Goat Performance

Supplementation of concentrate, *A.saligna*, cactus cladodes improves goat performance (intake, digestibility, body weight gain, feed conversion efficiency, hot carcass weight). Higher total dry matter intake and organic matter intakes were recorded in concentrate + cactus (T2) and concentrate + cactus +*A.saligna* (T4) than in concentrate (T1). The highest digestibility of OM and CP digestibility was recorded for goats fed on T1, T3 and T4 supplements. All animals gained modest body weight with significant differences between the treatment diets and it was higher in T4 compared to T1 and T2. The feed conversion efficiency of goats also showed a significant difference ($p<0.05$) and it was higher in T4 compared to T2. Goats supplemented with T4 exhibited significantly higher hot carcass weight and dressing percentage than goats supplemented with T2, T3, and T1. The size of the heart was larger in concentrate-supplemented (T1) goats than in T4-supplemented goats. The size of the testes was higher in T3-supplemented goats than in T2 and T4-supplemented goats.

4.4. Influence of the concentrate substitution regime (using *Acacia saligna* and cactus cladodes) on semen quality, the meat composition, the semen quality and the physico-mechanical and chemical characteristics of leather derived from Central Highland goats.

There was a significant ($p<0.05$) difference in testes weight, progressive motility, mass motility and concentration of semen in goats due to the experimental diets.Semen quality of goats were higher in T3-supplemented goats than in goats supplemented the other treatment diets. Testicle size was significantly ($p<0.01$) and positively correlated with motility($r=0.80$ and concentration ($r=0.81$). The fat content of meat was significantly ($p<0.05$) higher in *A.saligna* and concentrate (T3)-supplemented goats than in sole concentrate (T1) and *A. saligna*, concentrate, cactus supplemented goats-(T4) (no difference recorded between T1 and T4, $P>0.05$) and T2 supplemented goats). Moisture content of meat was significantly ($p<0.05$) higher in T2 (which was similar to T1) supplemented goats than compared to goats supplemented the other treatments. The protein content of goat meat was higher in T3 and T4 supplemented goats than in T1-supplemented goats (but T2 was not significantly different from T1, T3 and T4). Ash content of goat meat was higher in T2 and T1-supplemeted goats than in T3-supplemented goats. The moisture content of goat leather was significantly ($p<0.05$) higher in T4-supplemented goats followed by T3 and T2-supplemented goats.The fat content of leather was significantly ($p<0.05$) higher in T1 followed by T3-supplemented goats than in goats supplemented the other treatments. Tear resistance (N/mm) ranged from 32.40 to 39.60, with higher values observed in T1 and T3 compared to T2 supplements (T4 was not significantly different from the other treatments). The tensile strength (N/mm^2) of goat leather was higher in T4, T1, and T3 than in T2 supplements. The percentage of elongation was higher in goats supplemented T1 and T3 than in those of goats supplemented T2 and T4. Distension at crack (mm) of goat leather was higher in T3-supplemented goats than in T2 and T4-supplemented goats.

5. GENERAL DISCUSSION

5.1. Assessment of the goat production system, browse species availability and the production and utilization of cactus in the cactus-dominated areas of the eastern zone of Tigray, north Ethiopia

This study presents information on goat production practices and cactus production and utilization in the study area. The average land size per household (0.62ha) found in this investigation was similar to the value (0.7 ha) for Wukro-Kilte-Awlaelo, Atsbie-Wemberta and Ganta-Afeshum reported by Welday *et al.* (2019). However, it was lower than the value (1ha) reported by Gebretsadik *et al.* (2014) in the same area. Although, goats account for the largest composition of livestock in the study area, the communities' also involved in the production of cattle, sheep and donkeys. However, their contribution to livestock composition was small. The observed dominance of goats in the herd composition could likely be linked to indicators of feed availability such as the amount of grass cover, the type and abundance of existing feed (proportion of browse to grass in particular is likely high) sources, availability of water and vulnerability of animals to drought, in line with Abdulatife and Ebro (2015) and most goats are populated in low and mid altitude areas. The dominance of the number of females in the goat flock structure partly reflects households' preference for female goats to produce kids to increase the flock size (the number of goats). However, most of the time male goats after one year old were sold for immediate cash income (Taye *et al*., 2024).

Virtually every household in the study area had several years of farming experience, mostly for breeding (to increase animal numbers), which allows the farmer to build financial capital and the sale of surplus animals for cash that can be used for other agricultural enterprises, school fees, medical bills, and so on (ESGPIP, 2008) to get income. Natural grass and browse species were the main feed resources during the wet season while crop residues, cactus cladodes, browse species and grass hay were the main feed resources in the dry season. Goat milk was rarely used in the study area which might be partly because a significant number of farmers perceived the amount of goat milk to be low while in other cases, there was a lack of interest and established culture of using goat milk for consumption, which aligns with the findings of Zereu *et al*. (2016). The major goat production constraints in the study area were shortages of land, water, and labour availability. This corresponds with the finding of Zereu *et al.* (2016); Abrham et al. (2017), and Yemane *et al.* (2020), who reported water scarcity, inadequate feed, and limited grazing land as major constraints to goat farming.

There is a widespread and long tradition of use of cactus as forage for livestock that is harvested from both the wild and cultivated plots in Tigray region (Friew *et al*., 2008; Gebretsadik et al., 2014). Keyh cultivar was ranked as the most prevalent and vital for both animal feed and human food. In the case of Wukro-Kilte-Awlaelo district, certain households exclusively cultivated the Lematse cultivar. This aligns with the findings of Gebretsadik *et al.*(2013), which indicated that Keyh cultivar is the most prevalent followed by Lematse in the Ganta-Afeshum district. Animals given cactus (a large amount of cactus with a high moisture content) frequently experienced bloating and diarrhea, which were shown to be the main issues after consuming the plant. The study concludes that due to the abundance of the resource and a tradition of using and managing the plant (when fed to animals), the possibility exists to enhance utilization of cactus (for goat production) in Tigray region by providing an incentive for increased production and integration with other feed.

5.2. Evaluation of Nutritive Values of Cactus Cultivars and other Browse Species

5.2.1. Chemical composition and *in vitro* dry matter digestibility of browse species

This study deals with the chemical composition and *in vitro* digestibility of some browse species and cactus cultivars. The CP content of most grass species and cereal straws is low (i.e., below the 7% threshold required ruminants maintenance) during the dry seasons. Therefore animals fed such feeds cannot maintain normal ruminal function. On the other hand, the CP content of the trees/shrubs is well above this critical level during both seasons with slightly higher values in the wet season. These species thus can be used as a supplement to poor-quality roughages as can be observed in some experiments in Ethiopia (Abraham, 2023; Yirdaw, 2017; Taddesse *et al*., 2014) and elsewhere in Africa (Aganga and Tshwenyane, 2003; Osuga *et al*., 2006; Ammar *et al*., 2025). Fibre is important in the nutritive value of forages as its characteristics can have a great impact on the extent of digestion of organic matter.

The increased fiber content (NDF, ADF, and ADL) in tree and shrub species during the dry season was attributed to their more mature state and higher lignification (Hussain and Durrani, 2009), along with elevated temperatures that foster the growth of structural fibers in vegetation (Bismarck *et al*., 2005; Goudenhooft *et al*., 2019). Fibre is important in nutritive value of forages as its characteristics can have great impact on the extent of digestion of organic matter.

5.2.2. Chemical composition and *in vitro* dry matter digestibility of Cactus cladodes Cultivars

Since cactus remains green with enough quantity of water little nutritional difference might be observed when compared to other feed resources over different seasons. In most drier areas of Ethiopia (Borana, Tigray, Meiso) cactus, is used as a feed source for camel, goat, cattle and sheep (Tegene *et al*., 2007; Gebretsadik *et al.,* 2014; Taddese *et al*. 2014). During the wet season, cactus cultivars exhibited a greater CP content and *in vitro* dry matter digestibility compared to the dry season. However, the fiber content (NDF, ADF and ADL) of cactus cultivars was higher in the dry season than in the wet season.

5.3. Effect of supplementation of cactus cladodes, *Acacia saligna* and cottonseed cake on performance of goats

Natural pasture, hay and crop residue-based diets are important feed resources in most farming systems in Ethiopia and contribute much to the feed availability, particularly in the dry season. These feeds are poor in quality because of low CP and mineral contents, and low digestibility. Concentrate feeds are also inaccessible and not affordable to most farmers in Ethiopia. Supplementation with locally available feed resources was required to alleviate such deficiencies and improve animal performance. This study thus evaluated the value of the tree legume *A. saligna* leaves and cactus cladodes in grass hay based diets using Central Highland goats. The levels of dry matter and organic matter digestibility among the goats in this study were similar to the range values of 42.11%- 69.96% as reported by Hidosa (2017). The digestibility of dry matter, organic matter, CP, and NDF were observed to decline as the inclusion of cactus cladodes increases from 80 g/day to 160 g/day. Consistent with this finding Gebremariam *et al*. (2006), reported that the digestibility of acid detergent fiber, crude protein, and neutral detergent fiber decreased as the amount of cactus in the diet increased. In this study experimental diets that include cactus; T4-supplemented goats achieved a higher average daily weight gain compared to those T2-supplemented goats. Consistent with this finding Costa *et al*. (2013), reported a decline in daily weight gain among sheep as cactus supplementation increases. Diets that incorporated 80 gDM of cactus (a mix of concentrate, *A. saligna*, and cactus) demonstrated better feed conversion efficiency than those with 160 gDM of cactus (concentrate and cactus). This aligns with the findings of Costa *et al*. (2013), who reported that sheep's feed conversion efficiency decreases when cactus content increases. Goats receiving a mixture of concentrate, cactus, and *A.saligna* (80gDM of cactus) had a higher hot carcass weight compared to those on a diet with concentrate and cactus (160 gDM of cactus). Corresponding to these findings, Bezerra *et al*. (2021); reported a reduction in hot carcass weight from 15.6 kg to 14.4 kg as cactus supplementation in lambs increased from 51.9 gDM to 75.3 gDM.

5.4. Influence of the concentrate substitution regime (using *Acacia saligna* and cactus cladodes) on semen quality, the meat composition, the semen quality and the physico-mechanical and chemical characteristics of leather derived from Central Highland goats.

This study evaluated the concentrate substitution value of the browse tree *A. saligna* and cactus leaves in grass hay-based diets using Central Highland goats. The parameters considered in this study include semen quality, meat composition (fat, protein, ash), leather chemical (fat, chromic oxide, moisture content) and physico-mechanical characteristics (tensile strength, tear resistance, thickness, distension, tear load).

In this study goats produced semen motility of more than 70%, which is an acceptable range for fertility as recommended by many authors (Khalifa and El-Saidy, 2006; Hidalgo et al. 2007). Progressive motility of goats in this study was similar to the values reported in previous studies (Dhar et al., 2010; Akpa et al., 2013; Sultana et al., 2013; Itodo et al., 2020; Swarna et al., 2022). The individual variation in motility of spermatozoa was good for selecting bucks because motility is an important indicator (trait) for the quality of semen and it also determines the fertility of bucks (Nazir, 1988). Semen concentration of goats in this study was similar to the value, 2.82-4.29-7.1(x10^9/ml reported by previous scholars (Dana et al., 2000; Kheradmand et al. 2006 ; Sultana et al., 2013). Semen concentration of goats in this study was within the acceptable semen quality sperm cell concentration of $\geq 2 \times 10^9$ sperm cells/ml (Hidalgo et al., 2007). Sperm cell concentration is influenced by different factors such as age, breed, nutrient supply, climatic conditions (Mekasha et al., 2007; Akpa et al., 2013) and method of semen collection (Austin et al., 1961) and method of measurement of sperm concentration (Atiq *et al*., 2011). Semen volume of goats in this study was comparable to the values 0.42-0.82 (ml), reported in previous studies (Gebreslassie, 2012; Akpa *et al*., 2013; Michael, 2018). In this study testicle size in goats supplemented with T3 was higher than in goats supplemented with T2 and T4. Due to this, semen motility and semen concentration were higher in goats supplemented with T3 and T1. In line with this finding, Møller (1988) reported that larger testicles produce more concentrated sperm cells due to a bigger site of production and capacity compared to smaller testicles. An increment of testicle size might be contribute to the production of testosterone which increases spermatogenesis (Shi et al., 2018). Supplementation of protein sources, browse species like *Acacia saligna* improves testicular size, semen motility, semen volume, and semen concentration. Consistent with this study, Dana et al. (2000) reported that supplementation of up to 300 g per head per day of leucaena resulted in improved testicular growth, sperm production and semen quality of Ethiopian highland sheep.

Worldwide, the consumption of chevon (goat meat) has increased largely due to its distinct nutritional attributes when compared to other red meats. In addition to being a good source of dietary protein for human beings, chevon comparatively has a lower total fat, saturated fatty acid and cholesterol content, which makes it a healthful product (Mazhangara *et al*., 2019). In this study even those of goats supplemented with only concentrate had a meat with medium fat content but higher than that of goats supplemented with cactus and concentrate. The results of this study were similar to the findings of Dutta *et al*. (2023). Goat meat had a higher protein content than other meat components, with the exception of moisture, which did not suggest high-quality meat. Goats often favor the most nutritious parts of their diet and rely on browsing species; therefore, this may be why goat meat is an excellent source of protein. Prior studies (Teklebrhan *et al*., 2012; Dereje *et al*., 2016;Tadesse *et al*., 2016; Urge *et al*., 2017; Abebe *et al*., 2024)) have demonstrated that supplementing ruminants with concentrates improved the most leather quality measures, including chromium oxide, fat content, tensile strength, thickness and tear resistance. Besides, substitution of concentrate feeds by browse species (cactus, *A.saligna*) in the diet of goats improved tensile strength, tear resistance and thickness. The moisture content of goat leather was higher in *A.saligna* and cactus cladodes-supplemented goats than goats supplemented with other treatments. The fat content of goat leather was higher in the sole concentrate supplement (T1) than the other supplements. Tear resistance (N/mm) and tensile strength were higher in T1, T3, and T4 supplements than in T2 supplements. The percentage of elongation of goat leather was higher in T1 and T3 supplements than in those of T2 and T4 supplements. The most physico-mechanical parameters of goat leather (thickness, tensile strength, tear resistance) were higher in T1, T3, T4 than in concentrate and cactus (T2) supplements.

6. GENERAL CONCLUSION

The major feed resources used as animal feed in the study area were natural pasture, cactus cladodes, crop residue and browse species. Goats were the most dominant species compared to other livestock species in the study area. The present study highlights, there were potential local resources that could address farmers' challenges to obtain feed. Besides cactus and other browse species with the potential to address feed shortage were available in the study area. Among these, the most preferred and most abundant browses species by goats in the study area were *A. abyssinica, C. edulis*, **Hahot** *(Sageretia spiciflora), A. saligna*, **Seraw** *(Acacia etbaica),* **Atat** *(Maytenus obscura),* **Atami** *(Rhus vulgaris),* and **Tebeb** *(Becium grandiforum)*. From the studied cactus cultivars and browse species in the survey part of the study; the selected browse species had medium to high CP (a protein level that exceeds the maintenance requirements of ruminant animals) and relatively low fibre contents and high in *in vitro* dry matter digestibility. The CP content of the selected trees/shrubs and cactus cultivars was above 8% even during the dry season, which shows their potential role as supplements to animals fed on poor-quality roughages as basal diet. Notably, *A. saligna* and *D. viscosa* are promising options for livestock nutrition, especially as a protein boost for low-quality feed resources like grasses, crop residue in the dry season. Among the browses *Acacia saligna* along with Lematse cultivar were further evaluated for their potential concentrate replacement values. Goats fed on T4 supplements achieve suitable performance in most parameters: higher efficiency (better utilization of the feed), relatively high growth rate, high dressing percentage, and hot carcass weight, larger weights of kidney, proximal thoracic limb, and proximal pelvic limb. Goats in all treatment diets had good-quality semen in an acceptable range. Especially goats supplemented T3 produced good quality semen. Fat content of goats was higher in T3-supplements than goats supplemented the other treatments. However, protein content of meat was higher in goats' supplemeted with T3 and T4 than goats supplemented with T1. Goats supplemented with T1, T3 and T4 supplements had higher tensile strength and tear resistance and percentage of elongation. Goats supplemented with T3 and T4 had higher feed conversion efficiency, body weight gain and proximal pelvic limb. Finally, goats supplemented with T3 had good semen quality and fat content of meat. However, goats supplemented with T4 had higher proximal thoracic limb, hot carcass weight and dressing percentage. This result suggests feeding a mixture of cactus and *A. saligna* foliage may promote reasonable productivity enhancement in goats fed on grass hay provided that a small quantity of concentrate feed is also included in the diet. This mixed diet can thus be a viable option to improve goat production of the farmers for the studied area. Both cactus and *A. saligna* are locally available year-round, providing a reliable forage source that meets the maintenance requirements of animals and boosts economic returns for producers is an added benefit. Furthermore, substitution of 35gDM/day CSC either by *A. saligna* or cactus cladodes and *A. saligna* in the experimental diet provides relatively similar results in terms of meat and leather quality to that of goats supplemented with sole concentrate. This finding further confirms the potential of the identified browses to use as supplements for low-quality diets that predominate in the study area.

7. SCOPE OF FUTURE WORKS

The district officers, Development Agents and other stakeholders must be creat awareness to households for cactus production management improvements. Future research should dedicate a study to developing a scientifically sound, practical management strategy for cactus-induced bloating on farms.Further research could be done on *in saco* degradability and the anti-nutritional factor (e,g, tannin content) of the studied browse species. Total replacement of concentrate feed by cactus and browse species in the diet of goats and supplementing of mineral must be done. Further research could be done to evaluate the anti-nutritonal factor (Gossypol) found in cottonseed cake used in the feed trial. Further research could be done to evaluate the effect of *Acacia saligna* and concentrate feeds on the sperm morphology of farm animals. Evaluation of the biological (collagen, elastin) parameters of skin must be done further using these feed ingredients.

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LIST OF PAPERS

Paper I

Assessment of the goat production system, Browse species availability and the production and utilization of cactus in the cactus-dominated areas of the eastern zone of Tigray, northern Ethiopia

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Abstract
The major constraint of livestock production in most developing countries is lack of adequate quantity and quality of feed. Browse species, including cactus, and crop resisues are the primary alternative feed resources for animals during the dry season in Ethiopia, particularly in the dry areas of the Tigray region. Therefore, the objective of this study was assessment of the goat production system, browse species availability and the production and utilization of cactus in the cactus-dominated areas of the eastern zone of Tigray, north Ethiopia. Data for this study were collected using a survey questionnaire from 151 households on flock composition, importance, and constraints of goat production, cactus fruit production from different cultivars, importance of cactus production (feed, food, fence), feed resources, and cactus production constraints from four districts (Wukro-Kilte-Awlaelo , Atsbi-Womberta, Ganta-Afeshum, and Saesie-Tsaeda-Emba). Results indicated that the average land size per household in the study area was 0.62 ha. Goats are the dominant livestock species, and they are kept for breeding, followed by income generation. Most of the goats are herded separately during the daytime. Natural grass and browse species were the main feed resources in the study area. The most preferred browse species were Chea (Acacia abyssinica), Carisa edulis, Atat (Maytenus obscura), and Acacia saligna. But Tebeb (Becium grandiforum), Hahot (Sageretia spiciflora), Seraw (Acacia etibaica), Olea europea, and Atami (Rhus vulgaris) were the most desirable browse species. Fifty-three percent of the households in Saesie-Tsaeda-Emba practiced milking of goats. The major constraints of goat production in the study area were a shortage of land, water, and labour. In the study area, Keyh cultivar had the highest fruit production potential then followed by Lematse cultivar. The major purpose of cactus production is for food, and next for feed. Most of the households in the study area give cactus to animals after other feeds to decrease the occurrence of diarrhea and bloating. The major problem occurred during cactus feeding to animals was bloating. However, households used drenching dissolved detergent to solve this problem. The status of cactus production (population) in the study area is decreasing due to drought, land, and labour shortage. In conclusion, there is a considerable scope for utilizing the locally available browses (cactus and browse species) to enhance goat production in the study area.

Keywords: Keyh, feed resources, production constraints, importance of goat

INTRODUCTION

In Ethiopia, almost all goats are produced in mixed crop-livestock and pastoral and agro-pastoral systems. Flock sizes are larger in the lowland pastoral and agro-pastoral systems (Gizaw, 2010; Tadesse et al., 2017). They are managed under extensive traditional systems and produce the lowest compared to other Sub-Saharan African countries. Goats are mainly maintained for fulfilling multiple roles, ranging from socio-cultural purposes to providing meat, milk and manure for poor smallholder farmers living in dry and harsh environments of tropical regions (Aziz, 2010; Tilahun, 2023).

Goats consume a wide variety of grasses, weeds, leaves and small branches of bushes and trees and crop residues and the majority of the feed resources are dominated by pasture (grasses). However, these feeds are characterized by poor quality pasture that contributes to inadequate feeding and nutrition (Ben Salem and Smith, 2008; Duguma and Janssens, 2016; Ayele et al., 2021; Tsegaye, 2023) and productivity is low. Inadequate feed supply is a major constraint of livestock production in Sub-Saharan African countries (Yisehak and Janssens, 2014; Adegoke and Abioye, 2016; Amole *et al*., 2022). This obviously adds to the poor performance of ruminant livestock. Improvement of the performance of ruminants in Sub-Saharan Africa (Kaitho *et al*., 1998; Mekonnen *et al*., 2006, 2009; Mekoya *et al*., 2008; Makkar et al., 2022) calls for using the methods of extending the availability and quality of local feedstuffs like cactus cladodes and browse species. Cactus pear is increasingly being cultivated in semi-arid and arid regions since it can tolerate water-limited conditions, high temperatures and poor soils (FAO, 2005; Salem-Fnayou et al., 2014). In many arid areas, farmers use cactus extensively as an emergency forage that is harvested from both wild and cultivated stands to prevent the disastrous consequences of frequent and severe droughts (Nefzaoui and Ben Salem, 1996; Tegegne, 2007; Ahmed and Elsamani, 2024). *Opuntia ficus-indica* production for forage is variable, because the production techniques used are very poor and in most cases it is grown wild. Prickly pear cactus utilization as a forage for livestock has been mainly due to its availability during critical dry months of the year (Ben Salem and Smith, 2008; Gebretsadik et al., 2013; Pastorelli et al., 2022; Sipango et al., 2022). Despite the contribution of cactus cladodes as feed to animals in both dry and wet season, bloating is a major concern especially in wet season since animals depend on green forages and produce foam (gas) and results in death. But, farmers use some traditional mechanisms to reduce the occurrence of bloating and preventive mechanisms like using of olis, detergents, drying of cactus cladodes, adding of fiber source feeds and giving of cactus in little amount in differenet time interval within a day. Knowing goat management practices like feeding, watering, and constraints of goat production is important to farmers to improve goat management. Assessment of the trend and importance of cactus production and the number of fruits produced per cladodes is important to choose the best cultivar from the studied cactus cultivars for further plantation to increase its population. However, in the study area assessment of goat production system, availability of browse species and cactus production and utilization were not well studied. Therefore, the objective of this study was the assessment of the goat production system, availability browse species and the production and utilization of cactus in the cactus-dominated areas of the eastern zone of Tigray, north Ethiopia.

MATERIALS AND METHODS

Description of the Study Area

This study was carried out in the Eastern zone of the Tigray region located in northern Ethiopia. It is located between 13°33′ to 14°40′ N and 39°11′ to 39°59′ E. The total area of the zone is 561,000 ha, which is divided into seven districts: Erob, Hawzen, Wukro-Kilte-Awlaelo, Atsbi-Womberta, Ganta-Afeshum, Gulo-Mekeda, and Saesie-Tsaeda-Emba. The altitude ranges from 1500 to 3280 m above sea level. The study zone has three traditional agro-ecological zones: (i) highland, with areas over 2300 m above sea level; (ii) midland, between 1500 and 2300 m above sea level; and (iii) lowland, with areas less than 1500 m above sea level (Meles et al., 1997). Most of the districts are categorized as Highland or Dry Dega, followed by Midland or Dry Weinadega. The area has a semi-arid climate and receives bimodal rainfall: the main rainy season (June–September), locally known as Kiremt and a small rainy season (February–May), locally known as Belg. The rainfall is highly variable due to the complex influences of topography (Meles *et al*., 1997). The mean annual rainfall ranges from 520 to 680 mm, and the mean annual temperature varies between 16 and 20 °C (Kahsay *et al*., 2019).

Sample Size Determination and Data Collection

Purposive sampling method was used to select districts and households from the study area; Eastern zone of Tigray. In the first stage four representative districts (Wukro-Kilte-Awlaelo (Midland), Atsbi-Womberta (Highland), Ganta-Afeshum (Highland), and Saesie-Tsaeda-Emba (Highland)) were purposively selected based on the goat population and cactus production. The second two kebeles from each district were selected, i.e., Kokeb Tsibah and Gola-Genahti kebeles, Adega-Durhara and Emba-Esmeina kebeles, Era and Kelisha kebeles, and Adikisandid and Sherafo kebeles, which were selected from Ganta-Afeshum, Saesie-Tsaeda-Emba, Atsbi-Womberta, and Wukro-Kilte-Awlaelo districts, respectively, The sample size for the interviewed household per district was determined according to Kothari (2004) for an unknown population. (i.e.Sample Size=Z^2SD^2/e^2=34.57=35.

Where Z, is the estimated standard variation at 95% confidence interval (CI) which would be considered the point of the normal distribution corresponding to the level of significance (Z=1.96). Standard deviation (SD) was estimated at 0.15 or 15% and e, is the estimated error and was considered at 0.05 or 5%. With the assumption of 5% standard error a total of 140 households were interviewed but in order to decrease error a total of 151 households were included in the study.

The data were collected from 40 households from Genta-Afeshum district, 36 households from Saesie-Tsaeda-Emba district, 35 households from Atsbi-Wenberta district and 40 households from Wukro-Kilte-Awlaelo district making it a total of 151 households. The households are selected purposively based on having with at least three goats and greater than 2 year goat farming experience (Welday et al., 2019). Each of the households was interviewed individually using semi-structured questionnaires. Before the actually implementation of the field survey, pretesting of the semi-structured questionnaire survey was carried out using farmers in the selected areas. The questionnaire included flock composition, importance and constraints of goat production, cactus production practices, cactus utilization (feed, food, fence and soil conservation), feed resources (grass, browse, crop residue, and cactus) and cactus production constraints. Based on their abundance (availability) and palatability by goats (as given by the interviewed households or goat owners' ranking). The quality level of each forage species was determined according to Chen and Jia (2002), and other related references (Damiran, 2005; Ye and Du, 2014; Huang et al., 2018; Zhao et al., 2020). The forage species were categorized into the following five levels; **prefered forage species (a)** these species were preferred by livestock and consumed far in excess of its vegetative composition(highest utilisation relative to availability)**, desirable** forage species(**b**), readily eaten but corresponding to a lesser portion than preferred plants (selected in proportion to their availability), **undesirable** (**c**) (plant species with less preference by livestock)/ (consumed less frequently than they are encountered), **non-consumable (d)** (plant species grazed under compulsions in the absence of forage species) (consumed only under extreme conditions), **toxic** (**e**) (plant species, not grazed by animals at any stages because of containing toxic substances) (Damiran, 2005). The forage quality levels are referring based on the consumption of main types of local livestock including cattle, horses, sheep, and goats.The districts with respective kebeles are shown in Table 1.

Table 1. The selected kebeles from each district

	Eastern Zone of Tigray			
District	Ganta-Afeshum	Saesie-Tsaeda-Emba	Atsbi-Womberta	Wukro-Kilte-Awlaelo
Kebeles	Kokeb Tsibah Gola-Genahti	Adega-Durhara Emba-Esmeina	Era Kelisha	Adikisandid Mahbereweini
Total number of households	40	36	35	40

Statistical Analysis

Data were entered into a Microsoft Office Excel sheet every day after administering the questionnaire and analyzed using Statistical Packege for Social Science (SPSS) version 16 (SPSS, 2009). The index was calculated to provide the rank on the purpose of goat keeping, constraints of goat production, importance of cactus production, dominance of cactus cultivars, problems associated when animals consuming cactus, coping mechanisms/preventive measures when bloating occurred and constraints of cactus production. A nonparametric test like a chi-square test was used to explain the difference that may exist in qualitative parameters significant differences at $P< 0.05$. In short ranking index method was calculated as employed by Musa et al. (2006).

$$\text{Index} = \frac{\text{Rn} * \text{c1} + \text{Rn} - 1 * \text{C2} + \cdots + \text{R1} * \text{Cn}}{\Sigma \text{Rn} * \text{c1} + \text{Rn} - 1 * \text{C2} \ldots + \text{R1} * \text{Cn}}$$

Where Rn=value given for the least ranked level (e.g. if the least rank is 7^{th}, then Rn=7, Rn-1=6, Rn-2=5, Rn-3=4, Rn-4=3, Rn-5=2, Rn-6=1),
Cn=counts of the least ranked level (similar to the above 7^{th} rank =Cn and the count of the first rank=C1)
The quantitative data were analyzed using a general linear model univariate ANOVA (one way ANOVA). Mean comparisons were carried out using Tukey's honestly significant difference test. Level of significance was also considered at *P< 0.05*.

