CHEMICAL COMPOSITION AND *IN VITRO* ORGANIC MATTER DIGESTIBILITY OF MAJOR FEED RESOURCES IN SOUTH WESTERN ETHIOPIA †

[COMPOSICIÓN QUÍMICA Y DIGESTIBILIDAD In vitro DE LA MATERIA ORGÁNICA DE LOS PRINCIPALES RECURSOS ALIMENTCIOS EN EL SUDOESTE DE ETIOPÍA]

Tamene Tadesse[1,2*] Ajebu Nurfeta[1] and Adugna Tolera[1]

[1]School of Animal and Range Sciences, College of Agriculture, Hawassa University, P.O. Box 05, Hawassa, Ethiopia. Email: tametade2011@gmail.com, ajebu_nurfeta@yahoo.com, adugnatolera3@gmail.com
[2]Department of Animal Sciences, College of Agriculture and Natural Resource, Assosa University, P.O. Box 18, Assosa, Ethiopia. Email: tametade2011@gmail.com
**Corresponding author*

SUMMARY

Background: Green fodder followed by crop residue, agro-industrial by-products and non-conventional feeds make a large contribution to livestock feeding in Ethiopia. **Objective:** To identify and estimate chemical composition of major feed resources in south western Ethiopia. **Methodology:** The study was conducted in the highland, midland and lowlands of south western Ethiopia. A total of 26 indigenous browse and 12 grass species, 3 crop residues, 3 cereal grain mill by-products and 8 non-conventional feeds (2 local brewery by-products, 6 enset, vegetable and fruit by-product) were identified for this study. Triplicate feed samples were collected and assessed for nutrient analysis. **Results:** Crop residues in highlands and, natural pasture followed by crop residues and browses in midland and lowland agro-ecologies were the dominant feed resources. Most browse species, few indigenous grass species, *Colocasia esculenta* L., *Enset ventricosum* (Welw.) Cheesem, *Ipomoea batatas* L. leaves, and local brewery by-products possessed crude protein (CP) content >110 g kg^{-1} dry matter (DM). Conversely, CP concentration of *Acokanthera schimperi* (A.DC.) Benth. and *Bridelia micrantha* (Hochst.) Baill. across all agro-ecologies, crop residues, grass species in the lowlands, sugar cane leaf, banana peel and cereal grain screenings was <110 g kg^{-1} DM. Crop residues, *Ipomoea batatas L.* vine, sugar cane leaf, all grass species except *Molinia caerulea* L., *Setaria verticillata* L., *Stephania abyssinica* **(**Dill. & A. Rich.) Walp, *Paspalum fimbriatum* Kunth, have shown neutral detergent fiber value >550 g kg^{-1} DM. All the tested feed resources but, *Ricinus communis* L., *Acacia oerfota* (Forssk.) Schweinf., *Rhus natalensis* Krauss and *Balanites aegyptiaca* L. possessed <650 g kg^{-1} DM *in-vitro* digestibility. **Implications:** The present study contributes to the understanding of the browse species, vegetable and local beverage by-products in south western Ethiopia and could be considered as potential source of feed especially during the dry periods. **Conclusion:** The browse species as well as vegetable and local beverage by-products in south western Ethiopia can be used as potential complementary to poor quality crop residues and most grass species that are prominent in the region.

Key words: Indigenous browse species; grass species; supplement; by-product; agro-ecological zone.

RESUMEN

Antecedentes: Los forrajes verdes, seguidos de los residuos de cultivos, los subproductos agroindustriales y los piensos no convencionales, contribuyen en gran medida a la alimentación del ganado en Etiopía. **Objetivo:** Identificar y estimar la composición química de los principales recursos alimentarios en el suroeste de Etiopía. **Metodología:** El estudio se llevó a cabo en las tierras altas, medias y bajas del suroeste de Etiopía. Para ello se identificaron un total de 26 especies de ramoneo autóctono y 12 especies de gramíneas, 3 residuos de cultivos, 3 subproductos de molinería de cereales y 8 piensos no convencionales (2 subproductos de cervecería local, 6 de enset y subproductos de hortalizas y frutas). Se recolectaron y evaluaron muestras de alimento por triplicado para el análisis de nutrientes. **Resultados:** Los residuos de cultivos en las tierras altas y los pastos naturales, seguidos de los

† *Submitted September 17, 2023 – Accepted February 15, 2024.* http://doi.org/10.56369/tsaes.5160

ISSN: 1870-0462.