Model used for quantitative data;

$Y = \mu + \alpha i + eij$ Where Y=total observation due to i, μ=the overall mean, $\boldsymbol{\alpha}$i=district of the i^{th} level and eij=random error.

RESULTS

Goat Production system and Browse Species Availability

Composition of livestock species and land size in the study area

The average number of livestock species and land size per household are shown in Table 2. Households in the Wukro-Kilte-Awlaelo district had a large average land per household, compared to Ganta-Afeshum and Saesie-Tsaeda-Emba districts.The average land size per each household in the study area was 0.62 ha.The type of livestock reared in the study area includes sheep, goat, cattle, donkey and chicken. The average number of sheep per household was higher in Saesie-Tsaeda Emba than in the other districts. The average number of cattle was higher in Wukro-kilte-Awlaelo district than in Atsbi-Womberta and Saesie-Tsaeda-Emba districts. Households in Saesie-Tsaeda-Emba district had higher number of honeybee colony than that of households in Ganta-Afeshum and Wukro-Kilte-Awlaelo districts. The average number of goats per household was higher than the other livestock species in the study area and they are higher in Wukro- Kilte-Awlaelo district, than in the other districts.

Table 2. Average livestock composition and land size in the area

Livestock	District					
Species(N)	GA	STE	ATW	WKA	Average	P value
Sheep	4.42^{b} ±0.6	7.27^{a}±0.64	1.37^{c}±0.64	3.31^{bc}±0.6	4.09	0.0001
Goat	10.37^{b}±1.22	12.19^{b}±1.29	11.45^{b}±1.3	17.14^{a}±1.21	12.78	0.001
Cattle	4.65^{ab}± 0.43	4.25^{b}± 0.45	4.25^{b}± 0.46	5.97^{a}± 0.43	4.78	0.017
Donkey	1.70 ±0.2	1.08 ±0.21	1.51 ±0.21	1.78 ±0.2	1.51	0.09
Chicken	3.15±0.54	3.00±0.57	2.50±0.59	4.10±0.54	3.18	0.24
Honeybee colonies	0.37^{b}± 0.24	1.69^{a}± 0.25	0.85^{ab}± 0.26	0.56^{b}± 0.24	0.86	0.002
Land size(ha)	0.28^{b}±0.06	0.29^{b}±0.06	0.93^{a}±0.06	1^{a}	0.62	0.0001

Note: N= number of animals of per each households, GA= Ganta-Afeshum, STE= Saesie-Tsaeda Emba, ATW= Atsbi-Womberta, WKA= Wukro-Kilte-Awlaelo

Goat flock structure and goat keeping experience

Table 3 displays the results of the goat flock structure (age, sex group), and goat farming experience.The number of dry goats and breeding females was higher in households in Wukro-Kilte-Awlaelo district than in the other districts and the number of lactating does, breeding males and kids was higher in Saesie-Tsaeda-Emba district than in the other districts. The number of breeding females per households was higher in Atsbi-Womberta and Wukro-Kilte-Awlaelo distiсts than the other two districts. In all districts within goat flock structure, there were more breeding female goats (31%) than breeding male goats. Because, male goats might be sold for income generation, however, female goats are kept for breeding or kid production. Households in the Saesie-Tsaeda-Emba district had long goat keeping experience (31.84) then followed by households in Wukro-Kilte-Awlaelo (11.09) and Ganta-Afeshum (10.17) households. Finally, households in the study area had the longest experience with goat keeping (on average 14.87).

Table 3. Goat flock structure (Mean±SD) and goat keeping experience

Flock Structure(N) (in age and sex)	District				Significance level
	GA	STE	ATW	WKA	
Breeding males(>1year)	1.02^{ab}±0.14	1.39^{a} ±0.15	0.8^{b}±0.15	0.87^{ab}±0.14	0.032
Breeding females(>1year)	4.28^{ab}±0.54	2.44^{b}±0.56	5.08^{a}±0.57	5.95^{a}±0.52	<0.0001
Lactating doe(>15months)	3.25^{b}±0.37	4.69^{a}±0.39	2.34^{c}±0.39	3.43^{b}±0.3	0.001
Dry goats(>18months)	1.97^{a}±0.32	1.38^{ab}±0.34	0.31b±0.35	1.85^{a}±0.32	0.003
Old doe(> 8 years)	0.27±0.16	0.61±0.17	0.00±0.17	0.47±0.16	0.064
Kid(<4 months)	1.9^{c}±0.34	4.47^{a}±0.35	2.34^{bc}±0.36	3.41^{ab}±0.33	0.0001
Weaner(>4 months but less than 1year)	0.42±0.18	0.5±0.19	0.00±0.19	0.68±0.18	0.079
Goat keeping experience (in year)	10.17^{b}±2.03	31.84^{a}±2.14	6.4^{b}±2.17	11.09^{b}	0.0001

Note: N= number of animals per households, GA= Ganta-Afeshum, STE= Saesie-Tsaeda-Emba, ATW= Atsbi-Womberta, WKA= Wukro-Kilte-Awlaelo

The Purpose of keeping goats

The reasons (purpose) of keeping goats and the ranks given by households in the study area are shown in Table 4. Goats raised in the study area were primarily kept for breeding (to increase their number of goats or reproduction), income generation, and the production of milk and manure as first, second, third, and fourth ranks, respectively (except at STE).

Table. 4. Purpose of keeping goats in the study area

Importance	District									
	GA		STE		ATW		WKA		Total	
	Index	Rank	Index	Rank	Index	Rank	Index	Rank	Index	Rank
Breeding(reproduction)	0.258	1	0.261	1	0.318	1	0.270	1	1.107	1
Income	0.267	2	0.231	2	0.242	2	0.246	2	0.986	2
Manure	0.231	3	0.151	4	0.24	3	0.232	3	0.854	3
Milk	0.167	4	0.194	3	0.112	4	0.154	4	0.627	4
Home consumption	0.075	5	0.161	5	0.087	5	0.095	5	0.418	5

GA= Ganta-Afeshum, STE= Saesie-Tsaeda Emba, ATW= Atsbi-Womberta, WKA= Wukro-Kilte-Awlaelo

The major feed resources in the study area

The major feed resources found in the study area are shown in Table 5. The major feed resources used by farmers (>74%) during the wet season were natural grass, browse species, weeds, and cactus fruit peel. However, the major feed resources used by farmers (>77%) in all districts in the dry season were crop residue, cactus cladodes and browse species. In Saesie-Tsaeda-Emba district, 61% of households also used cactus cladodes as a primary source of feed during the wet /rainy season. During the wet season, few households in the other districts also used cactus cladodes as a source of feed. In the dry season, 56.29% of the interviewed households also utilize grass hay as animal feed in all districts. However, because grass hay is scarce and originates from small grasslands, farmers may not preserve it for the wet/rainy season instead they were stored crop residues.

Table 5. Feed resources in the study area

Feed Resources		District				Total	Chi-square
Wet season		GA	STE	ATW	WKA		Value
Natural grass	N	40	35	32	36	143	6.49^{ns}
	%	100	97.2	91.4	90	94.7	
Grass Hay	N	1	1	1	6	9	7.65^{ns}
	%	2.5	2.7	2.8	15	5.9	
Crop Residue	N	30	19	16	34	99	15.66***
	%	75	52.7	45.7	85	65.56	
Cactus Cladodes	N	12	22	2	6	42	32.16***
	%	30	61.1	5.7	15	27.8	
Cactus fruit Peel	N	36	35	20	19	111	38.45***
	%	90	100	57.1	47.5	73.5	
Browse Species	N	40	35	35	31	141	24.88***
	%	100	97.2	100	77.5	93.3	
Weed	N	38	33	14	30	115	37.43***
	%	95	91	40	75	76	
Dry season							
Natural grass	N	4	5	4	10	23	3.97^{ns}
	%	10	12.5	10	25	15.23	
Grass Hay	N	21	18	17	29	85	28.42***
	%	52.50%	50.00%	48.57%	72.50%	56.29%	
Crop Residue	N	37	35	31	35	138	3.57***
	%	92.5	97.22	88.57	87.5	91.4	
Cactus Cladodes	N	40	36	24	34	134	24.14***
	%	100	100	68.57	85	88.7	
Browse species	N	34	20	28	35	117	12.58***
	%	85	55.5	80	87	77.5	

GA= Ganta-Afeshum, STE= Saesie-Tsaeda Emba, ATW= Atsbi-Womberta, WKA= Wukro-Kilte-Awlaelo
N=number of households, *level of significance: $p<0.05$,**level of significance: $p<0.01$, ***level of significance: $p<0.001$.

Availability of Browse species in the study area

The results or response of households regarding to the availability and palatability of browse species in the study area are shown in Table 6 and summarized in Table 7. The selection of the browse species were based on animal preference, farmers' perceived quality of fodder and are classified in to preferable, desirable, undesirable, undesirable, noconsumable and toxic. *Acacia* *saligna* is most desirable browse species in Ganta-Afeshum district.But in Saesie-Tsaeda-Emba and Atsbi-Womberta districts more than half of the households; *Acacia saligna* was categorized in preferable forage quality level. In all districts *Carisa edulis* was categorized in preferable browse species especially, in Wukro-Kilte-Awlaelo district almost all households *Carisa edulis* categorized under preferable. Households in all districts; *Acacia abyssinica* also categorized in preferable browse species. Households in Genta-afeshum district *Acacia etbaica* categorized under preferable while in Atsbi-Wenberta under desirable browse species. Overall in the study area the **preferable** browses species were chea (*Acacia abyssinica*), Agam (*Carissa edulis*), and Seraw (*Acacia etbaica*), Acacha (*Acacia saligna*), Atat (Maytenus obscura); the **desirable** browse species in the study area were Hahot (*Sageretia spiciflora*), Atami (*Rhus vulgaris*) and Awlie (*Olea europea)*; the **undesirable** browse species by goats were Tahsas (*D.vicosa*) and Tebeb (*Becium grandiforum*) and the **nonconsumable** browse species were Kilaw (*Eculea schimperi*), and also this was only found in some part of Atsbi-Womberta district and in most areas of Wukro-Kilte-Awlaelo district.This plant is not browsed by goats normally but in the most driest period when the other browse species are shed their leaves it might be browsed by goats.

Table 6. Browse species quality level and their abundance in the study area

Browse species	Forage quality level	District				Total (N)(%)	Chi-square Value	Significance level
		GA	STE	ATW	WKA			
	a	0	26	29	7	62(41.05%)	91.8	0.0001
Acacia saligna	b	28	10	4	9	51(33.77%)		
	c	0	0	0	8	8(5.29%)		
D.vicosa	a	0	0	0	2	2((1.32%)	24.3	0.004
	b	2	0	0	3	5(3.31%)		
	c	32	36	23	16	107(70.86%)		
	d	0	0	2	3	5(3.31%)		
C. edulis	a	22	27	25	37	111(73.50%)		
	b	18	6	8	1	33(21.85%)	6	0.0001
	c	0	2	0	0	2(1.32%)		
E. schimperi	c	0	0	2	8	10(6.62%)	25.13	0.0001
	d	8	0	18	21	47(31.12%)		
O.europea	a	8	5	14	9	36(23.84%)		
	b	24	13	20	20	77(50.99%)	77.18	0.0001
	c	6	18	1	5	30(19.86%)		
Acacia abyssinica	a	40	36	33	19	128(84.76%)		
	b	0	4	2	8	14(9.27%)	33.92	0.0001
	c	0	19	0	2	21(13.90%)		
Acacia etbaica	a	26	3	0	19	48(31.78%)	44.26	0.0001
	b	4	10	22	16	52(34.43%)		
	c	2	0	4	3	9(5.96%)		
Sageretia spiciflora	a	0	0	0	3	3(1.98%)		
	b	36	34	27	3	100(66.22%)	55.73	0.0001
	c	0	2	2	12	14(9.27%)		
	d	0	0	0	15	15(9.93%)		
Rhus natalensis	b	23	10	0	1	34(22.51%)	18.48	0.001
	c	4	6	2	9	21(13.90%)		
Maytenus obscura	a	15	31	9	4	59(39.07%)		
	b	18	3	26	6	53(35.09%)	56.99	0.0001
	c	0	2	0	5	7(4.63%)		
Becium	a	28	2	0	4	34(22.51%)		
grandiforum	b	0	31	9	7	47(31.12%)	46.2	0.0001
	c	0	0	8	2	10(6.62%)		
	d	0	2	0	4	6(3.97%)		
Boscia angustifolia	a	0	5	0	4	9(5.96%)		
	b	0	31	0	14	45(29.80%)	54.7	0.0001
	c	0	0	0	0	2(1.32%)		
Rhus vulgaris	a	0	3	2	8	13(8.61%)	6.46	0.167
	b	0	7	17	16	40(26.49%)		
	c	0	0	2	0	2(1.32%)		

Note a=preferable, b=desirable, c=undesirable, d=noconsumable, GA= Ganta-Afeshum, STE= Saesie-Tsaeda Emba, ATW= Atsbi-Womberta, WKA= Wukro-Kilteawlaelo, N=number of households

Table 7. Summary of Browse/Forage quality level in the study area

Browse/Foage quality level							
Preferable(a)		Desirable(b)		Undesirable(c)		Nonconsumable(d)	
Species name	N	Species name	N	Species name	N	Species name	N
A.saligna	62(41.05%)	*O.europea*	77(50.99%	*D.vicosa*	107(80.76%)	*E. schimperi*	47(31.12%)
C. edulis	111(73.50%)	*A.etbaica*	52				
A.abyssinica	128(84.76%)	*S.spiciflora*	100(66.22%)				
M.obscura	59(39.07)	*R.natalensis*	35				
		B.grandiforum	47				
		R.vulgaris	40				

Note:N=number of households in the study area that practiced in the selection of browse species

Sources of water, watering frequency and distance from home to water source

Table 8 displays the findings regarding water sources, frequency of watering, and the distance from home to the water source. In the study area, the majority of households rely on the river for water in both seasons. In the study area, a well also serves as a water source for livestock in the dry season. During the wet (rainy) season, the majority of animals consume water from precipitation. In the Wukro-Kilte-Awlaelo district, households cover the greatest distances from their homes to the water source, exceeding 2 kilometers, particularly during the dry season. Goats here also trek farther to access water compared to other districts. During the dry season, most animals consume water each day. However, during the wet (rainy) season, many animals consume water after seven days as it is easily accessible, since households may not monitor their animals closely.

Table. 8. Water sources for animals in the study area, watering frequency and distance from home to water source

Water resource		District			Total
	GA	STE	ATW	WKA	
In dry season	**N (%)**	**N (%)**	**N (%)**	**N (%)**	**N (%)**
River	38(95)	17(47.22)	34(97.14)	32(80)	121(80.13)
Well	15(37.5)	6(16.66)	15(42.85)	18(45)	54(35.76)
Pipe-born water	6(15%)	4(11.11)	0	0	10(6.62)
Damb	0	10(27.77)	17(42.5)	0	40(26.49)
In wet season					
River	12(30)	6(16.66)	10(28.57)	16(40)	44(29.14)
Well	0	0	0	6(15)	6(3.97)
Pipe born water	5(13.88)	0	0	0	5
Damb	0	0	0	9(25.71)	9(3.31)
Watering frequency					
Wet season					
<7days	34(85)	34(94)	28(80)	25(62)	121(80)
No	6(15)	2(5.5)	7(20)	16(40)	31(20.5)
Dry season					
Daily	32(80)	35(97.2)	34(97.1)	31(77.50)	132(87.4)
3day	2(5)	0(0)	0(0)	4(10)	6(3.9)
4day	6(15)	1(2.7)	1(2.8)	6(15)	14(9.2)
Distance from home to water source(KM)	1.14^{b}	0.73^{b}	0.88^{b}	2^{a}	**P-value** 0.0001

GA= Ganta-Afeshum, STE= Saesie-Tsaeda Emba, ATW= Atsbi-Womberta, WKA= Wukro-Kilteawlaelo.

Milk production, Milking practices, Milk consumption status and Lactation length of goats in the study area

Table 9 shows the results of goat milking practices of households in the study area. In the Saesie-Tsaeda-Emba district, 53% (52.77%) of farmers participated in goat milking, while in Ganta-Afeshum, 25% (10) of households took part in milking their goats. However, in the other two districts, just a few farmers participate in milking their goats. According to the farmers' feedback (about goat milk consumption status of households) presented in Table 10, milk is consumed by children (10) and all families (23) when available in abundance; however, when in short supply, it is primarily consumed only by children. However, adults in the Islamic community of the Ganta-Afeshum district often mixed with coffee and drink (as indicated by the interviewed farmers). The data on the lactation length of goats is shown in Table 11. On average, the lactation length of goats in the study area ranged from 3.9 to 4.6 months. There is no significant difference (p>0.05) in the lactation length of goats among the districts. The reasons for the lack of milking practices in most households are outlined in Table 12. The possible explanations could be that a significant number of farmers in the study area perceived goat milk production to be minimal (35.76%) and subsequently lacked the interest and culture (21.85%) to utilize goat's milk. For these reasons, many farmers in the study area prioritized breeding goats over producing milk, purchasing them primarily to expand their herd and generating income through goat sales. They give more emphasis to cattle and they were milked their cows, even their feeding practice for cattle also different from goats, they were giving more improved feed resources like concentrate feed, quality pasture etc.

Table 9.Milking practice of goats in the study area

Question Is there milking practice		**District**					Chi-square Value	Significance level
Answere		GA	TSE	ATW	WKA	Total	18.84	<0.0001
Yes	N	10	19	4	7	40		
	%	25	52.77	11.42	17.5	26.49%		
No	N	30	17	31	33	111		
	%	75	47.22	88.57	85	73.5%		
Total		40	36	36	40	151		

GA= Ganta-Afeshum, STE= Saesie-Tsaeda Emba, ATW= Atsbi-Womberta, WKA= Wukro-Kilte-Awlaelo

Table 10. Priority given to drink milk from the households/Milk consumption status

Priority given to drink milk from households		**District**					Chi-square value	Significance level
		GA	TSE	ATW	WKA	Total		
Child	N	7	3	0	0	10		
	%	17.5	8.33	0	0	6.62%	47.117	<0.0001
For all	N	2	16	4	7	29		
	%	5	44.4	11.42	17.5	19.20%		

GA= Ganta-Afeshum, STE= Saesie-Tsaeda Emba, ATW= Atsbi-Womberta, WKA= Wukro-Kilte-Awlaelo

Table 11. Lactation length of goats in the study area

District	Mean(month)	Std. Error	F-value	Significance
GAN	4.425	.207	1.84	0.142
STE	4.611	.218		
AW	3.943	.221		
WKA	4.150	.207		

GA= Ganta-Afeshum, STE= Saesie-Tsaeda Emba, ATW= Atsbi-Womberta, WKA= Wukro-Kilteawlaelo

Table 12. Reasons why goats are not milked in the study area

Question	Reasons why goats are not milked	**District**						Chi-square Value	Significance level
			GA	STE	ATW	WKA	Total		
Anwere	No culture	N	5	0	22	6	33	56.15	<0.0001
		%	12.5	0	63	15	21.85%		
	Low milk	N	17	15	5	17	54		
		%	42.5	41.6	14.28	42.50	35.76%		
	No culture + Low milk	N	8	2	2	5	17		
		%	20	5.5	5.7	17	11.25%		

GA= Ganta-Afeshum, STE= Saesie-Tsaeda Emba, ATW= Atsbi-Womberta, WKA= Wukro-Kilte-Awlaelo

Herding of goat during the daytime

Methods of goat herding during daytime in the study area are presented in Table 13. The method of managing goats in the study area was influenced by the quantity of animals, the variety of species, the availability of feed resources, the extent of grazing lands, and the availability of labour. Most households in Saesie-Tsaeda-Emba district maintained their goats in isolated area (alone). Nonetheless, households in the Wukro-Kilte-Awlaelo district maintained their goats alongside different animals.The majority of households in the study area herded their goats separately 54 (35.76%) then next they kept with other animals 42 (27.81%) and followed with cattle 33 (21.85%).

Table. 13. Ways of herding goats during day time

District	Ways of herding practice of goats								Total	Chi-square value	Significance level
	with cattle		with sheep		Separately		With all animals				
	N	%	N	%	N	%	N	%			
GA	12	30	13	33	3	8	12	30	40	97.79	0.0001
STE	0	0	3	8	29	80	4	11	36		
ATW	6	17	0	0	5	14	24	69	35		
WKA	15	37.50	5	12.50	18	45.00	2	5.00	40		
Total	33	21.85	21	13.90	54	35.76	42	27.81	151		

Notice N=number of interviewed households, GA= Ganta-Afeshum, STE= Saesie-Tsaeda-Emba, ATW= Atsbi-Womberta, WKA= Wukro-Kilte-Awlaelo

Constraints of goat production

Table 14 displays the findings regarding the constraints of goat production. Various factors influenced goat production in the study area, including shortages of land and feed as well as diseases. The primary constraints in Ganta-Afeshum and Saesie-Tsaeda-Emba districts were the shortage of land and feed. In the Atsbi-Womberta district, the primary constraints were a shortage of water and feed, while in Wukro-Kilte-Awlaelo district, diseases and a shortage of feed were the main issues. Ingeneral, the primary constraints to goat production were identified as feed, land, water shortages, and diseases, ranked first, second, third, and fourth, respectively.

Table 14. Constraints of goat production

Constraints	**District**									
	GA		**STE**		**ATW**		**WKA**		**Total**	
	Index	Rank	Index	Rank	Index	Rank	Index	Rank	Index	Rank
Feed Shortage	0.247	2	0.234	2	0.230	2	0.230	2	0.941	1
Water shortage	0.172	3	0.147	4	0.239	1	0.170	3	0.728	3
Land Shortage	0.268	1	0.259	1	0.225	3	0.163	5	0.915	2
Labour shortage	0.160	4	0.206	3	0.123	5	0.151	4	0.64	5
Diseases	0.143	5	0.142	5	0.171	4	0.233	1	0.689	4
Predator	0.007	6	0.010	6	0.010	6	0.050	6	0.077	6

GA= Ganta-Afeshum, STE= Saesie-Tsaeda Emba, ATW= Atsbi-Womberta, WKA= Wukro-Kilte-Awlaelo

Cactus production and Utilization

Fruit production of cactus cultivars in the study area

Table 15 displays the quantity of fruit yielded from cactus cultivars for each cladode cultivated and distributed in the study area. The prevalent cactus cultivars identified in the study area included Keyh, Lematse, Tsaeda, Korem, Beless Aboy Halibo, and Shenawi, as well as Carrot, among others. The Keyh cultivar produced more fruit in the Ganta-Afeshum district compared to the Saesie-Tsaeda-Emba and Wukro-Kilte-Awlaelo districts. In the study area, the Keyh cultivar exhibited the greatest potential for fruit production, followed by the Lematse cultivar.

Table 15. Fruit production of cactus cultivars

Cultivar		District				P-value
		GA(N) Mean± Se	STE(N) Mean± Se	ATW(N) Mean± Se	WKA(N) Mean± Se	
Keyh	Min	11.63^{a}+0.65	8.66^{b}+0.7	12.8^{a}+0.71	5.55^{c}+0.66	0.0001
	Maxi	21.17^{a}+1.07	17.33^{b}+1.14	19.54^{ab}+1.16	11.92^{c}+1.08	0.0001
Lematse	Min	6.29^{b}+0.25	5.55^{b}+0.27	9^{a}+0.27	4.62^{c}+0.26	0.0001
	Maxi	8.9^{c}+0.38	8.52^{c}+0.4	14.02^{a}+0.41	10.4^{b}+0.38	0.0001
Tsaeda	Min	4.41+0.36	4.8+0.38	4.77+0.38	4.45+0.36	0.82
	Maxi	7.7+0.58	8.22+0.62	8.57+0.63	8.42+0.59	0.75
Korem	Min	1.75^{b}+0.1	2.25^{a}+0.1	0	0	0.0001
	Maxi	3.97^{a}+0.14	4.33^{a}+0.15	0	0	0.0001

Note: N= mean number of fruits produced from each cladodes, GA= Ganta-Afeshum, STE= Saesie-Tsaeda-Emba, ATW= Atsbi-Womberta, WKA= Wukro-Kilte-Awlaelo

Trend of Cactus production

Table 16 displays the answers provided by households regarding the trend of cactus production in every district. The area, occupied by cactus in the study area is diminishing. Based on interviews with 143 households, cactus production is declining in the study area. Particularly, in the Atsbi-Womberta and Wukro-Kilte-Awlaelo districts, the majority of the cactus population suffered from a disease caused by the cochineal insect. Moreover, cactus was heavily utilized through ongoing cutting and transportation, along with being provided to animals and allowing free grazing, which led to a decline in its population in the study area.

Table 16. Trend of Cactus production/population in the study area

District	Responses of households		Chi-square	Significance
	Increasing(N)	Decreasing(N)	Value	level
GA	6	34	11.7	0.008
STE	2	34		
ATW	0	35		
WKA	0	40		
Total	8	143		

GA= Ganta-Afeshum, STE= Saesie-Tsaeda Emba, ATW= Atsbi-Womberta, WKA= Wukro-Kilte-Awlaelo. N=number of households.

Cactus importance/utilization in the study area

Table 18 displays the rankings assigned by households regarding the importance/use of cactus production. In the study area, cactus has been extensively utilized for livestock feed (its pads and fruit peels), for human consumption (its fruits), as a barrier for crops, and for soil and water preservation. Nevertheless, farmers prioritize these various purposes according to their application in the specific districts. In the households of Ganta-Afeshum and Wukro-Kilte-Awlaelo district, cactus production was utilized primarily as animal feed and secondarily for human consumption. However, the primary purpose of cactus production in Saesie-Tsaeda-Emba and Atsbi-Womberta districts was for human consumption, followed by animal feed as the first and second priorities, respectively. In all districts the major purpose of cactus production was for food, for feed as first and second ranks respectively.

Table 17. Importance of cactus production

Importance	District									
	GA		STE		ATW		WKA		Total	
	Index	Rank	Index	Rank	Index	Rank	Index	Rank	Index	rank
Feed	0.313	1	0.266	2	0.268	2	0.325	1	1.172	2
Food	0.305	2	0.333	1	0.331	1	0.27	2	1.239	1
Income(sale)	0.191	3	0.196	3	0.133	4	0.168	3	0.688	3
Fence	0.122	4	0.138	4	0.211	3	0.14	4	0.611	4
Soil cons.	0.067	5	0.064	5	0.055	5	0.096	5	0.282	5

GA= Ganta-Afeshum, STE= Saesie-Tsaeda Emba, ATW= Atsbi-Womberta, WKA= Wukro-Kilte-Awlaelo, cons.=conservation

Ways/Forms of feeding cactus to animals

Table 18 displays the results of the ways of cactus feeding to animals. In the study area, animals could receive cactus cladodes in various ways, such as fresh after being cut directly, processed by chopping, dried, or blended with other feed. In Ganta-Afeshum, Saesie-Tsaeda-Emba, and Atsbi-Womberta districts, households provide cactus cladodes to their animals once after they have eaten other types of feed (such as fibrous feeds like hay, crop residues, and natural pastures). Nonetheless, the majority of households (65%) in Wukro-Kilte-Awlaelo feed cactus cladodes to their animals combined with other feeds. In the study area, a majority of households (68%) provide cactus cladodes to their animals either exclusively or following the consumption of other feed such as crop residues.

Table 18. Ways/Forms of cactus feeding to animals

District	Ways of feeding cactus				Chi-square value	Significance level
	Mixed with other feed		After other feed(alone)			
	N	%	N	%		
GA	0	0	40	100	40.21	0.0001
STE	9	25	27	75		
ATW	13	37.14	22	62.85		
WKA	26	65	14	35		
Total	48	31.78	103	68.21		

GA= Ganta-Afeshum, STE= Saesie-Tsaeda Emba, ATW= Atsbi-Womberta, WKA= Wukro-Kilte-Awlaelo

The dominant cactus cultivars in the study area

Table 19 presents the ranking results given by households to cactus cultivars based on their importance and abundance. In the study area, different cultivars were identified, but there is still a necessity for investigations to define these cultivars. In this study, from the cultivars previously listed in the cactus fruit production section, Keyh was recognized as the leading fruit-yielding cactus cultivar. Across all districts, the importance and occurrence of cactus varieties were Keyh cultivar, Lematse, and Tsaeda in the primary, secondary, and tertiary ranks, respectively. In general, the interviewed farmers stated that the Keyh cultivar was the most common and important for animal feed and human consumption. In Wukro-Kilte-Awlaelo, some households had solely the Lematse cultivar.

Table 19. The dominant cactus cultivars in the study area

Cultivars	District								Total	
	GA		**STE**		**ATW**		**WKA**			
	Index	Rank	Index	Rank	Index	Rank	Index	Rank	index	Rank
Keyh	0.413	1	0.333	1	0.353	1	0.346	1	1.445	1
Lematse	0.290	2	0.238	2	0.329	2	0.306	2	1.163	2
Tsaeda	0.288	3	0.220	3	0.174	3	0.201	3	0.892	3
Korem	0.006	4	0.142	4	0.104	4	0.121	4	0.373	4
Dekik	0.002	5	0.064	5	0.037	5	0.023	5	0.126	5

GA= Ganta-Afeshum, STE= Saesie-Tsaeda Emba, ATW= Atsbi-Womberta, WKA= Wukro-Kilte-Awlaelo

Problems associated with feeding cactus to animals

Table 20 shows the rankings given by households to the problems associated with animals consuming cactus cladodes. Giving fresh cactus pads to animals can result in several problems like bloating, diarrhea, injuries, and potentially death. Farmers surveyed in the study area reported that the main problem faced when feeding cactus to livestock was bloating throughout all districts. Diarrhea was also observed, especially when animals ingested both green forage and fresh cactus pads. Cactus cladodes and green forages contain a significant amount of water in the wet season and producing gas, potentially resulting in bloating and diarrhea.

Table 20. Problems associated with feeding cactus to animals

Problems	District							
	GA		STE		ATW		WKA	
	Index	Rank	Index	Rank	Index	Rank	Index	Rank
Bloating	0.454	1	0.430	1	0.4714	1	0.435	1
Diarrhea	0.329	2	0.393	2	0.362	2	0.370	2
Wt.loss	0.216	3	0.176	3	0.166	3	0.193	3

GA= Ganta-Afeshum, STE= Saesie-Tsaeda Emba, ATW= Atsbi-Womberta, WKA= Wukro-Kilte-Awlaelo, wt.=weight

Coping mechanisms to the problems associated with cactus feeding to animals(bloating)

Table 21 presents the ranks for coping strategies used to manage bloating in animals. In the study area, farmers utilize different traditional methods informed by their local expertise to tackle bloating. The majority of households in the study area used dissolved detergent for drenching to tackle bloating problems. In the Ganta-Afeshum district, a mixture of dissolved malt, egg, and pepper was used to tackle bloating problems caused by animals eating fresh cactus cladodes. Before feeding cactus cladodes to animals, drying them is done to minimize bloating, especially in the Wukro-Kilte-Awlaelo district, and this is ranked as the third method.

Table 21. Coping mechnisms to reduce bloating occurred in animals fed on cactus

Mechanism	District									
	GA		STE		ATW		WKA		Total	
	Index	Rank	Index	Rank	Index	Rank	Index	Rank	Index	Rank
A	0.158	2	0.175	3	0.165	3	0.160	2	0.658	3
B	0.153	3	0.203	1	0.197	1	0.162	1	0.715	2
C	0.312	1	0.201	2	0.194	2	0.118	5	0.825	1
D	0.135	4	0.140	4	0.124	5	0.132	4	0.531	4
E	0.074	5	0.109	5	0.054	7	0.104	6	0.341	7
F	0.064	7	0.057	7	0.146	4	0.1402	3	0.4072	5
G	0.072	6	0.084	6	0.103	6	0.132	4	0.391	6
H	0.028	8	0.027	8	0.015	8	0.05	6	0.12	8

A=oil, B= drenching dissolved detergent, C=drenching dissolved malt+ egg +pepper, D=dung +atela, e=adding water over the body, F=drying choped cactus, G=areki or acheto, H=disolved salt, GA= Ganta-Afeshum, STE= Saesie-Tsaeda Emba, ATW= Atsbi-Womberta, WKA= Wukro-Kilte-Awlaelo

Constraints of cactus production in the study area

Table 22 shows the ranks of constraints associated with cactus production in the study area. In the Ganta-Afeshum and Saesie-Tsaeda-Emba districts, the main constraint on cactus production was drought. Conversely, in the other two districts, the main constraint was diseases resulting from the rise of cochineal insects (more than half of the cacti in these areas are affected by this issue). The second constraint for cactus farming in the Atsbi-Womberta district was a lack of awareness; many households in this area simply cultivate cactus and let it grow naturally without applying management techniques like soil conservation, fencing, redirecting water to the plants, and substituting old cactus with new ones, almost similar to wild cactus. The main constraints of cactus farming determined in the study area were ranked as drought, insufficient land, and inadequate labour, in that order.

Table 22. Constraints of cactus production in the study area

Constraints	District								Total	
	GA		STE		ATW		WKA			
	Index	Rank	Index	Rank	Index	Rank	Index	Rank	Index	Rank
Land shortage	0.306	2	0.240	3	0.083	5	0.159	4	0.788	2
Labour	0.164	3	0.244	2	0.163	4	0.175	3	0.746	3
Drought	0.331	1	0.281	1	0.167	3	0.226	2	1.005	1
Lack of awareness	0.134	4	0.148	4	0.261	2	0.170	5	0.713	5
Diseases	0.063	5	0.085	5	0.323	1	0.268	1	0.739	4

GA= Ganta-Afeshum, STE= Saesie-Tsaeda Emba, ATW= Atsbi-Womberta, WKA= Wukro-Kilte-Awlaelo

DISCUSSION

Goat Production system and Browse Species Availability

Total land holding (farm size) and Composition of livestock per household

Households in the Wukro-Kilte-Awlaelo district possessed more land per household, following with Atsbi-Wemberta district. Conversely, the land sizes of households were smaller in the other two districts. The average land per household (0.62) identified in this study area was comparable to the value (0.7 ha) for Wukro-Kilte-Awlaelo, Atsbi-Wemberta, and Ganta-Afeshum reported by Welday et al. (2019). Nonetheless, it was below the value (1ha) reported by Gebretsadik et al. (2014). In the study area, the size of the land is decreasing because of the rapid increase in human populations and urban development.

In the arid areas of Ethiopia, the number of goats was higher than that of other livestock species. This could be because goats can withstand water scarcity, are smaller in size, have a short reproductive cycle, and can eat even bitter shrubs or trees. The average number of goats per household (12.78) in the study area were higher than that of other livestock species. The prominent presence of goats in the herd composition may be associated with signs of feed availability, including grass cover extent, types and quantities of available feed (with a particularly high ratio of browse to grass), water availability, and the animals' susceptibility to drought, as reorted by Abdulatife and Ebro (2015). In Wukro-kilte-Awlaelo district, the goat population exceeded that of goats found in Atsbi-Womberta district. Consistent with this, Welday et al. (2019) indicated that the goat population was higher in Wukro-kilte-Awlaelo (5) compared to Atsbi-Wemberta (2.8). This could be because the population of goats was generally higher in lowland and midland (Wukro-kilte-Awlaelo) agroecology. In the Saesie-Tsaeda-Emba district, the number of sheep exceeds that found in other districts. Households in Saesie-Tsaeda Emba district possessed a higher number of honeybee colonies compared to those found in Ganta-Afeshum and Wukro-Kilte-Awlaelo districts. In the study area, the population of goats exceeded that of other livestock species. This was similar with the finding by Getaneh et al. (2022), which revealed that the number of goats varies between 8 and 13.66, higher than that of other livestock. Nevertheless, this is higher than the results of Ahmed and Elsamani (2024), who reported that the average number of goats ranged from 7 to 10.5. Additionally, the average number of goats per household in this study was less than the value reported by Abraham et al. (2017) and Tilahun (2023): 43.67 and 14.40 respectively. This could be attributed to a scarcity of land, insufficient feed resources, and a deficiency in other management practices.

Goat Flock Structure and Goat Keeping Experience

The number of goats in each category (age, sex) reflects their significance to households, particularly in typical goat flock structures. The proportion of the different categories of goats indicates the producers' management preferences, which are influenced by their production goals (Adimasu et al., 2019). There were few male and old goats. In Wukro-Kilte-Awlaelo district, the number of dry goats and breeding females was higher than in other the districts, whereas households in Saesie-Tsaeda-Emba district households had more lactating does, breeding males, and kids compared to the other districts. The increased number in the goat herd composition reflects their importance to households in the study area. Households in the study area had the highest number of breeding female goats in their flock structure. This corresponds with the results of Gatew et al. (2015); Tilahun (2023), and Walle et al. (2024), who reported that breeding females constitute the highest proportion of goats, succeeded by kids and weaned goats. The dominance of females in the goat flock structure partly indicates that households prefer female goats for kid production to enhance the flock size (the total number of goats). Nonetheless, generally male goats over one year old were sold for quick cash earnings (Taye et al., 2024).

The practice of goat farming (experience in goat keeping) in the study area has persisted for several years. Nevertheless, certain farmers may transition from goat farming to sheep farming due to challenges related to goat management techniques, yet there are still farmers engaged in goat production. Households in the Saesie-Tsaeda-Emba district have extensive experience in goat farming (31.84), whereas those in Wukro-Kilte-Awlaelo district have less experience (11.09), and households in Ganta-Afeshum district also report lower value (10.17). Ingeneral, households in the study area had considerable experience in goat farming, averaging 15 years.

This result corresponds with the study by Getaneh et al. (2022), which suggested that the average goat farming experience is 13.33 years.

Purpose of keeping goats/Reasons why goats are raised

Goats were raised for various reasons such as meat, milk, sources of income, skin, manure, and cultural significance. The rankings assigned to these various purposes differ in these districts according to the responses from the surveyed farmers. In the study area, the main purpose of goat farming was breeding, followed by generating income, as well as producing milk and manure. Consistent with this finding, Gebretsadik et al. (2014) reported that the primary purpose of keeping small ruminants was first for breeding and secondly for generating income. In contrast to this finding, Abrham et al. (2017), Zereu et al. (2016), and Getaneh et al. (2022) reported that the primary reason for raising goats by household was to generate cash income, second for milk and meat production.

The major feed resources in the study area

In the study area, diverse feed resources were identified, encompassing crop residues, browse species, natural pastures, and cactus cladodes. Goats primarily depend on natural pastures and browse species. During the wet season, farmers predominantly utilize natural grasses, browse species, and weeds for feeding. Notably, half of the households in Saesie-Tsaeda-Emba district significantly incorporate cactus cladodes as feed during this season, with some households in other districts also using them. Conversely, in the dry season the major feed resources are crop residues, cactus cladodes, browse species, and grass hay. These findings align with previous research (Wondatir and Mekasha, 2014; Michaele, 2018; Gebremeskel et al., 2019, Abrham et al., 2017; Taye et al., 2024), who reported that crop residues, grass hay, and browse species are key feed resources in the dry season, while browse species, natural grass, crop residues, and weeds are significant in the wet season.

Availability of browse species in the study area

Browse species were categorized based on their availability and palatability to goats, resulting in classifications such as preferred, desirable, undesirable, non-consumable, and toxic. Farmers interviewed reported that no browse species in the study area were toxic to goats. The most preferred browse species in the study area included chea (*Acacia abyssinica*), Agam (*Carisa edulis*), Acacha (*Acacia saligna*), and Atat (*Maytenus obscura*). The most desirable browse species were Hahot (*Sageretia spiciflora*), Seraw (*Acacia etbaica*), and Tebeb (*Becium grandiforum*) in Ganta-Afeshum district. *Acacia etbaica* was also identified as a significant contributor to the goats' diet (Mengistu et al., 2017; Yayneshet et al., 2008).Tahsas (*D.vicosa*) was the most undesirable browse species. Kilaw (*Euclea schimperi*) was the most non-consumable species, found primarily in parts of Atsbi-Womberta and Wukro-Kilte-Awlaelo districts. This species was generally not consumed by goats normally, but it might be consumed during dry seasons when other browse species shed their leaves. This is supported by Dargo and Haftay (2019) who reported that the dry season progress less palatable species are also browsed by livestock.Generally, the most prevalent and frequently observed browse species in the study area were chea (*Acacia abyssinica*), Agam (*Carisa edulis*), Hahot (*Sageretia spiciflora*), Acacha (*Acacia saligna*), Seraw (*Acacia etbaica*), Atat (*Maytenus obscura*), Tahsas (*Dodonaea vicosa*), and Tebeb (*Becium grandiforum*), Kilaw (*Eculea schimperi*). This aligns with the findings of Gebremeskel Abraha (2016), who identified *Olea europea* (*olea africana*), *Carissa edulis*, *Acacia abyssinica*, *Acacia etbaica*, *Dodonaea angustifolia*, *Euclea schimperi*, and *Maytenus obscura* as present in the eastern zone of Tigray. Similarly, Giday et al. (2018) reported that

Acacia etbaica, *Dodonaea viscosa*, and *Rhus vulgaris* were the most dominant browse species, while *Acacia saligna*, *Carissa edulis*, *Acacia abyssinica*, *Euclea racemosa* (*Eculea schimperi*), and Atat (*Maytenus obscura*) were among the available tree species in Desa'a forest (Eastern Tigray, north Ethiopia).

Sources of water, watering frequency and distance from the household home to water source

The primary water source in the study area, regardless of the season, was the river, a finding that aligns with previous research (Mekuria et al., 2018; Yemane et al., 2020). During the wet season, rainwater served as the primary drinking water source for most animals. The Wukro-Kilte-Awlaelo district exhibited the greatest distance from homes to water sources, averaging 2 kilometers. In the dry season, most animals required daily access to water. Conversely, during the wet season, many animals accessed water only once a week due to its abundance and less frequent household monitoring. Goats, particularly in Wukro-Kilte-Awlaelo district, were observed traveling considerable distances to find water during the dry season.

Milk production (Milking practice, Milk consumption status, reasons why milking is not practiced)

In the study area, goats used as a milk source when the owner lacked a cow for milk production. This is similar to finding of Degen (2007) reported that when households had an adequate number of cows, they did not milk goats. In the study area, most households (73.5%) did not engage in milking goats. This aligned with the results of Hussein et al. (2023), who reported that 75.78% of respondents in the highlands did not milk goats. This might be due to that numerous farmers in the research area believe the milk yield from goats is inadequate (35.76%), and there is also a lack of cultural acceptance and interest (21.85%) concerning goat milk utilization. This was similar to the results of Zereu et al. (2016), who reported that most respondents (96%) did not consume goat milk due to various factors, including cultural beliefs (85%), limited awareness of goat milk's significance (9%), and the low amount of milk produced by goats (7%). The lactation length of goats ranged from 4-5 months.This was similar to the finding of Degen (2007), who reported the lactation period of goats was 300 day (six months). However, it was higher than the value 3 month reported by Hussein *et al*. (2023) and Abrham et al. (2017).The difference might be due to management practice, breed, parity, or diet. Begait goats under a semi-intensive management system had the longest lactation length, whereas goats managed under extensive management had the shortest lactation length (Abrham *et al*., 2017).

Goat herding during daytime

Methods of goat herding differ between households based on labour availability, feed resources, land size, herd size, and animal diversity. In the study area, many households maintained their goats separately when they had a high number of animals, a vast browsing area, and sufficient labour. If there were only a few goats and no labour available, they kept their goats alongside other livestock. In Gant-afeshum and Atsbi-Wemberta districts, most households keep goats alongside other animals during the day. In total, households managed their goats separately, with 54 (35.76%) while 42 (27.81%) households kept goats alongside other livestock, and 33 (21.85%) households kept goats with cattle. This is consistent with the results of Getaneh et al. (2022) and Taye et al. (2024), who reported that a significant number of goats were herded alone, followed by those herded alongside other animals and cattle during the day.

Constraints of goat production

In Ethiopia, the Eastern zone of Tigray is experiencing a decrease in grazing land because of urban growth and the spread of crop cultivation into these areas. Additionally, the scarcity of water caused by recurrent droughts affects the development of various natural feed sources. Several households in the study area also lack the labour to tend to goats and often let their animals roam in the rangelands, particularly in the Saesie-Tsaeda-Emba district; goats could be lost by predators. This was similar to the finding of Kocho (2007), who reported that predators lead to significant losses of young kids in goat-dominant Kebeles. In Ganta-Afeshum and Saesie-Tsaeda-Emba districts, the main issues were insufficient land and water. On the other hand, in Atsbi-Womberta district the main issue was lack of water, whereas in the Wukro-Kilte-Awlaelo district, the key concern was diseases. Throughout all districts, the primary challenges were recognized as lack of feed, land, and water, with diseases ranking first, second, third, and fourth accordingly. This was consistent with the results of Zereu et al. (2016); Abraham et al. (2017); Yemane et al. (2020), and Hussein et al. (2023) who reported that the primary constraints in goat farming were water scarcity, feed and land shortage, absence of high-yield goat breeds, and disease.

Cactus production and Utilization

Cactus production was often vital in many arid areas, such as the Tigray region of Ethiopia. This was because of insufficient rainfall and the presence of unfavorable conditions for cultivating other types of plants, including crops or grains, grasses, and fruits.

Cactus fruit production from each cladode in the study area

Cactus fruit production in Tigray was traditionally managed, and due to insufficient knowledge of modern orchard practices, most cactus plantations in the area are grown too densely and at higher elevations on steep terrains, complicating the complete harvesting of the fruits. Due to the previously mentioned agricultural issues, the use of the available resource is quite minimal, with the fruit harvesting percentage estimated to be no more than 28% (SAERT, 1994). Most of the fruit harvest is wasted in the field. This also affects the harvest quantity, meaning there is inadequate pruning and harvesting tools to minimize loss (Dulume, 2010).

The main cactus cultivars in the study area that were used for fruit production are Keyh, Lematse, Tsaeda, Korem, Beles Aboy Halibo, and Shenawi. Consistent to this study Bazie et al. (2019), reported that the primary cactus cultivars identified in the Ganta-Afeshum district are Lematse, Keyh, Tsaeda, and Beles Aboyhalibo. In the study area from these, the Keyh cultivar showed the highest potential for fruit yield, followed by the Lematse cultivar. This provides the reasoning for why households favor this cultivar in the research area. In the Erob district, the cultivars Neitsi (Tsaeda), Gerao (Keyh), Naharisa, Orgufa, and Suluhna were identified as high-yielding cultivars; yielding 423, 322, 317, 278, and 224 fruits respectively per cactus plant (Nefzaoui et al., 2010).

Trends of Cactus production (population)

Currently, the extent of land occupied by cactus in the study area is diminishing. Especially in the Atsbi-Womberta and Wukro-Kilte-Awlaelo districts, a considerable amount of the cactus population was affected by a condition linked to the cochineal insect. Most cactus species in the Wukro-Kilte-Awlaelo district have suffered damage and have predominantly vanished. This aligns with the observation by Gebretsadik et al. (2013), who reported that the cochineal insect was spreading and encroaching upon the cladodes through wind and human activities, causing the cactus to cease producing new cladodes and fruits, leading to their decline.

Importance of cactus /utilization of cactus in the study area

Cactus served various purposes, as it could be used for food, livestock feed, firewood, fencing, and for the conservation of soil and water by the households in the study area. The main purpose of cactus production in the Ganta-Afeshum and Wukro-Kilte-Awlaelo districts were for animal fodder, with its contribution to human food coming in second. On the other hand, in the Saesie-Tsaeda-Emba and Atsbi-Womberta districts, the main purpose of growing cactus was to provide food for households, while the secondary use was for animal feed. The main purpose of cactus farming in the study area was for animal fodder in the dry season, while its fruits served as food and a source of income in the wet season. This is consistent with the finding of Gebretsadik et al. (2013) and Friew et al. (2008), who reported that in the Tigray region, cactus production mainly acts as an essential source of emergency feed, especially in drought periods, and supports food and income generation during wet seasons.

Forms/ways of cactus feeding to animals

The majority of households in the Ganta-Afeshum, Saesie-Tsaeda Emba, and Atsbi-Womberta districts supplied cactus cladodes to their livestock, especially cattle, after other feed types were consumed. In contrast, numerous households in Wukro-Kilte-Awlaelo district provided their animals with cactus pads combined with various other feed types. Most households in the study area, the main method consisted of providing cactus to animals either by alone or following other feed sources such as crop residues. This corresponds with the findings of Friew et al. (2008), who reported that many households offer cactus to their animals after other feeds or alone.

Cactus cultivars (importance and abundance)

In the study area, the Keyh cultivar, along with Lematse, was the most common and important for animal feed and human food, particularly during the wet season when the growth of other plants such as cereals, vegetables, and fruits was difficult. This is consistent with the results of Gebremeskel et al. (2013), who found that Keyh cultivar, along with the Lematse cultivar, were the most commonly distributed cultivars in the Ganta-Afeshum district. In Wukro-Kilte-Awlaelo district some households depended exclusively on the Lematse cultivar, utilizing it for food and as animal feed. All farmers possess both spiny and spineless cactus; the spiny type is dominant even in the Ganta-Afeshum district.

Problems associated with feeding cactus to animals

Cactus cladodes serve as a crucial feed resource in many arid areas of Tigray; however, issues such as weight loss, bloating, and diarrhea can arise if cactus is the only feed utilized for animals. Bloating and diarrhea occurred when animals consumed fresh cactus containing high moisture content. This coincides with the finding of Gebremariam (2004); Gebretsadik et al. (2013), and Firew et al. (2008), who reported that issues such as bloating, diarrhea, physical injuries (tooth loss), and mortality are significant problems linked to feeding cactus to livestock. Bloating is occurred when animals consume green feed resources including fresh cactus cladodes that have the potential to produce foam or gas.However, diarrhea is occurred when animals consume more fresh cactus cladodes before animals fed fiber resource feeds like crop residue, hay etc or when animals fed on a feed containing high amount of fresh cactus cladodes than other feeds.

Coping mechanisms to the problems occurred when animals fed cactus (Bloating)

Households might use different techniques to tackle the problem of animal bloating caused by eating excessive amounts of high-moisture cactus cladodes, including the application of oil, providing a solution of detergent, administering a blend of malt, egg, and pepper, mixing dung with atela, spraying water on the animal's body, dehydrating chopped cactus, or utilizing areki or acheto, as well as dissolved salt. Among these techniques, most households interviewed in the study area utilized dissolved detergent to tackle bloating problems. This is consistent with the results of Gebremariam (2004). In the Ganta-Afeshum district, a mixture of dissolved malt, egg, and pepper was employed to address the bloating that resulted from feeding animals fresh cactus cladodes. In Wukro-Kilte-Awlaelo district, households employed drying as a third method to decrease the occurrence of bloating. Besides the previously mentioned methods, most households in the study area use spiny cactus after burning. In accordance with this, a greater percentage of farmers (55%) in the Irob district favor spiny cactus pear over spineless due to their belief that feeding spiny cactus after burning of it spines reduces the water content of cladodes, thus preventing bloating and diarrhea (Firew Tegegne et al., 2008).

Constraints of cactus production

In the Ganta-Afeshum and Saesie-Tsaeda-Emba districts, the main constraints to cactus production were drought. In the other two districts, the primary concern was diseases from cochineal insects, affecting more than half of the cacti in those districts. Moreover, in Atsbi-Womberta district, a major obstacle for cactus cultivation is the absence of knowledge; numerous households merely plant cacti and allow them to grow without utilizing any management strategies, like soil conservation, fencing, channeling water to the plants, or substituting old cacti with new ones. The main constraints recognized in the study area for cactus production were ranked as drought, lack of land, and inadequate labour in the first, second, and third orders respectively. This is consistent with the results of Gebretsadik et al. (2013), who reported that land shortage, diseases, and insufficient knowledge are major constraints to cactus production.

CONCLUSION

Goats are the primary livestock species in the study area, and the quantity of breeding female goats exceeded that of other types of goats. In the wet season, the primary feed resources included natural grasses and browse plants, whereas in the dry season, crop residue, cactus cladodes, browse plants, and grass hay became the main feeding resources. The most favored browse species in the research area were chea (*Acacia abyssinica*), Agam (*Carisa edulis*), Atat (*Maytenus obscura*) and Acacha (*Acacia saligna*). In the study area, households identified the primary constraints to goat production as a lack of land, followed by feed, and then water. In the study area, the Keyh cultivar abundant, followed by Lematse. The primary reason for cactus cultivation was for food, particularly during the wet (rainy) season. In the study area, the trend of cactus cultivation is declining due to significant challenges (drought, land shortage, and labour shortage). Additional studies might explore effective cactus management and reducing disease occurrences from cochineal insects to enhance cactus population and yield. The district officers, Development Agents and other stakeholders must be creat awareness to households for cactus production management improvements. Future research should dedicate a study to developing a scientifically sound, practical management strategy for cactus-induced bloating on farms.

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Paper II

Original article

Evaluation of the nutritive value of cactus (*Opuntia ficus-indica L.*) cultivars and other browse species in Eastern Tigray, Ethiopia.

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Abstract

Seasonal feed shortage is one of the major constraints for livestock production in Ethiopia. This study evaluated the nutritive value of five cactus cultivars (Dekik, Korem, Lematse, Tsaeda, and Keyh) and other browse species (Acacia saligna, Eculea schimperi, Olea europea, Carisa edulis, and Dodonaea viscosa) in Eastern Tigray, Ethiopia, for their potential to address feed shortage. These plants were chosen for their abundance and utilization as animal feed by the local community. The plants were characterized in terms of chemical composition and nutritive value across seasons. The forages differed significantly in chemical composition and Invitro dry matter digestibility. Among the browse species, D. viscosa had the highest crude protein (CP) content (17.73%) during the wet season, and O. europea and C. edulis had the lowest). Eculea schimperi had the lowest in vitro dry matter digestibility (IVDMD) (44.23%) during the wet season, and D. viscosa had the highest (70.47%). This plant also showed higher dry matter digestibility (DMD) (80.97%) and relative feed value (309.27) compared to the other browse species. Among cactus cultivars, the lowest CP content was recorded in Korem and Dekik in the dry season (7.8%), while the highest was in Lematse in the wet season (11.17%). The highest IVDMD was recorded in Keyh in the wet season (70.59%), while the lowest was in Tsaeda and Dekik in the dry season (61%). In this study, plant samples harvested in the wet season showed higher CP, IVDMD, relative feed value, and energy content than those samples harvested during the dry season, whereas plants harvested in the dry season showed higher fiber contents. We conclude that the cactus cultivars Lematse and Keyh and the browse species A. saligna and D. viscosa are superior than the other species and cultivars (for their better protein contents, digestibility, and lower fiber contents) for ruminants in the study area. However, feeding trials are needed to further affirm the results of this study.

Key words: Acacia saligna, Crude Protein, Dodonaea viscosa, Lematse, Nutritive value

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INTRODUCTION

Mixed crop-livestock production system in which livestock play a key role in the national economy and rural livelihoods, predominates Ethiopian rain-fed agriculture (FAO, 2018; Mekuria and Mekonnen, 2018). Livestock production in Ethiopia is, however, constrained by an inadequate supply of quality animal feed (Balehegn et al., 2020). The problem is even severe in areas, where erratic and unreliable rainfall results in seasonal fluctuations in feed supply.

Multipurpose browse species, either native or introduced, or both, offer considerable potential for use in mixed crop-livestock systems to alleviate and complement the low-quality forages from communal grazing lands and crop residues, in Ethiopia (Bezabih et al., 2014; Sisay et al., 2017). For a large part of the dry season, the browse species could maintain higher CP levels, which could partly help solve the shortage of energy and protein feedstuffs and supplement low-quality forages grazed by ruminant livestock (Sisay et al., 2017; Feyisa et al., 2022). Browse species are useful sources of animal feeds, as these plants remain green during the dry season and also provide vegetation with better nutritive value than other annual grass and herbaceous species that decline (Aregawi et al., 2008; Mangara, 2018; Belachew et al., 2020). Multipurpose browse species, can also complement crop production by maintaining soil fertility and fixing nitrogen, or when used as mulch (Murmu, 2018). Hence, the use of these forage plants can be a potentially efficient way to sustainably improve the nutrition of ruminants kept in smallholder farming systems. It would thus be justifiable to look for locally available alternative feed resources that are easily accessible to smallholder farming communities.