residuos de cultivos y el ramoneo en las agroecologías de las tierras medias y bajas, fueron los recursos alimentarios dominantes. La mayoría de las especies de ramoneo, algunas especies de gramíneas autóctonas, *Colocasia esculenta* L., *Enset ventricosum* (Welw.) Cheesem, hojas de *Ipomoea batatas* L. y subproductos de la cervecería local poseían un contenido de proteína cruda (PB) >110 g kg^{-1} de materia seca (DM). Por el contrario, la concentración de PC de *Acokanthera schimperi* (A.DC.) Benth. y *Bridelia micrantha* (Hochst.) Baill., en todas las zonas agroecológicas, residuos de cultivos, especies de pastos en las tierras bajas, hojas de caña de azúcar, cáscaras de plátano y granos de cereales fueron <110 g kg^{-1} MS. Se observó que los residuos de cultivos, *Ipomoea batatas* L. vid, hojas de caña de azúcar, en todas las especies de pastos excepto *Molinia caerulea* L., *Setaria verticillata* L., *Stephania abyssinica* (Dill. & A. Rich.) Walp, y *Paspalum fimbriatum* Kunth, mostraban un valor de fibra detergente neutro >550 g kg^{-1} MS. Todos los recursos alimentarios probados excepto *Ricinus communis* L., *Acacia oerfota* (Forssk.) Schweinf., *Rhus natalensis* Krauss y *Balanites aegyptiaca* L. poseían una digestibilidad in vitro <650 g kg^{-1} MS. **Implicaciones:** El presente estudio contribuye a la comprensión de las especies de ramoneo, los vegetales y los subproductos de bebidas locales en el suroeste de Etiopía podrían considerarse como una fuente potencial de alimento, especialmente durante los períodos secos. **Conclusión:** Las especies de ramoneo, así como los subproductos vegetales y de bebidas locales en el suroeste de Etiopía, pueden usarse como complemento potencial a los residuos de cultivos de mala calidad y a la mayoría de las especies de pastos que son prominentes en la región.
Palabras clave: Especies nativas; arbustivas; pastos; suplementos; subproductos; zonas agroeologicas.

INTRODUCTION

In Ethiopia, agriculture has contributed 44.7 % to overall GDP (NBE, 2017) at the same time as livestock has contributed 39-49% of general agricultural GDP and 17-25.3% of general country wide GDP (Shapiro *et al.*, 2017). However, poor quality feeds and inadequate nutrition has been pronounced to be one of the most crucial constraints for livestock production in Ethiopia throughout all agro-ecological zones for the duration of the dry season. In addition, the productiveness of natural pasture in Ethiopia is very low, because of drought, overgrazing, agricultural expansion, and populace pressure (Admasu *et al*., 2010; Gizaw *et al.*, 2017). Moreover, crude protein content of the grasses and herbaceous plants decline for the duration of the dry season, leading to prolonged periods of poor nutrition of livestock (Tesfaye *et al.*, 2009). As a result, the usage of communal grazing lands and private grazing land as feed sources were declined at the same time as the usage of crop residues, horticultural by-products and purchased feeds have normally been increased (Zewdie and Mekasha, 2014; CSA, 2017).

Major feed resources in Ethiopia include natural pasture (green fodder) grazing, crop residue, hay and agro-industrial by-products (Tolera *et al.,* 2012; CSA, 2022). Among which, natural pasture and crop residues contribute the largest proportion as livestock feed resources in the country. Also, there is significant contribution of indigenous plant species in livestock production across all agro-ecological zones of Ethiopia (Assefa, 2003). Crop residue, horticultural by-products, indigenous grass and browse species can make a large contribution to livestock feeding in the south western Ethiopia. However, the nutritive value of these feed resources could be affected by agro-ecology, soil type and other environmental factors (Robles, 2008) suggesting the need to obtain detail information in terms of nutritive values of locally available feed resources (Shinkute *et al.,* 2012). Chemical compositions, *in vitro* organic matter digestibility and metabolizable energy contents were commonly used to determine nutritive values of feed resources. Though some feed resources were evaluated in terms of chemical composition, there is limited information on the chemical compositions and *in vitro* organic matter digestibility of feed resources in south western Ethiopia. Therefore, this study was undertaken to identify and evaluate chemical composition as well as *in vitro* organic matter digestibility of potential fodder resources under different agro-ecological zones in south western Ethiopia.

MATERIALS AND METHODS

Study areas

This study was conducted in EQUIP project involvement zones such as Wolaita, Dawro, Bench Sheko and West Omo zones in south western Ethiopia. The study areas represent lowland, midland and highland areas with an average altitude ranging from 1430 to 2000 meters above sea level. The major farming system of the study areas is mixed crop-livestock system followed by agro-pastoral production system. *Enset ventricosum*, *Zea mays*, *Eragrostis tef* and *Triticum aestivum* L. are the most important crops produced in south western Ethiopia. Further description of the study zones are shown in Table 1.