The cactus plant is grown abundantly in many dry land areas of northern Ethiopia and can be used to address livestock feed shortages. It has the ability to maintain its greenness and nutritive value through the dry season. This plant can grow in areas receiving as little as 200 mm of rainfall (Georgis et al., 2010). It increases its importance that has been introduced in the marginal lands of Ethiopia to combat feed and food insecurity, to support household income, and prevent land degradation (Tegegne, 2007; Georgis et al., 2010; Belay et al., 2011; Ziadat & Bayu, 2015; Meaza et al., 2024). Cactus is widely grown in dry land areas because it can tolerate water-limited conditions, high temperatures, and poor soils (Sipango et al., 2022). In the Tigray region alone, wild cactus covered about 32000 ha of land (Belay et al., 2011). It is also increasingly cultivated by smallholder farmers. and is reported to be an important livestock feed, especially in moisture-deficient or drought-prone areas like in Tigray, Ethiopia (Tegegne, 2007; Georgis et al., 2010; Gebretsadik et al., 2013; Lijalem and Kebede, 2024). Cactus is available green throughout the year, rich in water and water-soluble carbohydrates, and therefore it is suitable as a supplement to crop residue when other feeds are scarce. However, it is low to moderate in CP content (Tegegne, 2007; Nipane et al., 2021), suggesting the need to search for alternative fodder plants that can be combined with this species.

Several indigenous browse species are untapped and can help to ease some of the problems associated with low feed quality and partly address the major problems of long-term sustainability of crop-livestock systems in Ethiopia. These feed resources in the Tigray region, for instance, are widely used by the farmers in conjunction with cactus and crop residues (Georgis et al., 2010; Tegegne, 2007). Although several works on the nutritional values (e.g., in terms of their digestibility and chemical composition) of browse species, including cactus—are available from different parts of Ethiopia (e.g. Fentahun et al., 2020; Gebreegziabher and Tsegay, 2015; Hassen et al., 2017; Bazie et al., 2019; Teklu et al., 2023), such studies are still scarce for the Tigray region, northern Ethiopia. Such studies are essential to identify from a pool of observed species a few promising species (that is, consistently better performing in at least two seasons in the same year) in the area where it is identified (in the present study case, eastern Tigray region). These studies are also vital for predicting the production performance of the grazing/browsing animals of the study area, identifying limiting nutrients for a target production, and for prioritizing individual species or pasturelands for management or development (Bezabih et al., 2014). Hence, the present study was conducted to evaluate (and compare over seasons) the nutritive value of five cactus cultivars (Lematse, Tsaeda, Dekik, Korem, and Keyh) and selected tree/shrub species (*Eculea schimperi*, *Dodoneae viscosa*, *Olea europea*, *Acacia saligna*, and *Carisa edulis*) identified from the Eastern Tigray zone, northern Ethiopia.

MATERIALS AND METHODS

Description of the study area

This study was carried out in the Eastern zone of the Tigray region located in northern Ethiopia. It is located between 13°33′ to 14°40′ N and 39°11′ to 39°59′ E. The total area of the zone is 561,000 ha, which is divided into seven districts: Erob, Hawzen, Wukro, Atsbi-Womberta, Ganta-Afeshum, Gulo-

Mekeda, and Saesie-Tsaeda-Emba. The altitude ranges from 1500 to 3280 m above sea level. The study zone has three traditional agro-ecological zones: (i) highland, with areas over 2300 m above sea level; (ii) midland, between 1500 and 2300 m above sea level; and (iii) lowland, with areas less than 1500 m above sea level (Meles et al., 1997). Most of the districts are categorized as Highland or Dry Dega, followed by Midland or Dry Weinadega. The area has a semi-arid climate and receives bimodal rainfall: the main rainy season (June–September), locally known as Kiremt and a small rainy season (February–May), locally known as Belg. The rainfall is highly variable due to the complex influences of topography (Meles et al. 1997). The mean annual rainfall ranges from 520 to 680 mm, and the mean annual temperature varies between 16 and 20 °C (Kahsay et al., 2019)

Sample collection

Samples were collected from Ganta-Afeshum, Saesie-Tsaeda Emba, and Atsbi-Womberta districts of the study area. These districts were selected purposively based on the abundance and utilization of the following browse species and cactus plants. These districts are relatively homogenous in terms of agroecology, farming system, and natural vegetation, though the former two districts are relatively rich in cactus plants. Five commonly grown, multipurpose cactus cultivars (Dekik, Keyh, Korem, Lematse, and Tsaeda and five tree/shrub species (*A. saligna*, *C. edulis*, *O.europea*, *E.schimperi*, and *D.viscosa/angustifolia*) were selected based on the abundance of the species and their broader utilization by the farmers in the study area (Gebretsadik et al., 2013 ; Mengistu, 2017; Atsbha and Wayu, 2020). Species selection was also based on extension agents' opinions and farmers' knowledge of the tree forages preferred by Animals. Samples of cactus cultivars were collected from two randomly selected (one each from Ganta-Afeshum (i.e. Kokob Tsibah) and Saesie-Tsaeda Emba (i.e. Emba-Esmena) kebeles while samples of the tree/shrub species were collected from a randomly selected kebele of Kelisha from Atsbi-Womberta district, where the above-listed trees/shrubs are dominantly found. For trees/shrubs, sampling was conducted in an enclosed area. Samples were harvested from cladodes or young leaves of cactus and the leaf part of the tree/shrub species during the wet season (August/September) and in the dry season (January/ February). The samples of tree/shrub were collected at the same time at early growth stage (before bearing flowers) from 5-10 plants from the same species. The samples from cactus cultivars were harvested before the plants began to produce fruits, from 2-5 plants from the same cultivar. The samples were oven-dried for 72 hours at 65 ^{o}C and reweighed to determine the DM content. The dried samples were ground separately and then passed through a 1 mm sieve. The nutritive quality of plants collected from the study area during the wet and dry seasons was evaluated on the basis of chemical composition, IVDMD, dry matter intake, dry matter digestibility, and relative feed value. Samples were analyzed at the Animal Science Laboratory of Mekelle University and Holleta Agricultural Research Center, Ethiopia.

Chemical analysis and *in vitro* dry matter digestibility

The ground samples were analyzed for chemical composition on a dry matter basis. The nitrogen (N) concentration was determined based on (AOAChemists, 1990). Crude protein (CP) content was calculated as 6.25 x N concentration. Neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) were determined according to Van Soest et al. (1991).The *in vitro* dry matter digestibility was determined using the two-stage (Tilley and Terry, 1963) method.

Determination of Relative Feed Value

Dry matter intake (DMI), digestible dry matter (DDM), and relative feed value (RFV) were estimated using the following equations

$\mathrm{DDM}(\%) = 88.9 - (0.779 * \%\mathrm{ADF})$; $\mathrm{DMI}(\%\text{ of BW}) = 120/(\%\mathrm{NDF})$ (Mertens, 2002)

$\mathrm{RFV} = ((\%\mathrm{DDM} * \%\mathrm{DMI}))/1.29$ (Jeranyama and Garcia, 2004).

Metabolizable energy (ME) was computed following the formula recommended in the Australian Agricultural Council (1990) as $\mathrm{ME}(\mathrm{MJ/kgDM}) = (0.17 * \%IVDMD) - 2$

Where, DDM is the dry matter digestibility; ADF is the acid detergent fiber (% of DM); DMI is the dry matter intake (% of BW) and RFV is the relative feed value. The forage quality grading standard assigned by the Hay Marketing Task Force of the American Forage and Grassland Council, the RFV, was assessed as roughages based on prime (>151), premium (151–125), good (124–103), fair (102–87), poor (86–75), and reject (<75) (Rohweder et al., 1978).

Statistical Analysis

The data on chemical composition, IVDMD and DMI, DDM, and RFV were analyzed using factorial(species and season) analysis of variance (ANOVA) using the general linear model procedure of Statistical Package for Social sciences (SPSS 16.0) software. In addition, Pearson's correlation coefficient (r) was used to decide whether there was a relationship between IVDMD, CP, ash, NDF, ADL and ADF. The statistical model included the effects of plant species, season and their interactions. Tukey's significance difference (HSD) was used to compare means ($P < 0.05$). The significance level was set at 5%.

The following model was used for data analysis:
$Y_{ijk} = \mu + A_i + B_j + (AB)_{ijk} + eijkl$, where Y_{ij} = response variable, μ = overall mean, A_i = effect of plant species/cultivars, B_j = effect of season, $(AB)_{ijk}$= interaction effect of season with species/cultivar, and e_{ijkl} = random error.

RESULT AND DISCUSSION
Chemical composition and *in vitro* dry matter digestibility of tree/shrub species

The chemical composition and in vitro dry matter digestibility of the tree/shrub species are shown in Table 1. Among the tree/shrub species, the highest DM content was recorded in *O.europaea* in dry (93.60%) and wet (92.81%) seasons; followed by *C. edulis* and *D.viscosa* in the dry and wet seasons. The lowest DM content was recorded in *E. schimperi* in the wet season (85.22%). The total ash content of the tree/shrub species ranged from 2.62% in *A. saligna* in the wet season to 9.48% in *C. edulis* in the dry season. Factors such as soil, climate, stage of maturity, and season contribute to variations in the nutritive values of forages. The DM, for example, increases as the plant matures and as the dry season advances (Mueller-Harvey, 2006), in line with what was observed in the current study. The ash value of *A. saligna* was slightly lower than the ash value of 7.9%-14.1% reported by Gebremeskel et al. (2019). The ash value of *C.edulis* and *O. europaea* was similar to the values 8.39% and 7.09% reported by Girma et al. (2015). However, the ash value of *C.edulis* was higher than the value 6.2% reported by Fentahun et al. (2020). The ash content of tree/shrub species reported in this study was higher than the reported data by Ali et al. (2020).
Overall, the CP ranged from 8.2 to 17.73%. *Dodonaea viscosa* had the highest CP content (17.73%) followed by *A.saligna* (15.92%) in the wet season. In the dry season *A. saligna* (14.25%) followed by *D. viscosa* (12.43%) had the highest CP content and *O. europea* had the lowest CP content. As expected a wide variation in CP content was recorded in this study between the species in both seasons; the amount of CP increased from dry to wet season. The CP values reported in this study were comparable to the results of other studies (Yayneshet *et al*., 2009; (Girma *et al*., 2015; Hassen *et al*., 2017; Flores *et al*., 2020) reported values (10.3%–24.4% for wet season and 7.6%–20.2% for dry season). The CP value reported for *D.viscosa* in this study was lower than those (14%) reported by Yisehak and Janssens (2013) but similar to the value (17.43%) reported by Ali *et al*. (2020). Similarly, the CP value reported for *C. edulis* and *O.europea* in this study was similar to the value reported by Ali *et al*.(2020). The CP value reported for *C. edulis* (8.12%) in the dry season and 10.32% in wet season was similar to the CP values 10.8% and 8.15% reported by Girma *et al*. (2015).However, it was lower than the CP value of 13.6% reported by Yisehak and Janssens (2013).The CP value reported for *O. europea,* 12.2% in the wet season

and 11.6% in the dry season, was lower than the value reported by Girma et al. (2015). The lower CP content of tree/shrub species during the dry season compared to the wet season may be attributed to a higher percentage of fiber fractions (NDF,ADF, ADL), lower soil moisture content, a higher age of the plant linked to leaf maturity, and less nitrogen availability (Anele *et al*., 2008; Anele *et al*., 2009; Belachew *et al*., 2013; Yayneshet *et al*., 2009;Yu *et al*., 2022) and translocation of nutrients especially nitrogen from leaf to stem (Hagen-Thorn *et al*., 2006).

The CP content is a very important index of the nutritional quality of a feed. The tree/shrub species tended to have higher CP content (range: 8–18%) which is above the recommended crude protein levels of 7% which supply the microbial requirements of nitrogenous compounds; below which ruminal fermentation of forages (digestibility) may be limited and NDF is not used adequately and feed intake decreases (Van Soest, 1994). Crude protein content of *A. saligna* and *D.viscosa* was above the recommended minimum requirement for early finishing lambs (14.5%CP) (NRC, 1985). The results showed the CP content of the tree/shrub species was adequate to be sufficiently high to warrant consideration of their use as a protein supplement to low-quality diets, except *C. edulis* and *O.europaea* in the dry season; which showed less promising potential than the rest tree/shrub species.

Fiber content of tree/shrub species in this study increases from the wet to the dry season. This might be due to low moisture content of soil, advanced maturity of plants, low rainfall and harvesting season (Hassen *et al*., 2007; Camacho *et al*., 2010; Arigbede *et al*., 2012). The NDF content was lowest in *D. viscosa* in both seasons and highest in *O. europaea* and in *E. schimperi* in dry season. The NDF content of tree/shrub species in this study ranged from 24.40% to 57.80%. The studied tree/shrub species had NDF content below 45% on dry matter basis with the except *E. schimperi* and can be classified as high-quality forages (Singh and Oosting, 1992), and their NDF content was below the threshold level of 60% (Meissner *et al*., 1991), beyond which the DM intake by the animal is negatively affected.

The ADF content was lowest in *D. viscosa* in both seasons and while highest in *O. europaea* in wet season. The ADF is made up of proteins, cellulose, and lignin, which prevent the cell wall's carbohydrates from breaking down at the rumen stage (Harper and McNeill, 2015). It is used to indicate the forage species' potential for consumption, energy availability, and diet digestibility i.e. thus, the lower the ADF content of the forage, the higher its nutritional quality and energy levels (Tambara *et al*., 2017). All the tree/shrub species in this study had ADF content below 40% and can thus be classified as high-quality forages (Kellems & Church, 2002).

The ADL content was lowest in *D. viscosa* in both seasons and highest in *C. edulis* in wet season and *E.schimperi* in the wet and dry seasons. Despite wide variations between seasons, with the except for *E. schimperi*, in both seasons in this study, tree/shrub species had lignin contents below the maximum threshold of 10%, which is expected to restrict the amount of DM consumed (Reed et al., 1988). Consequently, none of the tree/shrub species in this study is likely to affect on the animals' DM consumption. The higher fiber (NDF, ADF and ADL) content of tree/shrub species in the dry season was due to the advanced stage of maturity and lignification (Hussain and Durrani, 2009) and higher temperature because it promotes the development of structural fibers in plants (Bismarck et al., 2005 ; Goudenhooft et al., 2019).

Dodonaea viscosa in the wet season had the highest *in vitro* dry matter digestibility (70.47%) among the other tree/shrub species. The lowest IVDMD was recorded in *E.schimperi* in the dry season (44.24%). *In vitro* dry matter digestibility did not vary due to the interaction effect of season and species. However, it was varied among species and between seasons. It was higher in the wet season than in dry season and its value ranges from 44.24%-70.47%. This coincides with the values of previous studies (Hassen et al., 2017; Fentahun et al., 2020; Ravhuhali et al., 2022) who reported (62.3%–67.8%, 64.78%, 49.61% for wet season) and (50.8–65.8%, 57.35%, 44.69% for dry season) respectively. Due to their negative correlation between feed digestibility and ADF content, tree/shrub species with high ADF content may have low digestibility (McDonald et al., 2002). There is a physical restriction on eating when IVDMD is less than 550 g/kg. Additionally, the rate of digestion and transit through the gastrointestinal system implies that intake is limited; therefore weight loss is inevitable (Dynes & Schlink, 2002).

Table 1. Chemical Composition and *In vitro* DM Digestibility of Browse Species

Season		Chemical composition(%DM)					
	DM%	Ash	CP	NDF	ADF	ADL	IVDMD
Wet	41.72^{b}	6.55^{b}	13.53^{a}	39.61^{b}	18.00^{b}	9.30	58.00^{a}
Dry	42.54^{a}	7.42^{a}	10.75^{b}	41.59^{a}	19.15^{a}	8.88	53.62^{b}
SEM	0.110	0.084	0.23	0.33	0.28	0.203	0.55
P-value	<0.0001	<0.0001	<0.0001	<0.0001	0.009	0.304	<0.0001
Species							
A.saligna	39.07^{c}	3.73^{c}	15.08^{a}	36.18^{d}	17.97^{b}	9.47^{b}	57.75^{b}
C. edulis	41.01^{b}	8.92^{a}	9.26^{c}	40.92^{c}	18.59^{b}	10.49^{b}	50.49^{c}
O. europaea	49.61^{a}	7.26^{b}	9.34^{c}	43.83^{b}	23.48^{a}	7.45^{c}	57.10^{b}
E. schimperi	41.64^{b}	7.43^{b}	11.94^{b}	55.48^{a}	21.74^{a}	13.14^{a}	47.01^{c}
D.viscosa	33.39^{c}	7.58^{b}	15.08^{a}	26.54^{e}	11.13^{c}	5.19^{d}	66.69^{a}
SEM	0.175	0.134	0.36	0.53	0.44	0.32	0.87
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Species *Season							
Wet Season							
A.saligna	38.52	2.62^{e}	15.92^{ab}	34.38^{f}	16.92^{cd}	8.86^{c}	59.50^{bc}
C. edulis	40.59	8.36^{b}	10.32^{e}	39.83^{de}	17.24^{d}	11.29^{b}	51.50^{cd}
O.europaea	49.63	6.47^{c}	10.56^{de}	46.28^{c}	25.6^{a}	8.66^{bc}	58.74^{bc}
E. schimperi	40.927	8.75^{ab}	13.13^{bc}	53.16^{b}	20.08^{c}	11.94^{b}	49.79^{d}
D. viscosa	38.96	6.57^{c}	17.73^{a}	24.40^{h}	10.17^{f}	5.74^{de}	70.47^{a}
Dry season							
A.saligna	39.62	4.84^{d}	14.25^{b}	37.99^{e}	18.94^{c}	10.08^{bc}	56.00^{c}
C. edulis	41.44	9.48^{a}	8.2^{e}	42.01^{d}	19.94^{c}	9.68^{bc}	49.48^{d}
O. europaea	49.59	8.05^{bc}	8.12^{ef}	41.46^{d}	21.36^{bc}	6.24^{d}	55.46^{c}
E. schimperi	42.36	6.12^{c}	10.76^{d}	57.80^{a}	23.41^{b}	14.34^{a}	44.23^{e}
D. viscosa	39.69	8.6^{b}	12.43^{cd}	28.69^{g}	12.09^{e}	4.64^{e}	62.92^{b}
SEM	0.24	0.189	0.514	0.75	0.626	0.45	0.87
P-value	0.078	<0.0001	0.017	<0.0001	<0.0001	<0.0001	0.229

Means with different superscripts (a, b, c, d, e. f, g, h) in the same column are significantly different (P<0.05), SEM=standard error of mean, IVDMD=*In vitro* dry matter digestibility, NDF=neutral detergent fiber, ADF=acid detergent fiber, ADL= acid detergent lignin, DM=dry matter

Dry matter intake, dry matter digestibility, and relative feed value of tree/browse species

Dry matter intake, dry matter digestibility and relative feed value of tree/shrub species are shown in Table 2. The values for dry matter intake, DMDigt and relative feed value varied due to season, species and the interaction of species and season. However, there is no significant difference in the metabolizable energy of tree/shrub species due to the interaction effect of species and season. Overall, among the tree/shrub species dry matter intake, dry matter digestibility (DMD), and relative feed value (RFV) were significantly (p<0.05) higher for *D. viscosa* and lowest for *E. schimperi*. The dry matter digestibility was higher in the wet season than the in dry season, except in *O. europea* and its value ranges from 68.95%-80.97% in wet season and 70.66%-79.48% in dry season. This was similar to the value 52.5% to 76.3% in the wet season and 43.1%–67.2% in dry season reported by Ravhuhali et al., (2022) but it was higher than the values 64.75- 72.54 and 62.5-125.7 reported by Kazemi et al. (2012) and Geleti et al. (2013) respectively. Metabolizable energy of tree/shrub species was higher in wet season than in dry season and its value ranges from 7.11-7.86MJ. Metabolizable energy (ME) were significantly higher for *D.viscosa* and lowest for *E.schimperi* (ranges from 5.99-9.3MJ/kg). This is similar to the value (8.3MJ/kg) reported by Belete et al.(2024). The relative feed value of browse species in this study was similar to the value 100.94-246.88 reported by Kazemi et al. (2012) and Mayouf and Arbouche (2014). The tree/shrub species studied had a relative feed value above 151 value quality standard and could be classified into quality standard of prime forage (high quality standard) except *E.schimperi* in both seasons and *O.eurpoea* in wet season which are classified in to quality standard premium (1) and good (2) quality forages.

Table 2. Dry matter intake, dry matter digestibility and relative feed value of tree/shrub species

Season	Estimated parameters			
	DMI(%LW)	DMD(%)	RFV	ME(MJ/kg)
Wet	3.26^{a}	74.87^{a}	191.59^{a}	7.86^{a}
Dry	3.04^{b}	73.98^{b}	175.61^{b}	7.11^{b}
SEM	0.035	0.218	2.25	0.094
P-value	0.0001	0.0001	0.0001	0.0001
Species				
Acacia saligna	3.33^{b}	74.93^{b}	193.46^{b}	7.81^{b}
Carisa edulis	2.93^{c}	74.41^{b}	169.41^{c}	6.58^{c}
Olea europea	2.74^{c}	70.60^{c}	150.47^{d}	7.70^{b}
Eculea schimperi	2.16^{d}	71.96^{c}	120.98^{e}	5.99^{c}
Dodonaeae viscosa	4.55^{a}	80.22^{a}	283.70^{a}	9.33^{a}
SEM	0.055	0.34	3.55	0.15
P-value	0.0001	0.0001	0.0001	0.0001
Species *Season				
Wet season				
Acacia saligna	3.49^{b}	75.71^{c}	205.32^{c}	8.11^{bc}
Carisa edulis	3.01^{c}	75.46^{c}	176.35^{e}	6.75^{d}
Olea europea	2.59^{d}	68.95^{g}	138.84^{gh}	7.98^{b}
Eculea schimperi	2.25^{f}	73.25^{d}	128.18^{h}	6.46^{de}
Dodonaeae viscosa	4.92^{a}	80.97^{a}	309.27^{a}	9.98^{a}
Dry season				
Acacia saligna	3.16^{bc}	74.14^{cd}	181.6^{d}	7.52^{c}
Carisa edulis	2.85^{d}	73.36^{d}	162.46^{f}	6.41^{de}
Olea europea	2.89^{e}	72.25^{e}	162.17^{f}	7.42^{cd}
Eculea schimperi	2.07^{g}	70.66^{f}	113.78^{i}	5.51^{f}
Dodonaeae viscosa	4.19^{a}	79.48^{b}	258.12^{b}	8.69^{ab}
SEM	0.078	0.488	5.03	0.211
P value	0.0001	0.0001	0.0001	0.229

Means with different superscripts (a, b, c, d, e. f, g, h) in the same column are significantly different (P<0.05), SEM=standard error of mean, DMI=Dry matter intake; DDM = Digestibility of dry matter; RFV=Relative feed value.

Chemical composition and *in vitro* dry matter digestibility of cladodes of cactus cultivars

The chemical composition and *in vitro* dry matter digestibility of cactus cultivars are shown in Table 3. Cactus cultivars' chemical composition and in vitro dry matter digestibility differed according to season, species, and the interaction of season and species. The DM content of Korem and Tsaeda were significantly (p<0.05) higher than the other cactus cultivars. Cactus cultivars in this study ranged in dry matter content from 7.10% to 9.09%.

Keyh in the dry season had significantly ($p<0.05$) higher ash content than Dekik and Lematse. The cultivars with the lowest ash content during the wet season were Korem and Tsaeda. The ash content of cactus in this study was consistent with the results of the previous studies (Tegegne, 2007; Bazie et al., 2019) who reported a range value of 7.22%-26%.The ash and mineral concentrations of spineless cacti can be greatly affected by variables like the moisture and mineral contents of the soil. Cacti are prone to accumulating calcium in their cladodes when they experience water scarcity and high soil Ca compound levels (Nobel, 2002). Ben Salem (2014) and Salem et al, (2010) suggested that forage's high ash content is also a sign of its comparatively low energy content.

In the wet season (11.17%), cultivar Lematse had the highest CP content, followed by Keyh (10.72%), Lematse (10.13%), and Dekik (10.26%) in the dry season. The CP content of cactus cultivars was higher in the wet season than in the dry season. This was similar to the findings of Tegegne, (2007) and Hassen et al. (2017), who reported, 7.3% and 5.24% for the wet season and 4.3% and 3.24% for dry season respectively. The CP content of cultivars ranged from 7.8% to 11.17%, which is above the CP minimum maintenance requirement of ruminant animals. Sanon et al. (2008) concluded that forage consumed by goats that has a CP content of more than 10 g/100 of DM can increase ruminant N levels. Thus, based on CP results of the studied cultivars, to increase N in ruminant animals, Lematse in the dry and wet seasons and Keyh and Dekik in wet season should be used. As suggested by Misra et al.(2006) diets containing cactus cladodes should be supplemented with protein source feeds like *A.saligna* to satisfy the production requirements of ruminant animals.

In dry season, Lematse had significantly ($p<0.05$), the highest NDF content (24.86%) followed by Korem (24.16%) then Keyh (23.72%). The NDF content of cactus is higher in dry season than in wet season. Consistent with this study, Hassen et al. (2017), reported a higher NDF content of cactus cladodes in the dry season than in the wet season, 58.5% and 55.2%, respectively. However, Dias et al. (2023) reported a higher NDF content of cactus in the wet season (33.12%) than in the dry season (19.75%), respectively. The higher NDF content of cactus cladodes in the dry season might be due to sunlight exposure, and low moisture content and the maturity stage of cactus (Retamal et al., 1987).The variation in NDF content between different studies may be due to the site of sample collection, season, age of cactus cladodes, soil fertility, and other climate-related conditions. Jafari et al. (2015) and Kholif et al. (2016), stated that an NDF content in forage feeds above the critical level of 60% decreases voluntary feed intake, feed conversion efficiency, and the retention time of feeds in the gastrointestinal tract in livestock. Based on this justification, the cultivars studied might not affect the feed intake or feed conversion efficiency of animals.

Cactus cultivars' ADF content was not significantly affected by the interaction of cultivar and season. Nonetheless, the ADF content of Dekik during the dry season was significantly ($p<0.05$) higher than that of the other cactus cultivars. Lematse, had the lowest ADF content (12.12%) in the wet season. The dry season's lowest ADF content, was recorded in Lematse (12.12%). Acid detergent fiber content of cultivars varied from 12.12% to 19.66% .This was similar to the values range of 15% to 25%, reported in previous studies (Batista et al., 2009; Negussie et al., 2015; Teklu et al., 2023). The ADF content of cactus cladodes was higher in dry season than in wet season. This coincides with the findings of Hassen et al. (2017) and Dias et al. (2023), who reported higher ADF content in dry season (49.5% and 14.8%) than in wet season (43.3% and 12.46%) respectively.

The acid detergent lignin content of cactus cladodes ranged from 2.45% to 4.26%. This coincides with the reported value of 3.06% (Tegegne, 2007). The acid detergent lignin content of cactus cladodes in this study was higher in dry season (3.81%) than in the wet season (3.54%). This was similar to the finding of Hassen et al. (2017), who reported higher ADL contents in the dry season (17.2%) than in the wet season (15.4%).

The *in vitro* dry matter digestibility (IVDMD) of cactus was significantly higher in Keyh in wet season then followed by Lematse and Korem in the wet season. The in vitro dry matter digestibility (IVDMD) of cactus in this study was within the range value of 57-78.61% reported by previous studies (Hassen et al., 2017; Teklu et al., 2023; Bazie et al., 2019; Silva et al., 2022). The variation in digestibility might be due to the age of cactus cladodes, the fertility of the soil and its management, and the climate conditions of the area. Cactus cultivars have a greater IVDMD during the wet season than in the dry season. The results of Hassen et al.(2017), who reported 50.8% in the dry season and 63.2% in the wet season, are consistent with the results of this study. Cactus cladodes' nutritional quality varies due to plant type (variety), cladode age, sampling season, soil type, climate, growth stage and portion of the plant (Retamal et al., 1987; Mondragón-Jacobo and Pérez-González, 2001; Scalisi et al., 2016; Mounir et al., 2020; Kumar et al., 2021). Based on the Standard assigned by Hay Market Task Force of American Forage and Grassland Council all cactus cultivars are classified under quality standard 4 (based on NDF and ADF value) and standard quality prime(1)(based on relative feed value).

Table 3.Chemical composition and *in vitro* dry matter digestibility of cladodes of cactus cultivars

Season	Chemical composition(%DM)						%DM
	DM%	Ash	CP	NDF	ADF	ADL	IVDMD
Wet season	8.154^{b}	17.02^{b}	10.077^{a}	19.72^{b}	15.36^{b}	3.52^{b}	67.83^{a}
Dry season	8.423^{a}	19.60^{a}	8.61^{b}	23.10^{a}	17.34^{a}	3.80^{a}	62.99^{b}
SEM	0.053	0.096	0.055	0.044	0.118	0.049	0.119
P-value	0.002	<0.0001	<0.0001	<0.001	<0.0001	<0.0001	<0.0001
Cultivar							
Dekik	8.35^{b}	19.18^{ab}	9.06^{c}	20.05^{c}	13.11^{d}	3.82^{b}	63.70^{c}
Keyh	7.85^{c}	19.29^{a}	9.94^{b}	22.51^{b}	15.90^{c}	4.04^{a}	66.90^{a}
Korem	9.04^{a}	16.91^{d}	8.59^{d}	22.93^{a}	17.01^{b}	3.48^{c}	65.74^{b}
Lematse	7.10^{d}	18.55^{b}	10.65^{a}	21.96^{d}	17.05^{b}	3.04^{d}	66.97^{a}
Tsaeda	9.09^{a}	17.61^{c}	8.45^{d}	19.58^{e}	18.64^{a}	3.92^{ab}	63.76^{c}
SEM	0.08	0.15	0.08	0.07	0.18	0.05	0.19
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cultivar*Season							
Wet season							
Dekik	8.19	18.22^{c}	10.26^{b}	18.44^{f}	17.63^{b}	3.09^{c}	65.78^{c}
Keyh	7.60	17.16^{d}	10.72^{ab}	21.30^{d}	14.97^{d}	3.60^{b}	70.59^{a}
Korem	8.84	16.41^{e}	9.38^{c}	21.70^{d}	15.88^{c}	3.14^{c}	67.84^{b}
Lematse	7.05	17.10^{d}	11.17^{a}	19.06^{e}	12.12^{f}	2.45^{d}	68.76^{b}
Tsaeda	9.07	16.18^{e}	8.84^{d}	18.09^{g}	16.18^{c}	3.72^{b}	66.20^{c}
Dry season							
Dekik	8.51	20.13^{b}	7.87^{e}	21.67^{d}	19.66^{a}	4.26^{a}	61.61^{e}
Keyh	8.10	21.43^{a}	9.17^{c}	23.72^{c}	16.83^{bc}	4.19^{a}	63.20^{d}
Korem	9.24	17.40^{c}	7.8^{e}	24.16^{b}	18.24^{b}	3.52^{b}	63.64^{d}
Lematse	7.15	20.0^{b}	10.13^{b}	24.86^{a}	14.11^{e}	3.63^{b}	65.19^{c}
Tsaeda	9.10	19.05^{c}	8.06^{e}	21.07^{d}	17.84^{b}	4.137^{a}	61.32^{e}
SEM	0.118	0.215	0.122	0.099	0.26	0.07	0.26
P-value	0.265	0.0001	<0.0001	<0.0001	0.76	<0.0001	<0.0001

Means with different superscripts (a, b, c, d, e. f, g, h) in the same column are significantly different (P<0.05), SEM=standard error of mean, IVDMD=In vitro dry matter digestibility, NDF=neutral detergent fiber, ADF=acid detergent fiber, ADL= acid detergent lignin, DM=dry matter

Dry matter intake, dry matter digestibility and relative feed value of cactus cultivars

Dry matter intake, dry matter digestibility and relative feed value of cactus cultivars are shown in Table 4. Dry matter intake and relative feed value of cactus cultivars varied due to season, cultivar and interaction of season and cultivar. But, there is no interaction effect of season and cultivar on dry matter digestibility of cactus cultivars. Dry matter intake and relative feed value were significantly ($p<0.05$) higher for cultivar Tsaeda in wet season than the rest of the cultivars. Dry matter digestibility of Lematse (78.68%) was significantly ($p<0.05$) higher than the other cultivars and followed by Keyh (76.52%). Metabolizable energy of cactus cultivars was significantly higher in Keyh in wet season than the other cactus cultivars. The lowest metabolized energy was recorded in Tsaeda and Dekik in dry season. The relative feed value for all cultivars was higher than 151 value standard quality and classified in prime standard quality (high quality) forages(Kazemi et al. (2012).

Table 4: Dry matter intake, dry matter digestibility and relative feed value of cactus cultivars

Season	Estimated parameters			
	DMI	DMD	RFV	ME(MJ)
Wet season	6.119^{a}	76.93^{a}	364.88^{a}	9.53^{a}
Dry season	5.216^{b}	75.39^{b}	304.60^{b}	8.71^{b}
SEM	0.11	0.092	0.81	0.02
p-value	0.0001	0.0001	0.0001	0.0001
Cultivar				
Dekik	6.02^{b}	74.37^{d}	347.51^{b}	8.82^{c}
Keyh	5.35^{d}	76.51^{b}	317.23^{d}	9.37^{a}
Korem	5.25^{e}	75.60^{c}	307.78^{e}	9.17^{b}
Lematse	5.56^{c}	78.68^{a}	339.56^{c}	9.38^{a}
Tsaeda	6.16^{a}	75.64^{c}	361.62^{a}	8.84^{c}
SEM	0.18	0.145	1.82	0.032
P-value	0.0001	0.0001	0.0001	0.0001
Species *Season				
Wet season				
Dekik	6.50^{b}	75.16^{c}	379.20^{c}	9.18^{e}
Keyh	5.63^{d}	77.23^{b}	337.31^{d}	10.00^{a}
Korem	5.53^{e}	76.52^{c}	328.0^{e}	9.53^{c}
Lematse	6.29^{c}	79.45^{a}	387.69^{b}	9.68^{bc}
Tsaeda	6.63^{a}	76.29^{c}	392.19^{a}	9.25^{d}
Dry season				
Dekik	5.53^{e}	73.15^{e}	315.82^{f}	8.47^{h}
Keyh	5.05^{f}	75.78^{c}	297.16^{g}	8.74^{f}
Korem	4.96^{g}	74.68^{d}	287.56^{h}	8.81^{f}
Lematse	4.82^{h}	77.9^{b}	291.43^{h}	9.08^{e}
Tsaeda	5.69^{d}	74.99^{d}	331.06^{d}	8.42^{h}
SEM	0.025	0.206	1.82	0.045
P-value	0.0001	0.76	0.0001	0.0001

Means with different superscripts (a, b, c, d, e. f, g, h) in the same column are significantly different ($P<0.05$), SEM=standard error of mean, DMI = Dry matter intake; DDM = Digestibility of dry matter; RFV = Relative feed value

Relationship between chemical components and *in vitro* dry matter digestibility of cactus cultivars and tree/shrub species

The relationship of chemical components and *in vitro* dry matter digestibility in tree/shrub species and cactus cultivars is shown in Tables 5 and 6, respectively. The CP content and IVDMD of the studied plants (among cultivars and species) were positively correlated. However, their CP content and IVDMD were negatively correlated with the fiber content (NDF, ADF and ADL). This coincides with the findings of Mahyuddin (2008); Melaku et al. (2010); Mokoboki et al. (2019); Teklu et al. (2023) who reported *in vitro* dry matter digestibility was positively correlated with crude protein and negatively correlated with fiber content. The CP content of tree/shrub species was negatively correlated with ash content of tree/shrub species. In line with this finding of Oko et al. (2016), reported crude protein content was negatively correlated with ash ($r = -0.680$; $p<0.01$) and ADF ($r= -0.497$; $p<0.05$).

Table 5. Correlation coefficient(r) of the relationship between chemical components and IVDMD of tree/shrub species

	DM	Ash	CP	NDF	ADF	ADL	IVDMD
DM	1						
ASH	0.11						
CP	-0.47**	-0.57***					
NDF	-0.27	0.14	-0.50**				
ADF	0.138	-0.022	-0.59***	0.83***			
ADL	-0.56**	-0.078	-0.18	0.79***	0.55***		
IVDMD	0.27	-0.24	0.61***	-0.84***	-0.66***	-0.79***	1

Notice: asterisk in superscripts of the numbers indicates the significance of the correlated parameters: (*level of significance: p<0.05,**level of significance: p<0.01, ***level of significance: p<0.001).

Table 6. Correlation coefficient(r) of the relationship between chemical components and IVDMD of cactus cultivars

	DM	Ash	CP	NDF	ADF	ADL	IVDMD
DM	1						
ASH	0.11						
CP	0.27	-0.225					
NDF	0.69***	0.53**	-0.27				
ADF	-0.26	-0.29	-0.81***	0.12			
ADL	-0.25	0.25	-0.12***	-0.12	0.49**	1	
IVDMD	0.35	-0.65***	0.80***	-0.33	-0.70***	-0.41*	1

Notice: asterisk in superscripts of the numbers indicates the significance of the correlated parameters; (*=p<0.05,**=p<0.01, *** =p<0.001).

CONCLUSION

In conclusion, all tree/shrub species have CP levels above the maintenance nutrient requirement of ruminant animals, especially *Acacia saligna and Dodonaeae viscosa* have good potential as livestock feed and particularly as a protein supplement for low-quality roughages during the dry season. Based on relative feed value and fiber contents, they are also categorized in high quality-forages. Cactus cultivars are better in metabolizable energy when compared to tree/shrub species. Except for some tree /shrub species they were also shown to have potential in terms of their IVDMD and energy contents. However, these results need to be further confirmed using animal feeding trial experiments to examine whether the potential could be translated into animal performance. Further research is also needed on the individual mineral and ant-nutritional contents of the studied browse species.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest regarding the publication of this paper with the Journal of Science and Development.

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Paper III

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EFFECT OF SUPPLEMENTATION OF CACTUS (*Opuntia ficus-indica*) CLADODES, *Acacia saligna* AND COTTONSEED CAKE ON FEED INTAKE, DIGESTIBILITY, GROWTH AND CARCASS CHARACTERISTICS OF GOATS

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ABSTRACT: *The objective of this study was to evaluate the effect of supplementation of cactus (Opuntia ficus-indica) cladodes, Acacia saligna, wheat bran and cottonseed cake on growth, digestibility, intake and carcass characteristics of goats. A randomized complete block design was used in the experiment with 24 yearling central highland goats with an initial body weight of 15.6 - 16.1 kg. The same amount of grass hay (GH) + 150 gDM/head/day wheat bran (WB) was given to all animals. In addition to this the experimental diets consisted of 80 gDM of cottonseed cake (CSC) as treatment 1 (T1); 45 gDM of CSC + 160 gDM of cactus cladodes (CC) as T2; 45g DM of CSC + 80 gDM of Acacia saligna (AS) as T3; and 45 gDM of CSC + 80 gDM of CC + 40 gDM of AS as T4 (per day per goat). Data were gathered on the goats' growth, digestibility, intake, and carcass of major organs, edible and non-edible organs. The consumption of dry matter and organic matter was higher in goats fed T2 and T4 than in the T1 group. The dry matter (DM), organic matter (OM) and crude protein (CP) digestibility, average daily body weight gain, and feed conversion efficiency were higher in T4 and T3 goats when compared to T2 goats. Goats fed on T4 had higher hot carcass weight and dressing percentage on slaughter body weight basis than T2, T3, and T1 supplemented goats. Generally, the experimental diets improved goats' performance in descending order (T4 > T3 >T1 >T2). Supplementation of T4 (replacement of 35 gDM of cotton seed cake per day by 40 gDM of Acacia saligna and 80 gDM of cactus cladodes on dry matter basis) could be recommended to improve goat performance when the amount of concentrate feed is around 200g.*

Keywords: ***Digestion, Dry matter, Feed conversion efficiency, Goat nutrition, Protein.***

INTRODUCTION

Goats and sheep are farmers' preferred livestock in arid areas. For farmers in arid and semi-arid areas, small-scale ruminant production is their primary source of income (Nampanzira et al., 2015; Timpanaro and Foti, 2024). However, during periods of insufficient feed supply, sheep and goats raised in these locations frequently suffer from substantial nutritional deficits, resulting in low productive and reproductive performance (Salem, 2010). Feed shortages, land scarcity and the high cost of feed were the major constraints that hindered sheep and goat productivity (Diriba and Kebede, 2020). According to Endalew et al. (2016), in Ethiopia, livestock to have limited access to year-round feed supplies, and the majority of feed resources are of low quality. Therefore, it could be necessary to use plants like cactus that are adapted to dry and semi-arid environments.

Cactus (*Opuntia ficus-indica*) has a high-water retention capacity, high values in nutrients, and is well-adapted to semiarid environmental conditions (Costa et al., 2013). The chemical composition of spineless cactus cladode consists of 9.2-10% dry matter, 5.62-7.9% crude protein, 25.97-38.7% neutral detergent fiber, and 15.08-27.2% acid detergent fiber (Shruthilaya et al., 2022) as well as water content (89.9%) and energy (8.4-9.2 MJ metabolizable energy per kg dry matter), minerals, and vitamin A for inclusion in ruminant diets (Abidi et al., 2009; Costa et al., 2013; Bezerra et al., 2021; Nyambali et al., 2022). Spineless cactus are often grown by smallholder farmers in arid and semiarid regions to use for animal feed, fences for dwellings and farm plots, and fruits for human consumption (Alary et al., 2007). Spineless cactus cladodes are low in phosphorus, fiber, and crude protein (Batista et al., 2003; Kumar et al., 2018). Due to these limitations, supplementation of protein source feeds like legume browse species is required to use spineless cactus cladodes for animals as forage.

As such, in arid and semi-arid regions, browse species provide a source of nourishment for ruminants, especially during the dry season when there is an abundance of low-quality fodder and crop residues (Amole et al., 2022). Farmers commonly use *Acacia saligna* to feed sheep and goats during dry season. Acacia leaves and twigs from both young and mature trees are regularly collected and given to grazing animals. This is a common practice used by farmers (Meneses et al., 2012). Nevertheless, its continued use as animal feed may be restricted due to the presence of secondary plant compounds. The primary anti-nutritional substances found in some Acacia species are condensed tannins, which reduce the digestibility of organic matter, dry matter, and crude protein content (Ben Salem et al., 1999). However, drying of *Acacia saligna* is reported to reduce its tannin content than offering fresh leaves (Gebreslassie et al., 2021). In lambs, dried *Acacia saligna* leaves outperformed fresh leaves in terms of apparent digestibility of dry matter, organic matter, and crude protein content (Asefa and Tamir, 2006).

On smallholder mixed crop-livestock farms, such as those that predominate in Ethiopia, supplementation with concentrate is not a feasible option due to the cost and limited availability. In such a case, use of forages that are locally available, well-adaptive and cheap in price like cactus cladodes and *Acacia saligna* could be feasible. Previous studies conducted on the effect of cactus cladodes and legume browse species on the performance of ruminant animals in varied proportions showed that: supplementation with 300 gDM/day/head cactus and browse species mix (1:1 ratio) enabled body weight gain and prevented body weight loss of Somali goats (Taddesse et al., 2014). The total substitution of corn by cactus pear (280 gDM/kg), even if it resulted in reduced weight gain, the DM intake increases and improved the ability of sheep to digest the nutrients (Costa et al., 2013). To promote better animal performance, it is recommended to replace 63% of wheat bran with spineless cactus in sugar cane-based diets because of the optimal ruminal fermentation and higher volatile fatty acids synthesis for the animal (Lins et al., 2016). According to Aranda-Osorio et al. (2008), when cactus pear inclusion was raised from 15% to 30%, DM intake increased whereas feed conversion efficiency and overall live weight gain decreased. Other studies showed spineless cactus species can replace ground corn as a source of energy in diets for finishing lambs without changing the ADG, DMI, and ingestive behavior and yield of commercial cuts (de Alencar Alves et al., 2023). Additionally, in sheep fed *Acacia saligna* and wheat bran, the average daily body weight gain was similar to that of sheep fed on cottonseed cake and wheat bran (Yirdaw et al., 2017). Despite their abundant availability of cactus and *A.saligna* little research has been done in northern Ethiopia, especially Tigray region, on the effect of supplementing of *Acacia saligna*, cactus and concentrate, on the performance of goats. This study was conducted to evaluate the effect of dietary supplementation of cactus cladodes, *Acacia saligna*, wheat bran and cottonseed cake on feed intake, growth, digestibility, and carcass characteristics.

MATERIALS AND METHODS

Description of the study area

The study was conducted in the eastern zone of Wukro town in North Ethiopia's Tigray region, 820 kilometers north of Addis Ababa, 70 km south of Adigrat, the zonal city, and 40 km north of Mekelle, the regional capital. Its latitude is 13°47' 59.99'' N and its longitude is 39°35' 59.99'' E. This region is 1977 meters above sea level, with a distinct rainy season from July to September followed by a lengthy dry season. The mean annual rainfall is 300-350 mm. The mean annual temperature in the study area varies from a maximum of 31°c in May and a minimum of 8.3°C in July with an overall mean range from 11.1 - 28.3°C. The study area's primary farming method is a mixed crop-livestock subsistence economy. In order to minimize production risk and optimize the return on their limited land capital resource, smallholder farmers integrate the production of crops and livestock (Abegaz, 2005).

Animal management and experimental design

The experiment was carried out,using 24 yearling male central highland goats purchased from the local area market. Before the commencement of the feeding trial, the house was maintained and cleaned. Goats were adapted for 21 days to the feed and the experimental house. Within the experimental house individual pen was built with 0.75 meters in width and 1.2 meters in length. Goats were treated for worms and sprayed to defend against internal and external parasites during this time. They were also given antibiotics and ivermectin vaccinations to protect them from frequent diseases in the area. All of the goats were put in separate pens after the end of the adaptation period.

The experimental diet consisted of grass hay as roughage(basal diet), wheat bran, cottonseed cake, *Acacia saligna* leaves, and cactus cladodes as supplement. During the feeding trial, grass hay were given ad libitum to goats. The concentrates (cottonseed cake and wheat bran) were purchased from a neighboring market. Spineless cactus cladodes were collected from the closest local farmers to the study area. The spineless cactus cladode was manually cut into 1-2 cm length strips by lengthwise cutting.The chopped cactus cladodes were then dried in the air in the shade, being stretched out on a plastic sheet for eight days. *Acacia saligna* leaves were harvested from locally available trees and dried in air in shade for 4 days, by being spread out on plastic sheets until easily crushed by twisting. They were then stored in a well-ventilated, cool and dry area to prevent degradation or mold formation until the completion of the experiment. Then the feed ingredients were mixed properly in the required proportion for each treatment.

A randomized complete block design was used to conduct the feed trial. The experimental goats were blocked based on their initial average body weight of 15.9±0.237 kg. After the end of the adaptation period, their weight was determined by averaging two consecutive weighings that came after an overnight fast. Random assignments were made to each goat in a block to receive one of the four dietary treatments (six animals per treatment and four animals for block). The experimental diets were formulated according to Kearl (1982);to provide 48 gCP/day(Table 1).

Table 1: Amount of Feed Ingredients in Experimental Treatment

Experimental diets/treatments	Basal diet +Wheat bran	Supplement feed ingredients in gDM/head/day			CPI gDM/d
		CSC	AS	CC	
1	GH+150 WB	80	0	0	48.77
2	GH+150 WB	45	0	160	48.56
3	GH+150 WB	45	80	0	49.864
4	GH+150 WB	45	40	80	49.89

Note, GH=grass hay, CSC=cotton seed cake, WB=wheat bran, AS=Acacia saligna, CC=cactus cladodes, CPI=crude protein intake, DM=dry matter, g=gram, d=day

Data collection procedures

Feeding trial

Before the beginning of the feeding trial, the goats in the experiment were gradually acclimated to the experimental diet and environment over a period of 21 days. Then the feeding trial continued for ninety days. The experimental goats had unrestricted access to water and basal feed (natural grass hay) during the feeding trial. Concentrate (wheat bran and cottonseed cake), *Acacia saligna* and spineless cactus cladode (*Opuntia ficus-indica*) were combined for each treatment in an appropriate ratio as described in Table 1 and supplemented to goats. Additionally, salt was added to the experiment at 1% of the total experimental diet. The goats were given the experimental diet twice a day, at 8:00 a.m. and 5:00 p.m. Every day of the trial, the quantity of the feed each offered and refused by the goats was recorded. Before fresh feed was supplied each morning, feed refusals were gathered, weighed, and individually recorded for every animal. To determine the chemical composition, representative samples of feed that were offered and refused by each animal were gathered.

Feed and nutrient intake, changes in body weight, and feed conversion efficiency

Using a hanging scale, the initial and final body weights of the experimental goats were determined in the morning before they were fed. The amount of feed refused was subtracted from the amount offered to determine each goat's daily feed consumption. The calculation of nutrient intake involved multiplying the feed intake by the appropriate percentage of each parameter's approximate chemical composition (dry matter, organic matter, crude protein, neutral detergent fiber, and acid detergent fiber). Throughout the trial, follow-up body weight measurements were made every ten days to determine weight change. The average daily body weight growth and feed conversion efficiency were calculated using the formula below:

$$\text{Average daily body weight gain(g)} = \frac{\text{Final body weight} - \text{Initial body weight}}{\text{Number of feeding days}} * 1000$$

$$\text{Feed conversion efficiency} = \frac{\text{Average daily body weight gain (gram)}}{\text{Daily dry matter intake}}$$

Digestibility trial

After the end of the feeding trial, a digestibility trial was conducted. To collect feces for the digestibility trial, a fecal collecting bag was fastened to each goat. For three days, to allow for adaptation, the goats were left in the presence of the fecal collection bags. Following that, feces collection took place for 7 days, every morning before feeding the goats. Every day, the feces were gathered and weighed, and at the end of the trial, 20% of each goat's daily feces were collected for analysis. Each goat's feces were collected and packed in polyethylene plastic bags, which were then stored in a deep freezer at -20°C until the digestibility study was completed. Following the completion of the collection time, the feces were well combined. 10% of the sample was dried for 72 hours at 60 degrees Celsius, crushed through a 1 mm sieve, and then stored at -20 degrees Celsius for chemical analysis. The following Equations were used to calculate apparent digestibility (Zeng *et al*., 2018).

$$\text{Digestibility of Nutrients} = \frac{\text{Nutrient Intake–Nutrient excreted in feces}}{Nutrient\ Intake} * 100$$

The equation for DM digestibility estimation (Somanjaya *et al*., 2022) was;

$$DM\ digestibility = (\text{DM Intake} - \text{Feces DM})/(\text{DM Intake}) * 100$$

Carcass characteristics

Following an overnight fast, 20 experimental goats (five from each treatment) were slaughtered after the digestibility trial. Measurements included rib-eye muscle area (REMA), dressing percentage (DP), hot carcass weight (HCW), empty body weight (EBW), and slaughterer body weight (SBW). Weighing and recording of the edible offal—heart, liver with gall bladder, kidney, empty stomach, testes, and head with tongue—were also done. Similarly, the weight and records of the inedible offal (skin with feet, lungs, trachea, esophagus, spleen, and penis) were also conducted. Each goat's empty body weight was calculated by deducting its slaughter body weight from the weight of its digesta (gut filling) (Soares *et al*., 2012). Whereas hot carcass weight was measured after the weight of the head, tail, thoracic, abdominal, and pelvic chambers, as well as the legs below the knee joints, was removed. Then the hot carcasses were divided along the dorsal midline. Following that, the left half of the goat carcass was dissected into normal commercial cuts, including the neck, proximal thoracic limb, proximal pelvic limb, steaks, and brisket. The hot goat carcass was placed in a freezer for 24 hours at 4°C to cool it down. Then, according to Koyuncu *et al*. (2007) measurements on commercial carcass cuts and the REMA around the ribs, at the 11^{th} and 12^{th} rib positions were taken. After freezing for 24 hr. the cross-sectional area of the REMA (Longissimus dorsi) after making the cut on the 11^{th} and 12^{th} ribs perpendicular to the dorsal bone, was drawn using plastic paper. Transparent paper was used to quantify REMA. Graph paper of 5 mm by 5 mm was used to trace the rib-eye muscle area once more, as measured using transparent paper. To determine the REMA in cm^2, the area of the squares that felt into the tracing paper on both sides was measured, and the average of the two was used. Dressing percentage was computed using the empty body weight and slaughter body weight.

$$\text{Dressing percentage} = \text{HCW}/BWS * 100 \quad \text{and} \quad \text{Dressing percentage} = \frac{\text{HCW}}{\text{EBW}} * 100$$

Where HCW, SBW and EBW are hot carcass weight, slaughter body weight and empty body weight, respectively.

Chemical Analysis

Samples of feeds and feces were dried at 65°C for 48 hours. The dry samples were then ground (1mm screen) and stored for subsequent analyses of dry matter (DM), ash and, CP content was determined according to the official methods of AOAC (AOAC, 1990) and Neutral detergent fiber (NDF) determined using Van Soest et al. (1991) and Acid detergent fiber (ADF), and acid detergent lignin (ADL) were determined according to Van Soest and Robertson (1985). Dry matter content of the feed was determined by drying the samples in an oven at 105°C overnight while ash content was determined by burning the samples at 550°C for 5hr. in a muffle furnace. Nitrogen (N) was determined by the Kjeldahl method Kjeldahl method (CP = N×6.25).

Partial Budget Analysis

Partial budget analysis was done according the procedure of Upton (1979) to evaluate the economic advantage of the different treatment diets. In determining the partial budget analysis, variable costs and returns were involved in the calculation. Selling price difference of goats in each treatment before and after the experiment was considered as total return (TR) in the analysis.Net return (NR) was calculated by subtracting total variable costs (TVC) from total returns (TR). Total variable costs include the costs of all inputs that change due to the change in production technology. The change in net return (ΔNR) was obtained by the difference between change in total return (ΔTR) and change in total variable cost

(ΔTVC). This was used as a reference criterion for decision on the adoption of a new technology: ΔNR= ΔTR- ΔTVC. The marginal rate of return (MRR) measures the increase in net income (ΔNR) associated with each additional unit of expenditure (ΔTVC). This was expressed as: MRR (%) =ΔNR/ΔTVC X 100.

Statistical Analysis

After data on feed intake, digestibility, body weight gain and carcass characteristics were collected it was subjected to the analysis of variance model for randomized complete block design by using General Linear Model (GLM) procedure of SAS version 9.0(SAS, 2002).The treatment means were separated by Tukey's test. The statistical model used for the analysis of data was:

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

Where: Yij is the response variable (body weight gain, feed intake, digestibility, carcass characteristics; μ = the overall mean; Ti= the ith treatment effect; Bj = the jth block effect; eij = the random error.

3. RESULTS

Chemical Composition of Feed Ingredients and Treatments

The chemical composition of the feeds in the experiment is shown in Table 2. Cottonseed cake (CSC) contained more CP than wheat bran or *Acacia saligna*. Cactus cladode and hay had the lowest CP levels, with 6.13% and 5.38%, respectively. Cottonseed cake had 66.35% NDF and 37.62% ADF, whereas hay had 71.86% NDF and 45.87% ADF. *Acacia saligna* has a high ADL concentration.

Dry Matter and Nutrient Intake of Feed

Table 3 displays the results of the goats' nutritional and dry matter intake. The grass hay dry matter intake was greater in T1 and T3 compared to T2 and T4. Due to the absence of cactus cladode, cactus-supplemented goats (T2 and T4) consume more. This is because cactus has a lower crude protein content compared to other feed ingredients. Similarly concentrate dry matter intake of goats was higher in cactus-supplemented (T2 and T4) than non-cactus supplemented (T3 and T1). The total dry matter intake and organic matter intake of goats were higher in T2 and T4 than in T1. The reason for this could be the presence of cactus cladode, which had a lower NDF content compared to cotton seed cake and *Acacia saligna* (Table 2). There was no significant difference in the crude protein intake of goats. The NDF intake was higher in T2 (307.09 g/day) followed by T3 (289.45 g/day)>T1 (284.36 g/day)>T4 (266.44 g/day). Acid detergent lignin intake of goats was highest in concentrate + cactus supplemented goats then followed by concentrate + *Acacia saligna* >concentrate + *Acacia saligna* + cactus > sole concentrate supplemented goats.