Table 1. Description of the study zones for geographical location.

Parameter	Administrative zones			
	Wolaita	Dawro	Bench Sheko	West Omo
Latitude	7º10'N	7º13'N	7º21'N	6º38'N
Longitude	38º20'E	37º26'E	36º14'E	35º46'E
Altitude (m.a.s.l.)	2000	1750	1430	1500
Distance from Addis Ababa (km)	390	512	561	723
Minimum annual rainfall (mm)	1200	1201	400	1500
Maximum annual rainfall (mm)	1300	1800	2000	1800
Average minimum temperature (ºC)	10	15	22	20
Average maximum temperature (ºC)	20	27	27	29
Production system	Mixed	Mixed	Mixed	Agro-pastoralism

Source: SNNPRLFD (2020); NMA (2020).

Sampling procedures

Multi-stage sampling procedures were used to collect series of data. In the first stage, Wolaita, Dawro, Bench Sheko and West Omo zones were selected purposively by taking into account livestock production and experience of feeding browse and other feeds, logistic and coordination issues. Eight districts (Maraka, Tarcha Zuria, Shey bench, Menit Shahsa, Mizan Aman, Damot Gale, Abala Abaya and Sodo Zuria) were selected purposely to represent the existing agro-ecological zones (highland, midland and lowland agro-ecologies). The agro-ecologies were selected based on the Ethiopian agro-ecological zone classification (EIAR, 2011). Three Rural Kebeles (RKs) from highland, three RKs from midland and three RKs from lowland were purposely selected in compliances with their proximity to roads, accessibility of infrastructure and security status of the area in consultation with the experts in the Districts' livestock and fishery development offices. The total number of households sampled for the study was calculated based on the formula given by Yemane (1967):

$$n = \frac{N}{1 + N(e)^2}$$

Where n is the sample size (180); N is the population size (324) and e is the level of precision (0.05).

Semi-structured and structured questionnaires were used to gather information from households and key informants on type of feed resources availability: type of browse as well as grass species availability and their vernacular names, parts of plants eaten by animals, availability of non-conventional feeds and type of crop residue and horticultural by-products. Focus group discussions (FGD) were held in order to clarify the understanding of all issues. One FGD (composed of 8 to 10 members) in each RKs totaling 9 group discussions were conducted in the study. The FGD included district livestock feed production experts, development agents and farmers/ agro-pastorals that were drawn from people of different age groups, sex and those who had information on feed production as well as the present and past livestock production status in the study areas.

Feed sampling and chemical analysis

The major feeds which were grazed/ browsed by ruminants in the study areas were sorted on the basis of frequency of the respondents who mentioned each of the species and identified through the help of livestock herders, key informants, group discussions and direct observation before the collection of samples. Scientific names for the fodder species were obtained from published articles of flora of Ethiopia (Bekele, 2007; Hedberg and Edwards, 1989) and National herbarium of Addis Ababa University, Ethiopia. Sampling was made in triplicate for all feed resources in the study areas. Sampling of plant species was done in the wet season (from June to September 2020 during main rainy season) when the grasses and leaves of browse species were fully re-grown. The leaves of randomly selected 10 to 15 plants for each browse species were hand plucked while grass samples were harvested at about 5 cm above the ground. The feed samples were collected and then pooled for every individual feed type, browse and grass species under each agroecological zone. Triplicate feed samples were air dried under shade until transported to the laboratory. Then, the air dried samples were oven dried to constant weight at 60 ºC for 48 hours in order to carry out chemical analysis.

Analyses of the samples took place at the animal nutrition laboratory of the International Livestock Research Institute in Addis Ababa, Ethiopia. The oven dried feed samples were ground separately to pass through 1mm screen of a Willey mill and analyzed for DM and ash contents according to AOAC (1990). Nitrogen (N), crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin, in vitro organic matter digestibility (IVOMD) and metabolizable energy (ME) were estimated for the feeds with near infrared spectrophotometry (NIRS) using predictive equations developed for mixed feeds based on previously conducted conventional analysis on more than 500 samples (AOAC, 1990; Van Soest *et al*., 1991). FOSS 5000 feed analyzer with software package WinISI II was the NIRS instrument used to estimate the chemical composition.

Data analysis

The data for major feed resources were ranked by using Index method (Kosgey, 2004). Analysis of variance was carried out for chemical composition within agro-ecologies using General Linear Model procedure of Statistical Analysis System (SAS, 2002) for each agro-ecological zone due to the difference in the types of available fodder species. The statistical design used to analyze the data was Completely Randomized Design (CRD). Tukey's Student Range Test was used to separate means at $\alpha = 0.05$ level of significance.