Table 2 - Chemical composition of feed components on dry matter basis

Chemical composition parameters	Feed ingredients (supplements)				Basal diet
	Acacia saligna	Spineless cactus	Cottonseed cake	Wheat bran	Grass hay
DM	90.26	95.33	93.81	92.24	89.74
Ash	11.1	11.67	4.32	2.92	9.64
OM	88.89	88.33	95.68	97.07	90.36
CP	13.88	6.13	28.60	17.26	5.38
NDF	45.05	39.44	66.35	41.04	71.86
ADF	21.63	27.72	37.62	8.21	45.87
ADL	9.52	3.01	6.74	1.86	6.50

OM=organic matter, NDF=Neutral detergent fiber, ADF=Acid detergent fiber, ADL=acid detergent lignin, CP=crude protein, DM=dry matter

Table 3: Daily dry matter and nutrient intake

Intake(gDM/d)	Treatments				SEM	P-value
	1	2	3	4		
Grass hay DMI	264.28^{a}	229.53^{b}	244.45^{ba}	230.45^{b}	5.2	0.0023
Supplement DMI	208.15^{c}	296.63^{a}	258.26^{b}	289.45^{ba}	7.74	0.0001
Total DMI	472.44^{b}	526.16^{a}	502.71^{ab}	519.48^{a}	8.94	0.001
Nutrient Intake						
OMI grass hay	239.28^{a}	208.68^{b}	221.81^{ba}	208.14^{b}	4.63	0.0022
OMI supplement	191.27^{b}	265.20^{a}	237.07^{a}	260.59^{a}	7.01	0.0001
OMI Total	430.57^{b}	473.89^{a}	458.89^{ab}	468.74^{a}	8.04	0.019
CPI grass hay	14.64^{a}	13.18^{b}	13.36b	12.45^{b}	0.25	0.0008
CPI from the supplement	39.09^{b}	40.69^{ab}	43.01^{ab}	44.19^{a}	1.06	0.018
CPI total	53.74	53.88	56.37	56.64	1.05	0.114
ADFI grass hay	119.76^{ab}	125.38^{a}	111.12^{bc}	104.15^{c}	2.48	0.0004
ADFI from supplement	33.87^{d}	86.18^{a}	58.29^{b}	47.28^{c}	2.26	0.0001
ADFI total	153.64^{c}	189.50^{a}	169.42^{b}	151.43^{c}	3.23	0.0001
NDFI grass hay	190.63^{a}	169.78^{b}	178.28^{ab}	166.40^{c}	3.75	0.003
NDFI from supplement	93.72^{c}	137.31^{a}	111.17^{b}	100.04^{bc}	4.31	0.0001
NDFI total	284.36^{bc}	307.09^{a}	289.45^{b}	266.44^{c}	5.76	0.0028
ADLI grass hay	16.87^{ab}	18.24^{a}	15.50^{bc}	14.60^{c}	0.34	0.0001
ADLI from supplement	5.36^{b}	12.53^{a}	12.70^{a}	10.83	0.54	0.0001
ADLI total	22.23^{d}	30.78^{a}	28.21^{b}	25.43^{c}	0.55	0.0001

$^{a, b, c, d}$ = means within a row not bearing a common superscript letter differ significantly ($p<0.05$). DM=dry matter, OM=Organic matter, CP=Crude Protein, NDF=Neutral Detergent Fiber, ADF=Acid Detergent Fiber, T1= 150g DM of WB +80gDM of CSC, T2= 150g DM of WB + 45 g DM of CSC + 160gDM cactus, T3= 150g DM of WB + 45gDM of CSC+ 80gDM of AS, T4= 150g DM of WB +45gDM of CSC + 80gDM of Cactus+40gDM of AS, SEM=standard error of mean

Apparent dry matter and nutrient digestibility

Table 4 displays the apparent dry matter and nutrient digestibility data for goats. Goats supplemented with concentrate plus *Acacia saligna* + cactus cladodes (T4) had greater digestibility of DM, OM, and CP than goats supplemented with concentrate plus cactus (T2). The CP digestibility of goats was higher in *Acacia saligna*-containing experimental diets (concentrate + *Acacia saligna* (T3) and concentrate + *Acacia saligna* +cactus (T4)). On the other hand, the NDF digestibility was higher in goats supplemented with sole concentrate (T1) than in concentrate + cactus (T2) and concentrate + *Acacia saligna* (T3). This might be due to the presence of a higher amount of cottonseed cake containing high level of NDF in sole concentrate feeds. The ADF digestibility of goats was higher in the T3 supplement than in the concentrate + *Acacia saligna* +cactus (T4) supplement. However, the ADF digestibility of goats supplemented (T2) was the as same to the ADF digestibility of goats supplemented T1. The DM, OM, and CP digestibility of goats was higher in T4 compared to T2 supplement.

Table 4. Apparent dry matter and nutrient digestibility

Apparent Digestibility (g/kg)	Treatments				SEM	P-value
	T1	T2	T3	T4		
DM	642.2^{b}	611.7^{c}	641.5^{b}	669.6^{a}	0.38	0.0003
OM	608.8^{a}	572.2^{b}	609.0^{a}	622.7^{a}	0.31	<0.0001
CP	717.6^{a}	672.1^{b}	717.8^{a}	736.9^{a}	0.42	<0.0001
ADF	486.6^{ab}	497.0^{ab}	512.6^{a}	471.5^{b}	0.67	0.031
NDF	612.86^{a}	560.3^{c}	595.3^{ab}	582.0^{bc}	0.46	0.0002

$^{a, b, c, d}$ = means within a row not bearing a common superscript letter differ significantly (p<0.05). DM=dry matter, OM=Organic matter, CP=Crude Protein, NDF=Neutral Detergent Fiber, ADF=Acid Detergent Fiber, SEM=standard error of mean

Body weight change and feed conversion efficiency of goats

Table 5 displays the body weight and feed conversion efficiency data for goats given grass hay supplemented with concentrate, *Acacia saligna*, and cactus cladode. In all experimental diets, there was no significant variation between the goats' initial and final body weights. However, numerically, the initial body weight ranged from 15.6-16 kg, while the final body weight ranged from 18.6 to 19.2 kg. In comparison to concentrate + cactus (T2) and sole concentrate (T1), the average daily body weight gain of goats in concentrate+ cactus+ Acacia saligna (T4) and concentrate + *Acacia saligna* (T3) revealed a significant difference (p<0.05). Goats' feed conversion efficiency varied between 0.049 to 0.79. There was significant (p<0.05) variation in the feed conversion efficiency of goats between the experimental diets; goats in T4 had a greater feed conversion efficiency than goats in T2.

Table 5: Body weight change and feed conversion efficiency

Parameter	Treatment Feeds					
	T1	T2	T3	T4	SEM	P-value
IW(kg)	15.96	15.94	16.1	15.6	0.237	NS
FW(kg)	18.60	18.70	18.80	19.20	0.366	NS
BG(g/d)	25.55^{b}	26.22^{b}	28.88^{ab}	41.11^{a}	3.393	0.014
FCE	0.0541^{ab}	0.049^{b}	0.057^{ab}	0.079^{a}	0.007	0.019

$^{a, b, c, d}$ =Means with different superscripts in the same row differ significantly (P<0.05); BG=daily body weight gain; FW=final body weight; FCE = feed conversion efficiency; IW=initial body weight; SEM= standard error of mean, T1= 150g DM WB +80g DM of CSC, T2= 150g DM of WB + 45 g DM of CSC + 160g DM of cactus, T3= 150g DM of WB + 45g DM of CSC+ 80g DM of AS, T4= 150g DM of WB +45g DM of CSC + 80 gDM of Cactus +40g DM of AS

Carcass characteristics

Table 6 displays the results of the carcass parameters and commercial cuts of goats. For all experimental diets, there was a significant difference ($p<0.01$) in the goats' hot carcass weight and dressing percentage. Goats supplemented with concentrate+ *Acacia saligna* + cactus (T4) had higher hot carcass weight and dressing percentage (on slaughter body weight) than goats supplemented with concentrate+ cactus (T2), concentrate + *Acacia saligna* (T3), and sole concentrate (T1). Goats supplemented with T4 exhibited significantly higher hot carcass weight and dressing percentage than goats supplemented with T2, T3, and T1 supplements.

Table 6.Effect of concentrate, *Acacia saligna* and cactus cladodes on carcass characteristics

Carcass Parameters(kg)	Treatments				SEM	P-value
	T1	T2	T3	T4		
Final body weight	18.6	18.7	18.8	19	0.337	Ns
Slaughter body weight(SBW)	17.80	17.80	17.60	18.20	0.268	Ns
Hot carcass weight	5.9^{b}	6^{b}	5.84^{b}	6.7^{a}	0.129	0.002
Cold carcass weight	5.42^{b}	5.87^{ab}	5.68^{ab}	6.33^{a}	0.181	0.011
Empty Body Weight (EBW)	14.26	14.75	14.83	15.26	0.303	Ns
Rib-eye muscle area(cm^2)	4.95	4.825	5.275	5.87	0.408	Ns
Dressing percentage on SBW	33.09^{b}	33.63^{b}	33.11^{b}	36.77^{a}	0.66	0.001
Dressing percentage EBW	41.27^{b}	40.5^{ab}	39.34^{b}	43.91^{a}	1.056	0.009
Neck	0.725	0.612	0.695	0.718	0.056	Ns
Proximal thoracic limb	1.358^{b}	1.268^{c}	1.428^{b}	1.533^{a}	0.021	<0.0001
Steaks +Brisket	1.53	1.43	1.53	1.61	0.053	Ns
Lumbar + abdominal region	0.81	0.78	0.85	0.88	0.038	Ns
Proximal pelvic limb	1.64^{bc}	1.558^{c}	1.7^{ab}	1.815^{a}	0.025	0.002

a, b, c, d =Means with different superscripts in the same row differ significantly ($P<0.05$); SEM= standard error of mean, NS=non significance, T1= 150g DM of WB +80g DM of CSC, T2= 150g DM of WB + 45 g DM of CSC + 160g DM of cactus, T3= 150g DM of WB + 45g DM of CSC+ 80g DM of AS, T4= 150g DM of WB +45g DM of CSC + 80g DM of Cactus+40g DM of AS

Edible and non-edible carcass organs of goats

The results of the weights of heart, kidney, small intestine, large intestine, testes, blood, and gut contents are presented in Table 7 and showed significant differences among experimental diets. The size of the heart was larger in concentrate-supplemented (T1) goats than that of concentrate + *Acacia saligna*+ cactus (T4) supplemented goats. The size of kidney ranged from 62 - 73.6 grams and it was higher in T4-supplemented goats than that T1-supplemented goats. Goats supplemented with T1 had larger small and large intestine weight with its contents, compared to goats supplemented with concentration + *Acacia saligna* (T3) and concentrate + *Acacia saligna* + cactus (T4). The size of the testes of goats in this study was ranged from 121.6-150.2 grams and it was higher in T3 than in T2 and T4 supplements. The gut content of goats was ranged from 2531-3530 grams and it was higher in goats supplemented T1 than with T4.

Table 7.Weight of edible and non-edible carcass organs

Carcass organs	Treatments T1	T2	T3	T4	SEM	P-value
Edible carcass organs (g)						
Tongue, ear, head	1252.2	1252.2	1295.4	1281.2	37.31	Ns
Heart	78.8^{a}	70.2^{ab}	71.8^{ab}	65.40^{b}	2.73	0.032
Liver with gallbladder	252.6	242.36	224.4	242.6	11.5	Ns
Kidney	62^{b}	62.6^{b}	63^{b}	73.6^{a}	1.9	0.003
Small and large intestine and its contents	1395.4^{a}	1316.2^{ab}	1185.6^{b}	1212.6^{b}	21.22	0.000
Testes	132.8^{ab}	123.8^{b}	150.2^{a}	121.6^{b}	4.42	0.002
Empty stomach	436.8	458.8	469.0	469.8	21.55	Ns
Blood	580^{ab}	680^{ab}	720^{ab}	780^{a}	41.63	0.032
Total edible carcass organs (kg)	4.18	4.20	4.14	4.24	0.085	Ns
Non-edible carcass **organs(g)**						
Skin with feet, tail	2070	2062	2124	2084	58.89	Ns
Spleen	25.4	25	23.6	26	2.25	Ns
Penis	33.6	33.2	31.0	29	2.85	Ns
Lungs, trachea, esophagus	263.6	263.8	273.2	263.8	21.58	Ns
Gut content	3530^{a}	3041^{ab}	2763^{ab}	2531^{b}	205.97	0.027
Total nonedible carcass organs (kg)	5.72	5.16	4.94	5.07	0.27	Ns

$^{a, b, c, d}$ =Means with different superscripts in the same row differ significantly (P<0.05); T1= 150g DM of WB+80gDM of CSC, T2= 150g DM of WB + 45g DM of CSC + 160gDM cactus, T3= 150gDM of WB + 45gDM of CSC+ 80gDM of AS, T4= 150gDM of WB +45gDM of CSC + 80gDM of Cactus+40gDM of AS,Ns=non significance, g=gram, Kg=kilogram

Partial Budget Analysis

The result of the partial budget analysis indicated that the net return obtained in this trial (Table 8) was 304.128, 410.45, 557.34 and 766.908 ETB/goat for T1, T2, T3 and T4 diets, respectively. We did not include the cost of wheat bran because it is the same for all treatments.Accordingly, goat fed on mixture of CSC, *Acacia saligna* and cactus cladodes (T4) resulted in higher net return (766.908 ETB/goat) as compared to the other supplemented groups. On the other hand, goat fed on the first treatment diet (T1) resulted in 253.212 and 462.78 ETB/goat lower returns as compared to T3 and T4, respectively. The net returns from T3 and T4 supplement diets were 557.34 and 766.908 ETB/goat with marginal rate of return (MRR %) of 585.97 and 893.74 respectively. Marginal rate of return measures the increase in net income and effects of additional investment in a new technology on additional net return. Hence, investing on supplementation of concentrate feeds and forages to goats was found to be economically feasible. Hence, from the partial budget analysis result; treatment four revealed the highest MRR which could be recommended for supplementation of goats concentrate, cactus and *Acacia saligna* (T4) followed by treatment three (concentrate feed and *Acacia saligna)* had relatively higher body weight gain than goats supplemented the other treatments(T1 and T2).

Table 8. Partial budget analysis of the different feed ingridients supplemented to Central highland goats

Description	Treatments			
	T1	T2	T3	T4
Number of goats/treatment	5	5	5	5
Average purchasing price of goats	1620	1560	1540	1600
Hay DM intake in g/ day/head	264.28	229.53	244.45	230.45
Hay DM intake in KG /90 day in KG/head	23.78	20.657	22.000	20.74
CSC DM intake in g/ day/head	72.4 (208.15)	37.60(296.63)	42.26(258.26)	41.35 (289.45)
CSC DM intake in kg /90 day/head	6.516	3.384	3.803	3.721
Cost of feeds				
CSC(1KG=12Birr)	78.192	40.608	45.64	44.652
Hay(1kg=6 Birr)	142.68	123.94	132	124.443
Total variable cost(TVC)	220.872	164.55	177.66	169.092
Change in total variable cost (ΔTVC)	-	56.322	43.212	51.78
Average selling price of goats	2145	2135	2275	2536
Total net return(TNR)	525	575	735	936
Change in total net return(ΔTNR)	-	50	210	411
Net return(NR)	304.128	410.45	557.34	766.908
Change in net return (ΔTNR)	-	106.322	253.212	462.78
$\text{MRR} = \frac{\text{Change in net return}}{\text{Change in total variable cost}} * 100$	-	188.77	585.97	893.74

Note: T1= 150g DM of WB+80gDM of CSC, T2= 150g DM of WB + 45g DM of CSC + 160gDM cactus, T3= 150gDM of WB + 45gDM of CSC+ 80gDM of AS, T4= 150gDM of WB +45gDM of CSC + 80gDM of Cactus+40gDM of AS, g=gram, Kg=kilogram

DISCUSSION

Chemical composition of feed ingredients

Cottonseed cake contained higher crude protein content than wheat bran and *Acacia saligna.* Cactus cladode and hay had the lowest crude protein levels, with 6.13% and 5.38%, respectively. Cottonseed cake had 66.35% NDF and 37.62% ADF, whereas hay had 71.86% NDF and 45.87% ADF. *Acacia saligna* had a high acid detergent lignin (ADL) concentration of 9.52%. The crude protein (CP) content of cottonseed cake analyzed in this particular study (28%) exhibited similarity to the value of 28% as reported by Negussie et al. (2015). However, it was lower than the value of 38% reported by Al-asa *et al*. (2023).

The CP content of wheat bran in this study was similar to values of 16.2% and 17.7%, as reported by Yirdaw *et al*. (2017) and Negussie *et al*. (2015). However, it was higher than the CP value of 15.1% reported by Al-asa *et al*.(2023). Wheat bran's NDF content was comparable to the 39.5% recorded by Negussie *et al*. (2015). On the other hand, wheat bran's NDF content was less than the 35.5% that Yirdaw et al. (2017) reported. Wheat bran's ADF concentration turned out to be lower than the 12.6% and 11.6% reported by Yirdaw et al. (2017) and Negussie *et al*. (2015), respectively. *Acacia saligna's* CP content was comparatively similar to the value 14.20% recorded by Yirdaw *et al*. (2017). However, it was less than the value 16.4%–28.3% that Gebremeskel *et al*. (2019) reported. *Acacia saligna's* NDF content was less than the value 44.29% reported by Yirdaw *et al*. (2017). However, it was higher than the value range of 28%–36% reported by Gebremeskel *et al*. (2019). The present investigation found that the CP content of spineless cactus cladodes was higher than the values 3.6% and 3.26% reported by Negussie *et al*. (2015) and de Oliveira *et al*. (2022), respectively. However, it was similar to the values of 5.99%, 5.86% and 6.1% reported by Bezerra et al. (2021) and Alkhtib *et al*. (2023) respectively. NDF content of spineless cactus cladode was higher than the values reported by Negussie *et al*. (2015); Bezerra *et al*. (2021), and Alkhtib *et al*. (2023) of 23.3%, 26.5%, 25.97%, and 26%, respectively. In this experiment, the ADF content of cactus cladodes was more than the reported values of 15% and 23.39% by Negussie *et al*. (2015) and Bezerra *et al*. (2021). The age of the cladodes, the fertility of the soil, and the harvest season are a few possible explanations for this discrepancy. Dry matter intake (DMI) was negatively affected when the neutral detergent fiber (NDF) level exceeded 60%. Except cottonseed cake, the inclusion of feed ingredients in this study did not affect animal feed intake. The CP content below 7% and NDF content, ADF content, ADL content above 65%, 45% and 10% affects feed intake, feed conversion efficiency, feed digestibility of animals (Van Soest, P. J. 1994).

Dry matter and Nutrient intake of goats

Grass hay dry matter intake was higher in sole concentrate (T1) and concentrate + *Acacia saligna* (T3) supplemented goats than in concentrate + cactus (T2) and concentrate + *Acacia saligna* + cactus (T4) supplemented goats. Similarly, supplement dry matter intake of goats was higher in cactus containing diets (T2 and T4) than in the non-cactus-containing diets (T1 and T2). Goats supplemented cactus-containing experimental diets (T2 and T4) consume more to fulfill their dietary needs due to the presence of cactus which contains low protein level compared to other feed ingredients. There is a direct correlation between an increase in dry matter intake and an increase in organic matter intake. Similarly, as organic matter intake increases, dry matter intake increases (Widyobroto et al., 2016). Goats supplemented with T2 and T4 consumed more total dry matter and total organic matter than T1 supplemented goats. Given that cottonseed cake has a higher NDF concentration than cactus cladode, which has a lower NDF level (Table 2). The total dry matter intake was found to be similar to the values 407.3 – 647.1 g/day, 481.5- 586.3 g/d and 349-515 g/d reported by Worku and Urge (2014); Gebremariam *et al*. (2006) and Megersa et al. (2012) respectively. However, it was lower than the value, 754-822 g/d reported by Hidosa (2017). The total organic matter intake was like to the values 339.3-538.7g/d, 384.8- 515.1 g/d and 316-475g/d reported by Worku and Urge (2014); Gebremariam *et al*. (2006) and Megersa *et al*. (2012) respectively. However, organic matter intake was comparatively lower than the value 741.1- 827 g/day reported by Hidosa (2017). The observed disparity in intake could potentially be explained by the increased consumption of dry matter and the enhanced nutritional value of grass hay in earlier research. Their increased intake as the amount of cactus cladodes increases may have been caused by factors such as the cactus pear's high palatability, low fiber content, and high passage rate (Costa *et al*., 2012).

The amount of crude protein consumed by goats across all experimental diets did not differ significantly. But, numerically it was higher in *Acacia saligna* containing diets (T3 and T4) supplemented goats than in goats supplemented non-*Acacia saligna* containing diets (T1 and T2). The study found that the goats' crude protein intake was comparable to the values reported by Gebremariam *et al*. (2006) and Megersa *et al*.(2013), which were 48.6-55.5 g/d and 16-69 g/d, respectively. It was lower than the value 43.9-110 g/h/d reported by Worku and Urge (2014). The Neutral detergent fiber (NDF) intake of goats was higher in T2 (307.09 g/day) followed by T3 (289.45 g/day)>T1 (284.36 g/day)>T4 (266.44 g/day). The study's NDF consumption for goats was comparable to Gebremariam *et al*.(2006) 's reported value of 235.1–388.0 g/d. In line with this finding, Sileshi *et al*. (2021) observed that the experimental animals' daily consumption of NDF and acid detergent lignin (ADL) decreased when dietary energy and protein levels increased. Goats' body weight, the kind and quality of the feed, the amount provided, the breed, and the feed's palatability are some of the variables that might affect feed intake. Han *et al*. (2019) further emphasized that palatability plays a significant role in determining feed consumption in livestock. Additionally, the dietary NDF content, which is known for its slow degradation and low rate of passage through the rumen, is considered to be limiting. Small ruminants' intake and digestion of roughages are greatly influenced by the fiber content, particularly the NDF (Mertens, 2002 and Harper and Mcneill, 2015).The NDF intake of goats in this study increased linearly with increasing cactus cladodes from 80 gDM/day to 160 gDM/day in the experimental diet, which is similar to the finding of Costa *et al*. (2012).

Apparent dry matter and nutrient digestibility of goats

The dry matter, organic matter and crude protein digestibility of goats was higher in concentrate + *Acacia saligna* + cactus (T4) than concentrate + cactus (T2). This might be due to the positive associative effect of combined feed ingredients (*Acacia saligna* and cactus cladodes). Dry matter digestibility and organic matter digestibility of goats in this study were similar to the range value 42.11% - 69.96% reported by Hidosa (2017). The increased crude protein digestibility of goats in T3 and T4 compared to goats in T2 could be attributed to the presence of *Acacia saligna* which enhances digestibility. This notion is supported by the fact that the digestibility of nutrients in ewes is enhanced by an increased level of *Acacia saligna* supplementation (Maamouri *et al*., 2011). The NDF digestibility was higher in goats supplemented with T1 than in goats supplemented T2 and T4. This may be due to the presence of a higher amount of cottonseed cake, which contains a high level of NDF, in T1 (Table 2). Similarly, the NDF digestibility of goats was higher in T3-supplemented than in T2-supplemented animals. The ADF digestibility of goats was higher in T3 T3-supplemented than in T4-supplemented goats. Gebremariam et al. (2006) observed that the digestibility coefficients for ADF, CP, and NDF decreased as the quantity of cactus increased in the diet. Similarly, the digestibility coefficients of DM, OM, CP, and NDF decrease as the level of cactus cladodes increases from 80 g/d to 160 g/d. Dietary OM digestibility was reduced when barely replaced by cactus. Contrary to this, studies by Salem (2010) and Costa *et al*. (2013) reported that the digestibility coefficients of DM, OM, and CP in sheep increased linearly as the amount of cactus cladodes in the diet increased. This discrepancy can result from the cladodes' age, the fertility of the soil, or the harvesting season or the species of the animals.

Body weight change and Feed conversion efficiency of goats

There was a significant difference ($p<0.05$) in the growth rate of goats between the treatment diets. Body weight gain of goats was higher in supplemented concentrate + *Acacia saligna* + cactus (T4) than in sole concentrate (T1) and concentrate + cactus (T2) supplements. The combination of cactus and *Acacia saligna* in the experimental diet increases weight gain. This coincides with the finding of de Oliveira *et al.* (2022), who reported goats fed on a combination of spineless cactus and Leucaena hay gained weight daily at a rate that was 68.5% more than that of goats grazing only on pasture. Enhancing the ruminal microorganism population's growth performance with values of 42.84 g/day is primarily attributable to the synchronization of the crude protein of leucena hay and the energy of the spineless cactus. The range reported by Rahman *et al*. (2014) and de Oliveira *et al*. (2022) which were 30.8-43.5 g/d and 13.5-42.84 g/d, respectively, was within the range of daily growth rate found in our investigation. On the other hand, the gains were lower than the 41.67–60.65 g/d range found by Hidosa (2017).

Reasons for the reduced growth rate of goats observed in this study might be due to the small quantity of roughage feeds (natural grass hay) that are ingested, the portion of crude protein in the hay that is indigestible, and the feeds' palatability (Mulligan *et al*., 2001). Furthermore, the animals' actual consumption of the intended supplement feed and their possible reaction to weight growth were factors. For example, in treatment 2 (T2), leftover feed resulted in an actual consumption of just 40.69 DM g/d of crude protein, compared to the planned CP intake of 48.56 DM g/d. This disparity suggests that the goats may not have eaten all of the supplement feed that was provided, which may have affected their overall nutritional intake and consequent weight increase.

When comparing cactus-containing diets, it was found that goats supplemented with T4 had a higher average daily weight gain than those supplemented with T2. This aligns with findings from Costa *et al*. (2013), who observed that the daily weight gain of sheep decreases as the amount of cactus supplementation increases. However, this is inconsistent with the study by Nyambali *et al*. (2022), which reported that heifers fed diets with 10% and 20% cactus had lower average daily gains (ADG) compared to those fed commercial diets. In the current study, the weight gain of goats was highest in those supplemented with T4 compared to goats supplemented with T1 and T2. This observation is supported by the findings of Degen *et al.* (2000) who suggested that the provision of *Acacia saligna* had a positive effect on body weight change in animals.

Goats supplemented with T4 had a greater feed conversion efficiency ($p<0.05$) than goats supplemented with T2. Goat feed conversion efficiency was found to be comparable to the range of 0.05-0.09 reported by Rahman *et al*. (2014) and Hidosa (2017). Diets using 80 gDM cactus (concentrate + *Acacia saligna*+cactus) had a higher feed conversion efficiency than diets containing 160 gDM cactus (concentrate + cactus). This finding is comparable to that of Costa *et al*. (2013), who found that sheep's feed conversion efficiency drops when cactus levels rise. Diets containing cactus pear forage are beneficial when there is sufficient nitrogen available, as proven by Misra *et al*. (2006). This could be because cactus and *Acacia saligna* are available at the same time as a source of energy and protein, respectively, which could support ruminal microbial communities and improve animal performance. The nutritional composition of the experimental diets used in this study comparatively proved to be fairly adequate in increasing the goats' body weight. In contrast to sheep in other studies', findings, goats in this study grew at a relatively slower rate than the recommended growth rate. In line with this finding Awassi lambs grow faster than Baladi kids and can get to the desirable market weight (Haddad and Obeidat, 2007). This could be because goats have different nutritional needs than sheep and consume less concentrated feed, which ultimately helps sheep perform better in feedlots (Sheridan *et al*., 2003).

C arcass characteristics of goats

The hot carcass weight and dressing percentage of goats supplemented with T4 were significantly higher than those of goats supplemented the with other treatments. Goats fed on T4 (containing 80gDM cactus) supplement had a higher hot carcass weight than goats fed on T2 (containing 160 gDM cactus). This was in line with the recommendation made by Bezerra *et al*. (2021), who reported that hot carcass weight decreased from 15.6 to 14.4(kg) as cactus supplementation to lambs increased from 51.9 gDM to 75.3gDM. The higher hot carcass weight of goats in T4 might be due to the lower NDF content of cactus cladodes and *Acacia saligna*. Concurred to this study, Mirzaei-Alamouti *et al*. (2021) reported a linear increase in hot carcass weight was found by decreasing dietary NDF concentration on a quantitative level. In this study, the dressing percentage and hot carcass weight of goats were found to be lower than those reported by Worku and Urge (2014), which were 35.4%–41.1% and 47.1%–58.9% and 6–9.7 (kg), respectively. There is no significant difference in the rib-eye muscle area of goats among experimental diets. The rib eye muscle area in this study was similar to the value 4.3- 7.7cm^2 reported by Worku and Urge (2014). The larger body weight of goats, the kind of feed, the breed of animals, and the setting in which the trials were conducted in the prior study could all be contributing factors to the discrepancy. The proximal pelvic limb was varied in weight from 1.558 to 1.815 (kg). The proximal pelvic limb of goats supplemented T4 was larger than that of goats supplemented with T2 and T1 supplements. The proximal thoracic limb was varied in weight from 1.268 to 1.533 (kg). The proximal thoracic limb of goats supplemented T4 was larger than that of goats supplemented T2, T3 and T1. Goats' neck and proximal pelvic limb weights had greater values than that of values of 0.47 kg and 1 kg respectively reported by Atay *et al*. (2011). The kind of feed, age, breed, and quantity of concentrate supplementation may all have a role in this discrepancy. When goats were supplemented with T4, their carcass characteristics improved. Numerically, goats fed on this experimental diet (T4) had a greater rib-eye muscle area compared to those of goats fed on the other treatments.

Edible and non-edible Carcass organs of goats

The kidney and spleen weights of goats in this study were similar to the values, 42-63g and 59-78g reported by Worku and Urge (2014) but lower than the values of 82g and 97g respectively reported by Atay *et al*. (2011). Kidney weight of the experimental goats increases significantly as body weight increases. Similarly, spleen weight increases as body weight increases numerically. The testes weight of goats in this study ranged from 121.6-150.2 grams and it was higher in goats supplemented with T3 than in goats supplemented with T2 and T4. The testis weight of goats was higher than the value of 80g reported by Atay *et al*. (2011). However, it was lower than the value 155g-206.3g reported by Alemu *et al*. (2010) and Worku and Urge (2014). There was no significant difference in the empty stomach weight of goats in all experimental diets. But numerically, it was smaller in goats fed on T1 than in goats supplemented with the other treatments. The kind of feed, particularly the amount of fiber, affected the weight and growth of reticulo-rumen (Cardoso *et al*., 2016; Klein *et al*., 1987). The goats' empty stomach weight was lower than the value, 573-795g reported by Worku and Urge (2014). The gut content of goats ranged from 2531-3530 grams and it was higher in goats supplemented with T1 than in goats supplemented with T4. The gut content of goats was lower than the range of 4.2-5.8 kg reported by Worku and Urge (2014). The reason for the lighter weight of goat carcass organs in this study might be due to lower quality of the hay and the amount of concentrate feed left, as well as the initial body weight of the animals. As recommended by Bezerra *et al*. (2021) up to 50 gDM of spineless cactus could be included in the diet of confined lambs. Similarly, in this study it is possible to include up to 80g DM/d of spineless cactus in the experimental diet to improve goat performance. Therefore, T4 (150 wheat bran, 45 cottonseed cake, 40 *Acacia saligna* and 80 cactus cladodes (gDM/d) could be recommended to small holder farmers to feed their animals to improve performance of animals.

Partial Budget Analysis

The result of the partial budget analysis indicated that the net return obtained in this trial (Table 8) was 304.128, 410.45, 557.34 and 766.908 ETB/goat for T1, T2, T3 and T4 diets, respectively. We did not include the cost of wheat bran because it is the same for all treatments.Accordingly, goat fed on mixture of CSC, Acacia saligna and cactus cladodes (T4) resulted in higher net return (766.908 ETB/goat) as compared to the other supplemented groups. On the other hand, goat fed on the first treatment diet (T1) resulted in 253.212 and 462.78 ETB/goat lower returns as compared to T3 and T4, respectively. The lower net return in T1 could be attributed to the lower feed conversion efficiency of the goats supplemented with treatment one as well as the lower fedd intake (relatively high amount of feed left over). The net returns from T3 and T4 supplement diets were 557.34 and 766.908 ETB/goat with marginal rate of return (MRR %) of 585.97 and 893.74 respectively. Marginal rate of return measures the increase in net income and effects of additional investment in a new technology on additional net return. Hence, investing on supplementation of concentrate feeds and forages to goats was found to be economically feasible. Hence, from the partial budget analysis result; treatment four revealed the highest MRR which could be recommended for supplementation of goats concentrate, cactus and Acacia saligna (T4) followed by treatment three (concentrate feed and Acacia saligna) had relatively higher body weight gain than goats supplemented the other treatments(T1 and T2).The difference in MRR value is due to the cost of the concentrate mixture among the treatments and selling price as influenced mainly by body condition of the goats. Producers or farmers are advised to use T4 (45 CSC+40AS +80CC+150WB (g DM/head/day) as feed for their animals (especially goats) when this amount of concentrate feed is present.

CONCLUSION

The study demonstrates that dietary supplementation of goats with diets containing concentrate and browse plants improves some performance parameters. Goats supplemented with cactus-containing diets consume more DM and OM than those of goats which utilize non-cactus-containing diets. Goats on the T4 diet (concentrate + cactus + *Acacia saligna*) exhibited higher DM, OM, and protein digestibility than those on the T2 diet (concentrate + cactus). The study observed larger testis size in goats fed with concentrate + *Acacia saligna* (T3) compared to those on concentrate + cactus (T2) and concentrate + *Acacia saligna* + cactus (T4). Goats on the T4 diet achieve better performance in most cases: higher efficiency (better utilization of the feed), relatively high growth rate, high dressing percentage, and hot carcass weight, larger weights of kidney, proximal thoracic limb, and proximal pelvic limb. Since both cactus and *Acacia saligna* are locally available year-round, they provide a reliable forage source that meets the maintenance requirements of animals and boosts economic returns for producers. Further research could be done to evaluate the effect of total replacement of concentrate feeds by cactus cladodes and *Acacia saligna* on the performance of goats. Further research could be done to evaluate the anti-nutritonal factor (Gossypol) found in cottonseed cake used in the feed trial. Producers or farmers are advised to use T4 (45 CSC+40AS +80CC+150WB (g DM/head/day) as feed for their animals (especially goats) when this amount of concentrate feed is present.

DECLARATIONS

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Data availability

The data that support the study findings are available from the corresponding author upon request.

Author contribution

Genet Berhe: Conceptualization; Methodology; Data curation; Formal analysis and writing original draft of the manuscript, Amsalu Sisay and Teferi Aregawi: reviewing; editing; supervision; validation.

Consent to publish

All participants have consented to the submission of the research article to the journal.

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Paper IV

Influence of the concentrate substitution regime (using *Acacia saligna* and cactus cladodes) on semen quality, the meat composition, the semen quality and the physico-mechanical and chemical characteristics of leather derived from Central Highland goats.

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ABSTRACT

Goats are the most important animals in Ethiopia, providing meat, milk, fiber, cash income and acting as insurance, especially in the dry season. However, the production from goats is low in Ethiopia, largely because of poor nutrition. This study aims to evaluate the effect of concentrate substitution with Acacia saligna leaf and cactus cladodes on semen quality, meat composition and leather characteristics of male Central Highland goats in Ethiopia. A randomized complete block design was used to assign 20 male Central Highland goats with an initial average body weight of 15.9±0.24 kg (mean±S.D.) in five replications to one of the four treatment feeds. The treatment diets contain grass hay and 150 wheat bran gDM/day/head) for all treatments and supplemented with T1= 80 cottonseed cake (T1), T2= 45 cottonseed cake +160 cactus cladodes(CC), T3= 80 Acacia saligna leaf (AS) + 45 cottonseed cake, and T4= 45 cottonseed cake + 40 Acacia saligna leaf +80 cactus cladodes(gDM/day/head). The goats were kept on the experimental diets for 90 days. In this study semen quality, meat chemical composition (ash, fat, protein, moisture) and for leather physico-mechanical (tensile strength, tear resistance, elongation, tear load, thickness) and chemical (chrome content, moisture content and fat content) properties of goats were analysed. The testicle size of goats in this study was significantly (p<0.01)) higher in T3 than in T1, T2 and T4. Semen progressive motility of goats in T3 was higher than goats in T2 and T4. Semen mass motility of goats was higher in T3 than in T2 and T4. But semen progressive motility of goats in T1 was comparable to goats in T2, T3 and T4. Semen concentration of goats was higher in T3 supplement than in T4-suppelement. The fat content of meat was higher in T3-supplemented goats, than in T1 and T2-supplemented goats. Goats in T1, T3 and T4 had higher tensile strength, tear resistance, tear load, cracking and bursting load of leather than in T2. Results also show that most of the physico-mechanical and chemical characteristics of goat leather were comparable to the acceptable quality standards suggested by the United Nations International Development Organization. The experimental diets in this study were enough to improve quality of semen that fulfills the quality standards for fertility of male animals. Especially, supplementation of T3 to goats produces good quality semen. Substitution of 35gDM CSC either by Acacia saligna or cactus cladodes and Acacia saligna in diets can provide relatively similar results in terms of meat content and leather characteristics to those of goats supplemented with sole concentrate. Partial replacement of concentrate in the diet of goats by locally available feeds, Acacia saligna or cactus has the potential to enhance the quality of semen, meat and leather produced from Ethiopian Highland goats.

Keywords: Highland goat, meat quality , goat leather, substitution

INTRODUCTION

Goats are important for diversifying production, creating employment, increasing income, building capital, contributing to human nutrition, poverty reduction, saving, risk mitigation, and manure production (Fikru and Gebeyew, 2015; Gobena, 2016) and for meat, milk and skin production (Degen, 2007; Mijena and Getiso, 2022). Goats are a key resource for ensuring sustainable livestock production (Lohani and Bhandari, 2021). The goat is an important source of animal protein for humans in warm climates (Kirton, 1988; Mazinani and Rude, 2020). They also help to meet the increasing protein needs of the world's rapidly expanding population (Webb, 2014; Rout et al., 2021). Goat meat is widely regarded as lean meat, and the demand for this healthy meat is expected to increase. Given the large resource base and significant role of goat production in the national and household economy, recently livestock improvement strategies gave emphasis to enhance red meat production by improving smallholder goat production (Shapiro et al., 2015).

Goat producers must employ new technologies and feeding methods to improve goat meat productivity and yield. Better management and feeding of goats are essential to improve carcass composition (Webb, 2014; Gobena, 2016). Concentrate feed supplemented goats, produced meat with a fat content that can meet the demand of the market (;Ameha, 2006 ; Sebsibe *et al*., 2007; Tsegaye, 2009; Terefe, 2013; Tadesse *et al*., 2016; Alemu *et al*., 2020;; Hassen *et al*., 2020). The fat content of goat meat was improved as the amount of concentrate supplementation increases (Atti *et al*., 2006; Safari *et al*., 2009; Dutta et al., 2023). The average goat meat composition ranges 74-76% moisture, 20.6-22.3 protein(g/100), 0.6-2.6 fat (g/100), (Devendra, 1988), 1-

1.1% ash, 75.42% water, 3.55% fat, 19.95 % protein and 1.06% mineral matter (Lalhriatpuii and Singh, 2021); 18.9% protein, 2.98% fat (Longobardi *et al*., 2012).

Goat skins are also valuable raw materials for leather products in which local highland goats produce thick, flexible and high quality skins with high price premium in the international leather products market (Solomon et al., 2014). Goat skins are highly valued as raw material because of their high demand for superior-quality leathers (Russel et al., 2005). Skins of goats and sheep are important by-products of small ruminants in sub-Saharan Africa and contribute to national revenue in most countries (Wilson, 1992). In Ethiopia hide and skin contribute marginally to the national economy due to low production of standard quality (Alemnesh et al., 2018).The leather/skin quality of domestic animals is affected by the level of nutrition, breed, pre-slaughtering management, age, sex and tanning method and chemicals used (Teklebrhan *et al*., 2012; Tadesse *et al*., 2015; Ebrahiem *et al*., 2014; Ebrahiem, 2016; Nasr *et al*., 2017). Supplementation of concentrate feed to small ruminants could increase the quality of leather characteristics like tear resistance, thickness, grain strength, load at burst, percentage of elongation and tensile strength, (Teklebrhan et al., 2012; Mohammed et al., 2012; Negussie et al., 2016; Urge et al., 2017; Abebe et al., 2024). However, this concentrate feed was not available and its cost was not affordable to farmers (Ben Salem and Smith, 2008).Tensile strength, tear load, thickness, and cracking load were higher in kid and lamb than in ewe, doe, ram, and buck. Thus, skin quality is higher in young animals than in old animals (Ebrahiem, 2016).

Nutritional regimes that improve average daily growth (ADG) also enhance testicular development and sexual maturity in ram lambs (Gemeda and Mekasha, 2016; Rossi *et al*., 2019).

The nutritional regime is important in determining successful collection and production of good-quality semen (Abdullah *et al*., 2015). Concentrate supplementation improves weight gain and scrotal circumference, semen volume, sperm concentration, sperm cell motility and sperm membrane potentiality (Azizunnesa *et al*., 2013). In Ethiopia several studies were done on the fertility of female small ruminants (Mukasa-Mugerwa and Lahlou-Kassi, 1995; Urgessa *et al*., 2013; Neme, 2016; Amare Berhe and Ahmed, 2019) but few studies were done on the fertility of male small ruminants (Dana et al., 2000; Gebre, 2007;). However, the effect of supplementation of *A. saligna*, cactus cladodes, and concentrate on semen characteristics of central highland goats was not studied. To produce leather from small ruminants with adequate amounts and the required qualities, changing the feeding system or using alternative available feed resources like *Acacia saligna* and cactus cladodes instead of concentrate could be important (Ben Salem and Smith, 2008). Cactus pear could be an important forage crop for livestock in the arid and semi-arid regions (Howard, 2002; Hirich *et al*., 2020; Nasser *et al*., 2022). Several researchers have done their work on supplementattion of different concentrate feeds in different proportions on growth performance and carcass characteristics of goats but the work done on substitution of concentrate feed by browse species including cactus on semen quality, meat composition and leather characteristics of goats was scarce. Therefore, the objective of this study was to evaluate the effects of concentrate substitution by *Acacia saligna* and cactus cladodes on semen quality, meat chemical composition and leather physico-mechanical and chemical characteristics of goats.

MATERIALS AND METHODS

Description of the study area, animal management, the number of animals and the experimental diets are already described in the previously puplished paper (feeding and digestibility trial) and the following methods are also described for the newly added parameters for this paper.The experimental diets consisted of 80 gDM of cottonseed cake (CSC) +150 80 gDM of wheat bran as treatment 1 (T1); 45 gDM of CSC + 150 80 gDM of wheat bran +160 gDM of cactus cladodes (CC) as T2, 150 80 gDM of wheat bran + 45g DM of CSC + 80 gDM of *Acacia saligna* (AS) as T3; and 45 gDM of CSC + 150 80 gDM of wheat bran + 80 gDM of CC + 40 gDM of AS as T4 (per day per goat).

Data Collection Procedures

Semen Collection and Evaluation

Semen was colected from fourteen central highland goats then semen from twelve bucks was used for analysis. After a doe was presented to the buck the semen was collected through bucks mounting of oestrus doe (Baindha *et al*., 2024). Semen samples were collected using the Artificial Vagina method. The calibrated collecting tubes were held towards the penis or artificial vagina to receive the ejaculated semen. Immediately after collection, the samples were assessed for aspects of semen motility, semen colour, and volume (mL). Semen volume was measured by reading the measurements on the calibrated collecting tube (Baindha *et al*., 2024; Masethe *et al*., 2024; Ramukhithi *et al*., 2017). The semen colour was assessed directly by visual observation and was graded as per Jha *et al*.(2013) as watery(1), milky(2), yellowish white (3) and creamy white(4).

Sperm concentration was determined with the aid of a spectrophotometer. Semen mass activity was subjectively assessed by placing a drop of semen (10μl) on a pre-warmed slide and using a 40×objective lens Microscop (scored from 0=no activity to 5= maximal activity). Semen progressive motility (ranging from 0% = total immobility to 100% =high motility) (Chemineau *et al*., 1991) was subjectively assessed on an extended drop of semen under a cover slide at 100× objective lens using a drop of oil immersion (scored at 10% unit intervals) and physiological saline.

Skin preparation and processing

After slaughtering of the goats, twenty (20) fresh skins were taken to Wukro Sheba Tannery Industry for further processing or to change into crust leather. The skin was transferred to wooden slats, and excess fat, blood, and other impurities were removed before spreading the salt. The first skin processing process is preservation; the purpose of preservation is to increase shelf life.Wet salting was performed in accordance with the Ethiopian standard authority. The skin was carefully folded and kept at a slant position to allow oozing of moisture from the skin. The skins were kept under these conditions for seven days in a well-ventilated shed. Prior to soaking, preservation of raw hides and skins are practiced to stabilise the skin temporarily using common salts (sodium chloride). As described by Tadesse *et al*. (2016), the major steps involved in skin processing are soaking (to remove blood, dirt, salt, dung)(rehydrates the cured hides and skins to remove salt), liming(to remove the hairs, and nails, and to alter the properties of the skin protein (collagen)(to remove hair and flesh from the skins), deliming is to remove lime from the pelt, fleshing (removing of the flesh and natural fats of skins, since the presence of fats could accelerate skin degradation), unhairing (the animal skins are steeped in an alkali solution that breaks down the structure of the hair at its weakest point (the root) and so removes the hair, bating operation is done to split the fibres into fibrils, degreasing process is carried out to eliminate the excess of natural fat substances from the skin. If the residue is not removed it can cause fatty acid spues, uneven dyeing and finishing, waxy patches in alum tanned leathers and pink stains in chrome tanned wet blue. High amounts of fat can also cause hardness to touch and loss of physical strength. They observed that there is increase of the breakdown of the fats when the lipase was combined with protease in the process. pickling (acidification of the scudded pelt in drum with salt solution and pre-diluted acid to preserve and condition the pelt for tanning(the skins are then treated with acid to preserve them for up to two years), and tanning (conversion of skins to leathers by adding tanning materials).During tanning, the skin structure is stabilised in its open form by replacing some of the collagen with complex ions of chromium. Depending on the compounds used, the colour and texture of the leather changes. When leather has been tanned it is able to 'breathe' and to withstand 100^{o}C boiling water, as well as being much more flexible than an untreated dead skin). After passing these processing stages, the skins were changed to crust leather. Then the chemical and physico-mechanical characteristics of goat crust leather were assessed.

Physico-Mechanical Skin/ Leather Quality

After skins were processed into crust leather, they were sent to the Ethiopian Leather Industry Development Institute (LIDI) in Addis Ababa for physico-mechanical and chemical laboratory analysis. The crust leather was conditioned for 48 hours at 21.6±2 ^{o}C and 67.5±5% relative humidity in accordance with ISO 2418 :2008 standard process. Skin samples were collected for the test in accordance with the ISO 2418 : 2008 protocol. Samples with standard sizes were taken from the butt region ((Snyman and Jackson-Moss, 2000).

The main parameters measured to ascertain the physico-mechanical characteristics of leather were thickness, tensile strength, tear resistance, elongation, tear load, load at burst, distension at burst, load at crack and distension at crack. Every sample's leather thickness was tested in millimeters (mm) using a standard protocol ISO 2589: 2002. A dynamometer was used to measure the tensile strength, tear strength, and percentage of elongation; a lastometer was used to measure the distension and grain strength using the ball burst test. The capacity of leather to elongate in response to mechanical forces is known as elongation. The load at the crack of leather is the load at which the grain of the leather just starts to crack. It serves as an index of the total strength of the leather.

Tensile strength and percentage of elongation

Tensile strength is a measure of the maximum amount of force a leather can withstand before breaking. Elongation refers to the ability of a leather product to lengthen/stretch when stress is applied to it and represents the maximum extent to which the leather can stretch without breaking. Tensile strength and percentage of elongation (the length of the sample at break) were determined using the test method of ISO-3376:2011. The sampling method and sampling location were done according to ISO 2418:2008. The following formula was used to determine tensile strength and elongation percentage:

$$Tensile\ strength(\frac{N}{mm^2} = \frac{\text{Maximum load or breaking load(N)}}{\text{the initial Cross sectional Area }\left(\text{thickness(mm)} * \text{width(mm)}\right)}$$

$$Elongation = (\text{length at break(mm)} - \text{initial length(mm)})/\text{initial length} * 100$$

Tear load/tear strength

Tear strength is an important factor that determines the strength of the leather against static and dynamic forces. Tear resistance (or tear strength) is a measure of how well a material can withstand the effects of tearing. The tear resistance indicates its resistance to tearing force. A tearing strength test is carried out on a leather to determine the fiber strength of that leather. The average tear load and tear resistance were determined using the test methods of the ISO-3377-2: 2011 and ISO-3376:2000, respectively. Samples were conditioned according to ISO-2419 :2002. The sampling locations were according to ISO-2418 [2008]. The samples' thickness complied with ISO 2589:2002. The tear load was the highest load reached at the point of tearing. A tearing strength test was carried out on a leather to determine the fiber strength of that leather.

$$Tear\ resistance\left(\frac{N}{mm}\right) = \text{Force at tear (N)/thickness at tear(mm}$$

Leather Chemical Tests

The major parameters used to measure the leather chemical characteristics include fat content, chromic oxide and moisture content. The climatic condition to test the chemical characteristics was a temperature of 21.1 ^{o}C, relative humidity of 30.8%. The sampling condition and sampling location for chemical characteristics were according to ES ISO 4044:2002 and ES ISO 2418:2005, respectively.

Moisture content

A standard procedure [SLC- 3] was used to determine the moisture content or volatile substances of 5g of dried, chopped skins. When samples were dried at 102±2°C to a constant weight, the proportion of weight lost was considered the moisture content. More than eight hours could not be spent on drying in total.

$$.Moisture\ content\ = \frac{\text{Sample (wt befor drying} - \text{wt after drying)}}{\text{Sample wt.before drying}} * 100$$

Fat content

The fat content of the moisture-free samples was determined using the standard Soxhlet extraction method [SLC-4]. Dichloromethane was the solvent used to extract the fat content from the samples. After the solvent was distilled from the flask, the extract materials were dried at 102±2°C to a constant weight. The total drying time is not allowed to exceed eight hours. The following formula can be used to determine the amount of fat and other soluble compounds using dichloromethane:

$$\text{Fat content} = (\text{extract weight})/(\text{sample weight}) * 100$$

Chromic-oxide content

Tanning is a process in which the leather-making protein is completely stabilized against heat, enzymatic biodegradation and thermomechanical stress by converting the fibrous protein of raw hide or skin into a stable material and making the leather suitable for a wide variety of end uses (Everton et al., 2020). In tanning processes tanning materials crosslink with the reactive site of fibrous protein, and it involves the conversion of putrefiable skin or hides to a non-putrefiable material (Alex and Arthur, 2016). Among the tanning agents Chromium (III) salts are extensively used compounds due to their quality and the higher stabilization they impart to leather.The chromic oxide content of the leather after tanning, is defined by the quantity of chromium compounds (Cr_2O_3) found on it. It is determined from the leather ash by oxidizing the leather ash, followed by iodometric titration of hexavalent chromium ions (SLC-8).

$$\text{Chromicoxide}\ \% = (\text{chrome weight(g)})/(\text{sample weight(g)}) * 100$$

Meat chemical composition analyses

The meat chemical composition was done at Addis Ababa University in the School of Nutrition and Food Science. Samples for meat composition were taken from the longissimus dorsi muscle thoroughly mixed, and frozen at -20˚C until required. About 3 g of the sample was weighed into a pre-weighed crucible dish. The samples were then incubated in an oven at 100˚C overnight to determine the percentage of dry matter. Ashing was carried out at 600 ˚C for 2h. The rest of the sample materials were oven-dried, ground, and stored in a refrigerator at 4˚C until required for the analysis of protein and fat percentages. Total fat was extracted using a Soxhlet apparatus for 6 hours with ethyl ether (boiling point of 34.5˚C), and the dried residue was weighed for fat content. Crude protein was determined by the standard Kjeldahl procedure (AOAC, 1990).

Statistical Analysis

After data on meat composition and skin/leather were collected the data were subjected to the analysis of variance model for randomized complete block design by using the linear model procedure of SAS version 9.0(2002). Treatment means were separated by Tukey's test. The statistical model used for analysis of data was $Yij = \mu + Ti + Bj + eij$;

Where: Yij is the response variable (meat composition, skin quality); μ = the overall mean;

Ti= the i^{th} treatment effect; Bj = the j^{th} block effect; eij = the random error.

RESULTS

Semen quality parameters of goats

The results of goat semen progressive motility, mass motility, volume and semen colour are shown in Table 1. There was a significant difference in testes weight, semen progressive motility, semen mass motility and concentration of semen in goats ($p<0.05$). Progressive motility of goats in T3 was significantly ($p<0.05$) higher than goats in T2 and T4. Similarly, mass mobility was higher in T3-supplemented goats than in T2 and T4. However, the progressive motility of goats in T1 was comparable to goats in T2, T3 and T4. Semen concentration was higher in goats in T3 than in T4. Semen concentration was significantly ($p<0.05$) higher in goats in T3 than in T4. However, the semen concentration of goats in T1 and in T2 was not significantly different from the semen concentration of goats in T3 and T4. The size of the testicle in goats in this study was significantly ($p<0.01$) higher in T3 than in T1, T2 and T4, and its value ranged from 122.31-150 (g). The colour of semen in goats varied from milky to white creamy (grade 2-4); 1=watery, 2=milky, 3=yellowish creamy, 4=creamy white. Almost all goats in T3 and T1 have semen colour of creamy white (grade 4). There was no significant difference in the semen colour of goats due to the experimental diets. Its average value ranged from 1-4.

Correlation coefficient of semen parameters of goats

The correlation coefficient of semen parameters is shown in Table 2. Semen motility was significantly ($p<0.05$) and positively correlated with semen concentration ($r=0.73$) and semen colour($r=0.63$). Semen concentration was also positively correlated with semen colour ($r=0.37$). Testicle size was significantly ($p<0.01$) and positively correlated with motility($r=0.80$ and concentration (r=0.81). Semen volume had non-significant (p>0.05) positive correlation with semen motility (r=0.11) and a negative correlation with semen concentration (r=-0.05).

Table 1. Semen quality parameters and the size of testicle

Parameters	Treatments				SEM	P-value
	T1	T2	T3	T4		
Testes weight(g)	133.32[b]	122.31[c]	150[a]	120.45[c]	1.26	0.0052
Mass motility(0-5 grades)	4.23[ab]	3.66[b]	4.9[a]	3.5[b]	0.24	0.022
Progressive motility(%)	80[b]	74[bc]	91.33[a]	70[c]	1.2	0.0039
Concentration($x10^9$/ml)	3.22[ab]	3.18[ab]	5.44[a]	2.55[b]	0.49	0.025
Semen Volume(ml)	0.60	0.45	0.61	0.5	0.19	0.94

[a, b, c, d] =Means with different superscripts in the same row differ significantly (P<0.05); T1= 150g DM of WB+80gDM of CSC, T2= 150g DM of WB + 45g DM of CSC + 160gDM cactus, T3= 150gDM of WB + 45gDM of CSC+ 80gDM of AS, T4= 150gDM of WB +45gDM of CSC + 80gDM of Cactus+40gDM of AS,Ns=non significance, g=gram, Kg=kilogram

Table 2. Correlation between sperm motility, semen concentration, semen volume and semen colour

Parameters	Mass motility	Progressive motility	Semen concentration	Semen colour	Semen volume	Testicle size
Mass motility	1					
Progressive motility	0.96***	1				
Semen concentration	0.70*	0.73**	1			
Semen colour	0.58*	0.63*	0.37[ns]	1		
Semen volume	0.065[ns]	0.11[ns]	-0.05[ns]	0.3[ns]	1	
Testicle size	0.79**	0.80**	0.81**	0.36[ns]	0.1[ns]	1

astrix ***=p<0.001, **=p<0.01, *=p<0.05, ns=non significant correlation between parameters

Meat chemical composition

The results of the meat chemical composition of central highland goats are shown in Table 3. The fat content of meat was significantly (p<0.05) higher in *Acacia saligna* and concentrate (T3) supplemented goats (2.77%) than in sole concentrate (T1) (2.29%) and *Acacia saligna*, concentrate and cactus (T4) supplemented goats (2.44%). Moreover, the fat content of goat meat was higher in T1 and T4 supplements than in T2 supplements. Moisture content of goat meat was significantly ($p<0.05$) higher in T1 (75.56%) and T2 (75.66%) supplements than that of T3 (75.30%) and T4 (74.16%) supplements.The protein content of goat meat was higher in T3 and T4 than in T1 supplements. Ash content of goat meat was higher in T2 (2.11%) and T1 (2.06%) supplements than in T3(1.79%) supplements.

Table 3. Effect of concentrate, cactus cladodes and *Acacia saligna* supplementation on the meat chemical composition of goats.

	Experimental diets/Treatments				SEM	P-value
	T1	T2	T3	T4		
Ash (%)	2.058^{a}	2.11^{a}	1.79^{b}	1.89^{ab}	0.06	0.011
Fat (%)	2.29^{b}	1.56^{c}	2.77^{a}	2.44^{b}	0.066	<0.0001
Protein (%)	19.95^{b}	20.30^{ab}	20.59^{a}	20.67^{a}	0.102	0.001
Moisture (%)	75.56^{a}	75.66^{a}	74.16^{c}	75.30^{b}	0.026	<0.0001

Means bearing different superscripts (a, b, c) in a row differ significantly.T1=150 grams of wheat bran (WB) + 80 g of cotton seed cake (CSC), T2=150g of WB+ 45 g of CSC+ 160g of cactus cladodes (CC), T3=150g of WB+ 45g of CSC+ and 80g of *Acacia saligna* (AS), T4=150 g of WB+ 45 grams of CSC+ 80 g of CC and 40 g of AS, SEM=standard error of mean,

Chemical characteristics of goat leather

Fat, Chromic oxide and moisture content of leather

The results of the fat, chromic oxide, and moisture content of skin are presented in Table 4. The leather in this study contains, on average, 8.93% fat, 11.87% moisture, and 4.5% chromic oxide. There was no significant difference in chromic oxide content of skin among experimental diets. The moisture content was significantly ($p<0.05$) higher in T3 and T4 supplements than in T1 and T2 supplements. The fat content of leather was significantly ($p<0.05$) higher in the sole concentrate supplemented (T1) goats than in T3, T2, and T4-supplemented goats. The skin weight of goats was not significant among the experimental diets.

Table 4. Fat, Chromic oxide, moisture content of leather

Chemical tests	Experimental diets/Treatments				SEM	P-value
	T1	T2	T3	T4		
Fat%	10.26^{a}	9.30^{b}	7.96^{c}	8.20^{c}	0.073	<0.0001
Moisture%	11.24^{d}	11.62^{c}	12.24^{b}	12.44^{a}	0.048	0.0001
Chromic oxide%	4.50	4.50	4.50	4.56	0.033	NS
Skin weight(kg)	1.29	1.22	1.28	1.30	0.027	NS

Means bearing different superscripts (a, b, c) in a row differ significantly. T1=150 grams of wheat bran (WB) + 80 g of cotton seed cake (CSC), T2=150g of WB+ 45 g of CSC+ 160g of cactus cladodes (CC), T3=150g of WB+ 45g of CSC+ and 80g of *Acacia saligna* (AS), T4=150 g of WB+ 45 grams of CSC+ 80 g of CC and 40 g of AS, SEM=standard error of mean

Physico-mechanical characteristics of goat crust leather

The results of the physico-mechanical characteristics of goat leather are presented in Table 5. The thickness of goat leather ranged from 0.8 mm to 1 mm. There was a significant difference in average thickness of leather and it was higher in T1 and T3-supplemented goats. Tear resistance (N/mm) of goat leather ranged from 32.40 to 39.60, and it was higher in T1, T3, and T4-supplemented goats than in T2-supplemented goats. The average tear load (N) of goat leather ranged from 27.99 to 36.96 and it was higher in T1-supplemented goats than in goats supplemented the other treatments. The tensile strength (N/mm^2) of goat leather ranged from 16.78–18.55 and it was higher in T4, T1, and T3 supplemted goats than than T2-supplemented goats. The percentage of elongation of goat leather ranged from 39.60% to 43.16% and it was higher in T1 and T3-supplemented goats than in those of T2 and T4-supplemented goats.

Cracking load (N) of goat leather ranged from 252.34 to 295.62N, and it was higher in T1 (295.62N) and T4 (284.46N) supplements than in T2 (252.34N) supplements and it was higher in T1-supplemented goats than in T3-supplemented goats. Distension at crack (mm) of goat leather was ranged from 7.72 to 8.28, and it was higher in T3 and T4-supplemented goats than in T2-supplemented goats. Bursting load (N) of goat leather ranged from 278.22 to 354.78N, and it was higher in T1-supplemented goats than in T2- supplemented goats.

Table .5. Physico-mechanical characteristics of goat crust leather

Physical tests	Experimental diets/Treatments				SEM	P-value
	T1	T2	T3	T4		
Tensile strength(N/mm^2)	18.12^{a}	16.78^{b}	18.54^{a}	18.55^{a}	0.116	0.0018
Elongation (%)	43.16^{a}	39.60^{b}	43.28^{a}	40.54^{b}	0.27	0.0007
Tear load parallel to the back bone (N)	33.08^{a}	26.84^{b}	32.80^{a}	32.56^{a}	0.37	0.0006
Tear load perpendicular to the backbone(N)	38.90^{a}	29.60^{c}	35.80^{b}	34.96^{b}	0.88	0.0289
Average tear load	36.96^{a}	27.99^{c}	34.19^{b}	33.92^{b}	0.54	0.0024
Tear resistance(N/mm)	38.16^{ab}	32.40^{c}	39.60^{a}	36.30^{b}	0.61	0.015
Average Thickness(mm)	0.98^{a}	0.81^{b}	0.96^{a}	0.94^{a}	0.03	0.007
Grain strength (Ball burst test						
Distension at crack(mm)	8.16^{ab}	7.72^{c}	8.28^{a}	8.02^{b}	0.06	0.0043
Load at crack(N)	295.62^{a}	252.34^{c}	277.00^{b}	284.46^{ab}	2.04	0.0007
Distension at burst(mm)	8.82	8.34	8.98	8.72	0.15	NS
Load at burst(N)	354.78^{a}	278.22^{c}	329.00^{b}	325.38^{b}	5.69	0.0091
Thickness (mm)	1.00^{a}	0.90^{b}	0.96^{ab}	0.94^{ab}	0.02	0.027

Mean bearing different superscripts (a, b, c) in a row differ significantly.T1=150 g of wheat bran (WB) + 80 g of cotton seed cake (CSC), T2=150g of WB+ 45 g of CSC+ 160g of cactus cladodes (CC), T3=150g of WB+ 45g of CSC+ and 80g of *Acacia saligna* (AS), T4=150 g of WB+ 45of CSC+ 80 g of CC and 40 g of AS, SEM=standard error of mean,

DISCUSSION

Chemical composition of feed ingredients

As the chemical compsotion analysis results were presented in **Paper III,** this paper discusses semen quality, meat composition and leather characteristics

Semen quality parameters

Semen motility

There was a significant difference in progressive motility, mass motility and semen concentration of goats ($p<0.05$) among the experimental diets. In this study, the progressive motility of goat semen ranged from 70% to 91.33%, showing higher levels in T3-supplemented goats compared to those receiving other treatments. The values reported by Sultana *et al*. (2013), Itodo *et al*. (2020), Swarna *et al*. (2022), Dhar *et al*. (2010), and Akpa *et al*.(2013) respectively. In this study, the semen mass motility score of goats was greater in T3-supplemented goats compared to those in T2 and T4 groups, ranging from 3.5 to 4.9. Similar findings of 2.4-4.75 were documented in earlier studies (Swarna *et al*., 2022; Sacko *et al*., 2022; Gebreslassie, 2012 and Michael, 2018). Semen motility rises with the increase of protein sources in the diets of goats. This aligns with Dana *et al*. (2000) who reported that supplementation of 100 to 300 g per head per day of leucaena resulted in improved testicular growth, semen production, and semen quality of Ethiopian highland sheep. The variation in spermatozoa motility among individuals was beneficial for selecting bucks, as motility serves as a crucial indicator of semen quality and influences the fertility of bucks (Nazir, 1988). The primary factor for determining whether a semen sample is accepted or rejected is the motility of the sperm (Swarna et al., 2022). Goat semen is considered quality if its sperm cell motility exceeds 70% (Hidalgo *et al*. 2007; Khalifa and El-Saidy, 2006). This variation might be due to breed, age, nutrition and season (Theron, 2001).

Semen concentration and semen volume

Semen concentration of goats in this study was higher in T3 compared to T4 (there is no significant difference between T1 and T2) and it varied from 2.55-5.44($x10^9$)/ml. This resembled the value, 2.82-4.29-7.1($x10^9$/ml documented by earlier researchers (Sultana *et al*., 2013; Dana *et al*., 2000, and Kheradmand *et al*. 2006). However, it was higher than the results 1.7-2.41x 10^9/ml), 0.62-1.58($x10^9$/ml), 1.75X10^9/ml and (2.1-2.7x10^9/ml reported by Sacko *et al*. (2022); Swarna *et al*. (2022); Dhar *et al*.(2010) respectively. Semen concentration of goats in this study was within the acceptable semen quality sperm cell concentration of $\geq 2 \times 10^9$ sperm cells/ml (Hidalgo *et al*., 2007). Sperm cell concentration is influenced by different factors such as age, breed, nutrient supply, climatic conditions (Akpa *et al*., 2013; Mekasha *et al*., 2007) and method of semen collection (Austin et al., 1961) and method of measurement of sperm concentration (Atiq *et al*., 2011).

The semen volume of goats in this research ranged from 0.45 to 0.61 ml. These values were similar to the ranges of 0.42-0.82 (ml) indicated in earlier research (Gebreslassie, 2012; Michael, 2018; and Akpa *et al*., 2013). However, it was lower than the value 0.97-1.1 (ml) reported by Dana *et al*. (2000) and Hossain *et al*. (2019). The reduced semen volume observed in this study could be attributed to the collection method, the feed type, and the frequency of semen collection. Electro ejaculation for semen collection produces a greater ejaculate volume compared to the artificial vagina (Mattner and Voglmayr, 1962; Jiménez-Rabadán et al., 2012).

The semen volume of goats in this study fell within the acceptable range for good quality semen (0.5-3ml), except for goats supplemented with T2. Both the quantity and quality of animal semen are affected by genetic type, diet, collection frequency, season (Dotche et al., 2019), and the technique used for semen collection. In this research, the size of testicles in goats receiving T3 supplementation was larger than in those supplemented with T2 and T4. As a result, semen motility and concentration were greater in T3 and T1 supplemented goats. Consistent with this finding, Møller (1988) noted that larger testicles generate more concentrated sperm cells owing to a greater production area and capacity in comparison to smaller testicles. An increase in testicle size could enhance testosterone production, which elevates spermatogenesis (Shi et al., 2018). Supplementing with protein-rich browse species such as Acacia saligna enhances testicular size, semen motility, semen volume, and semen concentration. In agreement with this study, Dana et al. (2000) found that supplementation of leucaena, up to 300 g per head daily, enhanced testicular development, sperm output, and semen quality in Ethiopian highland sheep.

Semen colour

The colour of semen in goats varied from milky to white creamy (grade 2-4); 1=watery, 2=milky, 3=yellowish creamy, 4=creamy white. Almost all goats in T3 and T1 have semen colour of creamy white (grade 4). There was no significant difference in semen colour of goats due to the experimental diets. Its average value ranged from 1-4. This was similar to the findings of Jha *et al*. (2013); Asaduzzaman et al. (2021), and Jha et al. (2018) who reported the semen colour values of 3.15 for bulls, 3.8 for rams and 3.1-3.2 for bucks respectively.

Correlation coefficient of semen quality parameters of goats

Motility was significantly ($p<0.05$) and highly correlated with semen concentration ($r=0.73$) and semen colour($r=0.63$).Testes weight was significantly ($p<0.01$) and highly correlated with motility($r=0.80$) and concentration($r=0.81$). In line with this research concentration of semen was positively correlated with motility($r=0.18$, $p<0.001$) (Goshme *et al*., 2020). However, there is no relationship between semen volume with semen motility ($r=0.11$) and semen concentration($r=-0.05$). In agreement with finding of Webb *et al*. (2004), semen concentration was positively correlated with semen colour.

Meat Chemical Composition

The fat content may be present as intermuscular fat (between the muscles), intramuscular fat (marbling, i.e., within the muscles), and subcutaneous fat (under the skin/adipose tissue) (Hall et al., 2016).Whether in the adipose tissue or muscle, fat contributes importantly to various aspects of meat quality and is central to the nutritional value of meat (Wood et al., 2008). Nutritionally, goat meat is regarded as being superior to other red meats, due to the lower saturated fat and cholesterol content and it contains more polyunsaturated fatty acids than beef and lamb (Ivanović et al., 2016; Van der Weele et al., 2019). Goats in the present study that received a supplement of *Acacia saligna* and concentrate (T3) exhibited a higher meat fat content (2.77%) compared to those receiving only concentrate (T1) (2.29%) and those with a mix of *Acacia saligna*, concentrate, and cactus (T4) (2.44%). This could be due to goats that are supplemented consuming all the feed and utilizing it efficiently, resulting in higher fat content. In line with this finding, goats provided with concentrate feed and unlimited access to green fodder had greater meat fat content compared to those receiving only concentrate and barely grain (Dutta et al., 2020). Consistent with earlier reported values of 1.56% to 2.06% (Hwangbo et al., 2009; Dutta et al., 2023), the fat content in goat meat for this study varied between 1.56% and 2.77%. However, it was less than the reported values of 2.35-3.24% for Barbari finishing kids (Dutta et al., 2020), 3.225% for hair goats (Atay et al., 2011), and 3.28% for Egyptian Baladi goat kids (Moawad et al., 2013). The reduced meat fat content observed in this study compared to previous research may be attributed to factors such as the animal's age, sex, breed type, body weight, and diet (Casey et al., 2003). Conversely, the fat content of meat in kids was diminished when Alfala was partially substituted with *Acacia saligna* in the kids' experimental diet (El-Waziry et al., 2019). In a similar vein, Karaca et al. (2016) noted that as the nutritional quality of the diet increases, so does the accumulation of intramuscular fat. The comparatively low fat content in goat carcasses affects the transformation of muscle into meat and ultimately influences meat quality (Webb et al., 2005).

The moisture content of meat was significantly greater ($p<0.05$) in goats receiving T1 (75.56%) and T2 (75.66%) compared to those receiving T4 (75.30%) and T3 (74.16%). The moisture level of goat meat in this research (74.16%-75.66%) was comparable to the values previously reported, which ranged from 74.57%-76.35% (Moawad et al., 2013; Atay et al., 2011; Dutta et al., 2023; Bezerra et al., 2021; Hwangbo et al., 2009). Nonetheless, it exceeded the documented moisture level of 72.84% (Worku et al., 2020). The fat content varies inversely with the water content, whereas the protein content remains stable within the muscle (Juárez et al., 2012). The protein levels in goat meat were greater in T3 (20.59%) and T4 (20.67%) compared to T1 (19.95%) supplements. This suggests the superior meat quality of goats in T3 and T4 supplements. This could be attributed to *Acacia saligna* being highly palatable and accepted by goats, along with cottonseed meal, which is abundant in oil and proteins. Nonetheless, cottonseed meal has gossypol, which restricts its application in animal feed (Gadelha et al., 2014). The typical protein content in goat meat was comparable to the values reported between 18.23-20.5% (Moawad et al., 2013; Dutta et al., 2023; Worku et al., 2020; Tadesse et al., 2016). Nonetheless, it exceeded the documented values of 17.7-18.91% (Atay et al., 2011; Bezerra et al., 2021) and lower than the reported value of 22.52% (Hwangbo et al., 2009). The ash content in goat meat was greater in T2 (2.11%) and T1 (2.06%) than in T3 (1.79%). The mean ash content of goat meat in this research (1.79-2.11%) exceeded the previously reported range of 1.21%-1.59% (Nath et al., 2017). Nevertheless, it was less than the stated values of 4.4% (Shija et al., 2013). Goat meat serves as an excellent source of lean meat because it contains higher protein levels, minimal intramuscular fat, and desirable fatty acids, as goats store comparatively more polyunsaturated fatty acids (PUFA) than other ruminants (Banskalieva et al., 2000)

Chemical characteristics of crust leather

Fat, Chromic oxide, Moisture content

There was no significant difference in the skin weight and final body weight of goats as a result of the experimental diets. The skin weight of goats in this study was similar to the finding of Silva *et al*. (2020) who reported that the skin weight of goats ranged from 1.14-1.27 kg. However, it was lower than the value 1.58-1.69kg reported by Tadesse et al.(2016).The skin is the largest organ of the body and grows as the animal increases in size, developing at the same rate as body weight (Brand *et al*., 2019).

There was no significant difference in the chromic oxide content of leather in this study. The chromic oxide content in this study (4.5%) was higher than the reported values of 3.21%-3.39% (Mohammed *et al*., 2012; Tadesse *et al*., 2016) and it is above the minimum requirement for upholstered leather and for garment (2.5%). The moisture content of leather was higher in goats supplemented T3 and T4 than in goats supplemented T1 and T2. Moisture content ranged from 11.23% to 12.43%, which aligned closely with the reported value of 11.79% to 11.93% (Tadesse *et al*., 2016). However, it was lower than the reported values of 12.9-13.56% (Mohammed *et al*., 2012; Nasr *et al*., 2017). The moisture content of goat leather in the current study was within the range of 12 -14% set for the ideal moisture content of leather (SATRA spotlight: 2006) and within the requirement (12-15%) set by the Ethiopian Standards (ES 1195 : 2005) which is less than the minimum requirement for chrome crust leather of 14–16% (ES 1189). Properly tanned leather should have a controlled moisture content (typically around 10–14%). Excess moisture often means the leather was not fully dried, improperly tanned, or poorly finished.High moisture weakens the leather fibers, reducing strength, durability, and shape retention.Moist leather is more prone to mold, mildew, and bacterial growth, which shortens its lifespan (Kelly et al., 2019).

The fat content of goat leather ranged from 7.96 to 10.26%. The fat content of leather was higher in goats supplemented T1 compared to those of goats supplemented T3, T2, or T4. This might be due to the presence of high amount of cottonseed cake in T1 which results in leather with high fat content. Even if the fat content of the leather is not above the recommended values, peresence of high fat content did not indicate the quality leather because it implies leather may feel greasy or oily, poor dye penetration, reduced adhesion of finishes e.t.c. The fat content of goat leather in this study coincides with the reported value of 11% (Nasr *et al*., 2017).The fat content of goat leather was higher than the reported value of 5.01–6.16% (Tadesse *et al*., 2016). But it was lower than the reported value of 14.2–16.8% (Mohammed *et al*., 2012). The difference in fat content of goat leather in this study might be due to lower nutritional level of feed, improper removal of fats during the tanning process, age, sex and the breed of the animals. Fat content of leather in this study is higher in goats supplemented higher level of concentrate (T1). But, the moisture content of leather decreases as concentration supplementation increases. Coincides to this study Stosic (1994) and Mohammed et al.(2012), Urge et al. (2017) reported an inverse correlation between the moisture and fat contents of leather. Additionally, weaker leather has been related to fatty skins (Stosic, 1994). The fat content in all treatment groups in this study was above the standard level (4–10%) for garment leather making and within the standard levels 3–12% for upholst leather (UNIDO, 1996).

Physico-mechanical characteristics of crust leather

Thickness

The results for physico-mechanical characteristics of goat crust leather are presented in Table 5. Goat leather thickness ranged from 0.8 mm to 1 mm. The average leather thickness of goats was significantly higher in T1, T3 and T4-supplements than in T2-supplements. Consistent with this study, the thickness of small ruminants leather at higher level of concentrate supplementation as reported by previous researchers (Passman and Sumner, 1983; Stosic, 1994; Merkel et al., 2013; Negussie et al., 2015; Abebe et al., 2024). The value of leather thickness in this study is lower than values reported by previous studies (Negussie *et al*., 2015; Tadesse *et al*., 2016; Merkel *et al*., 2013). However, it was higher than the reported values of 0.53 mm (Urge *et al*., 2017). The lower leather thickness of goats could be due to a low level of nutrient supplementation, differences in species and breed of animals, lower body weight and other management practices.

Tear load and tear resistance

The goat leather tear resistance ranged from 32.5 to 39.33 N/mm, with the highest tear resistance observed in T3 than in goats supplemented with T2 and T4. This might be due the presence of *Acacia saligna* and the efficient utilization of the feed by goas in T3. The tear resistance in T1 (38.16) and T3 (39.33 N/mm) of goats in this study is almost within the minimum requirement of upper shoe goat leather (40 N/mm). Passman and Sumner (1983) found that leather from better-fed sheep wethers had higher tear resistance. Compared to the vertical and parallel sampling direction of the leather in the current study the vertical samples required more tear load than the parallel samples. This was similar to the finding of Dereje *et al*. (2016), who reported vertical sampling of leather needs more load than parallel sampling direction in camel. The average tear load was higher in T1-supplemented goats than in goats supplemented the other treatments. Consistent with this finding previous scholars (Tadesse *et al*., 2016; Urge *et al*., 2017 ; Abebe *et al*., 2024), reported that as the level of concentrate supplementation increases, the average tear load increases. The average tear load of goat leather in this study was within the minimum value required for the upper shoe leather (30N) (UNIDO,1996).But it was lower than the minimum average tear load of leather upper footwear 50N [ISO-3377;2002] test method.

Tensile Strength

Goat leather tensile strength was higher in T4, T1, and T3-supplemented goats than in T2-supplemented goats. This might be due supplementation of protein source feeds to goats in the three treatments (T1, T3, and T4). This was similar to the finding of Cloete *et al*. (2006) who reported that the tensile strength of Ostrich skin increases as the level of protein supplementation increases. Most mammalian fresh skin contains 64% water, 33% protein, 2% fat, 0.20% minerals, and 0.80% other substances.Most of the protein in the skin consists of 29% collagen, 0.30% elastin, 2% keratin and 1% globulin and albumin and 0.70% mucin and mucoid (Sharphouse 1983). The extent of tensile strength depends on the quality of collagen fibers that the specific skin type contains. Collagen protein is a fibrous protein that has a strong influence on the physical properties and strength of the skin, with the structure of its molecules consisting of polypeptides that form a spiral or helix. The result of tensile strength was similar to the reported values of 15.2 N/mm^2 and 17.1 N/mm^2 for low and high levels of supplementation, respectively (Urge et al., 2017). But it was lower than the reported values of 23.9N/mm^2 and 31.8N/mm^2(Merkel *et al*., 2013) and 21.6N/mm^2 and 26.5N/mm^2 (Tadesse *et al*., 2016), 26.7 and 30.4N/mm^2 (Negussie *et al*., 2016) for low and higher levels of nutrition, respectively. Contrary to this study, Merkel *et al*. (2013) reported that the tensile strength of Boer and Spain goat breeds was numerically higher at low level of supplementation (0.5% of body weight) (26.1 N/mm^2) than at a higher level of supplementation (1.5% of body weight) (24.6 N/mm^2). This might be due to species and breed differences, as well as the amount of concentrate feed given in the previous study might be higher. The relationship of goat leather thickness and tensile strength is proportional (as leather thickness increases tensile strength of goats' increases). Similar to this study the tensile strength of lamb skin increased as its thickness increases directely (Passman and Sumner, 1983). The tensile strength value of 18.5 N/mm^2 estimated in T1, T3 and T4 was almost similar to the minimum value for upper shoes leather (20 N/mm^2) ISO3376:2011. However, it was higher than the value of the tensile strength of the standards for the leather cloth from goat (15 N/mm^2) (British standards, 1984) and the minimum requirement for the tensile strength of goat lining leather (15 N/mm^2) ISO 3376: 2011. Supplementation of the experimental diets to goats in this study produced leather with a tensile strength above 15 N/mm^2.

Percent of Elongation

The goat leather percent of elongation ranged from 39.40 to 43.40%, and it was higher in goats supplemneted T1 and T3 compared to goats supplemented T2 and T4. Consistent with this study, the percentage of elongation significantly decreased from 86.2% to 77% as the level of concentrate supplementation increased from 1.2% of their body weight to 1.5% of their body weight (Negussie *et al*., 2016). The percentage of elongation of leather in this study was lower than the previously reported values of 52.1%–55.8% (Urge et al., 2017) and 55.8%–56.60% (Ebrahiem *et al*., 2014). This difference might be due to breed, level of nutrition, or type of feed, age and weight of animals used in this study. Elongation is an important property to be considered when choosing garment leather because a low elongation value results in easy tear, while a high elongation value causes leather goods to become deformed very quickly or even lose usability (Zengin et al., 2017). The percentage of elongation reported in this study (39.60–43.28%) was in line with the minimum recommended percentage of elongation for goat upper shoe leather (40%), the ISO-3376:2011 test method, and for high-quality leather (30-80%) for the Kenyan Bureau of Standards for upper leather.

Grain Strength (Ball burst test)

The ball burst test and grain crack are other physical properties for testing the quality of leather. It is intended to indicate the grain resistance to cracking during the top lasting of the shoe uppers (Covington, 2009; Kuria et al., 2016). Grain strength (distension) indicates the amount that the leather can be stretched before the upper grain layer cracks. Distension at crack was higher in goats supplemented with T1, T3, and T4 compared to goats supplemented with T2. This was similar to the reported values of 10.2-11.1mm for high concentrate supplementation and 9.5-10.7 mm for low concentrate supplementation (Urge et al. 2017; Passman and Sumner, 1983). In this study, goats in all treatment diets had grain distension higher than the minimum performance requirement for leather uppers of footwear (Shoe upper leathers) or the minimum standard (7mm) set for quality leather (BASF,1984). The requirements of quality standards in terms of distension at grain crack should be a minimum of 6.5 mm and distention at ball burst at 7.0 mm, respectively, as per the Kenya Bureau of Standards (KEBS) specifications for shoe upper leather.

Cracking load of goat crust leather was higher in goats supplemented with T1 (295N) and T4 (284N) than in goats supplemented with T2 (251.9N). This coincides with the reported range of values from 225 to 235N, from 235 to 323N, for low and high levels of concentrate supplementation respectively (Passman and Sumner, 1983; Urge et al., 2017). The cracking load of goat leather was higher in T1 supplemented goats (high level of concentrate) than in T2 and T3 supplemented goats (low level of concentrate). This was similar to the finding of Stosic (1994), who reported the load at the grain-crack of goat leather under a low level of nutrition, 340.9N, which was lower than that of goats at a high level of nutrition;347N. This might be due to the presence of higher amount of concentrate feed in T1 than in the other treatments, which has the potential to improve grain crack. In general, the goat crust leather in this study exceeded the minimum requirements of the Kenyan Bureau of Standards for good quality upper leather; elongation 30-80%, tensile strength >10N/mm^2, distension at grain crack, and distension of the grain ball burst >7mm. But the value for tear strength (less than 55N/mm) and thickness(less than 1.2mm) was below the minimum requirements by the Kenyan Bureau of Standards for good quality upper leather (Cheloti M et al., 2023).

CONCLUSION

In conclusion, goats supplemented T3 (concentrate and *Acacia saligna*) had a higher meat fat content and semen quality. Substitution of 35gDM/day CSC either by *Acacia saligna* or cactus cladodes and *Acacia saligna* in the experimental diet results in relatively similar results in terms of meat content and leather characteristics to that of goats supplemented sole concentrate. Most of the parameters for leather chemical and physico-mechanical quality tests were comparable to the quality standards set by United Nations International Development Organization (UNIDO). The study's experimental diets are sufficient to improve the quality of semen and meet the requirements for male animals' fertility. In particular, giving goats T3 supplements results in high-quality semen. Supplementation of T3 (150g wheat bran+45g+80g *Acacia saligna* DM per head per day) and T4 (150g wheat bran+45g+40g *Acacia saligna*+80g DM cactus cladodes per head per day) for goats will be recommended to farmers, traders to improve productive and reproductive quality of goats. Further research must be done by supplementing these feed ingredients or *Acacia saligna*, on the biological properties (collagen and elastin) of leather and semen morphology of farm animals.

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BIOGRAPHY SKETCH

The author, Genet Berhe Kihshen, was born in Edagahamus, Eastern Zone Tigray Regional State (Ethiopia) on October 31, 1986. She attended her elementary, junior and secondary school in Comasubha, Adikelebes and Edagahamus (from 1994-2005) respectively. After completion of grade 12, she joined Alemaya (now Haramaya) University in January 2006 G.C. and was awarded a Bachelor of Science degree in Animal Science in June 2008. After one year she joined Haramaya University to pursue an MSc. in March 2009 by the sponsorship of Ministry of Education and was awarded the degree in Animal Production in January 2012.She was employed by Ministry of Education as lecturer in the Mettu University branch of Gambella College of

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Appendix

Figure 2: Goats browse *Acacia abyssinica* in Atsbi-Wemberta(Kelisha)

Figure 3: Keyh Cactus cultivar in Saesie-Tsaeda- Emba district

Figure 4: Live Goats at international slaughter house of Abergelle Abaitor (Mekele)

Figure 5: Cactus population affected by free grazing of animals in Saesie-Tsaeda-Emba District

Figure 6 Cactus population affected by Cochineal insect in Atsbi-Wemberta