RESULTS

Feed resources identified in south western Ethiopia

The forage browse species identified are listed with their scientific and vernacular names, edible parts consumed by the animals, and the animal species that most favored the feed are presented in Table 2. About 26 indigenous browses were identified being commonly used as livestock (cattle, goats, sheep and equine) feed. All livestock species in the study area consumed browse species at one time or another during the year, depending upon availability and the preference by animal species.

It was also observed that farmers/ agro-pastoralists had an experience of using grass species for their livestock. A total of 12 improved and indigenous grass species were identified from all agro-ecological zones with their scientific and vernacular names, which were commonly used are presented on Table 3.

Type of feed resources identified

Major livestock feed resources in highland, midland and lowlands of south western Ethiopia are shown in Table 4. In highlands, crop residue followed by natural pasture, browse species, improved fodder, enset leaf, vegetable and fruit by-products, natural pasture hay, and agro-industrial by-products was the main feed resource. Conversely, Natural pasture followed by crop residue, browse species, improved fodder, hay and agro-industrial by products was major feed resource both in the midland and lowlands. The most dominant feed resource in highlands was crop residue, while, natural pasture was the major feed resource in midland and lowland agro-ecological zones of south western Ethiopia (Table 4).

Chemical composition of common browse species

Chemical composition, *in vitro* organic matter digestibility (IVOMD) and metabolizable energy (ME) of the leaves of browse species in the three agro-ecological zones of south western Ethiopia are presented in Table 5. The crude protein (CP) contents of the browse species for the highland, midland and lowlands ranged from 105.2 to 246.2, 114.5 to 287.8 and from 75.6 to 224.9 g kg^{-1} DM, respectively. In the highland, the highest CP content was recorded for *Vernonia amygdalina* and the lowest was recorded in *Lantana camara.* In the midland, *Ricinus communis* had the highest CP content followed by *Vernonia amygdalina* and *Hypericum hirsutum* whereas, the highest CP contents were for *Grewia bicolor* and *Cordia africana* and the least CP content was for *Acokanthera schimperi* in the lowlands. The neutral detergent fiber (NDF) and acid detergent fiber (ADF) contents of commonly used browse species ranged from 406.9 to 563.6 and 268.8 to 409.1 g kg^{-1} DM, respectively in highlands. In the mid lands, NDF and ADF contents were varied between 273.4 and 523.1 g kg^{-1} DM; and 185.5 and 451.2 g kg^{-1} DM, respectively. In the lowland, the NDF content varied from 265.8 to 654.9 g kg^{-1} DM and the ADF contents from 255.6 to 413.8 g kg^{-1} DM. The highest NDF content was recorded for *Arundinaria alpine* and the highest ADF contents were observed in *Erythrina abyssinica* and *Cordia africana* in the highlands. *Piliostigma thonningii* has the highest NDF

Table 2. Browse species commonly used as livestock feed under various agro-ecological zones of south western Ethiopia.

Scientific name	Common name	Vernacular name			Preferred plant parts	Livestock species
		Wolaita	Dawro	Menit		
Erythrina abyssinica Lam.	Flame tree	Bortuwaa	Borto		Leaf	Cattle, shoats
Cordia africana Lam.	Large leaved cordia	Mokota	Mokotha		Leaf	Cattle, sheep
Arundinaria alpine K. Schum.	Mountain bamboo	Woisha	Woisha		Leaf, shoot	Cattle, sheep, equine
Vernonia amygdalina Delile	Bitter leaf	Garaaa	Garaa		Leaf	Cattle, shoats
Lantana camara L.	Lantana		Shahsha	Gagurach	Leaf, twig	Goats
Mussaenda erythrophylla Schum. & Thonn.	Red flag bush		Dawro daama		Leaf, twig	Cattle, sheep
Acanthus pubescens (Oliv.) Engl	*Acanthus*	Ohaa	Okhaa	Osut	Leaf, twig	Cattle, shoats
Erythrina brucei Schweinf.	Red hot poker tree	Bortuwaa	Bortuwaa		Leaf	Cattle, shoats and equine
Ficus sycomorus L.	fig-mulberry	Etaa	Etaa		Leaf	Cattle, goats
Piliostigma thonningii L.	camel's foot tree	Kalikalaa	Kankallaa		Leaf, twig, pod	Cattle, shoats
Bridelia micrantha (Hochst.) Baill.	Mitseeri	Kanakasileta	Kanakasiliyaa		Leaf	Cattle, shoats
Acokanthera schimperi (A.DC.) Benth.	Poison bush	Ladiyaa	Ladiyaa		Leaf	Goats
Ricinus communis L.	Castor bean	Kobuwaa	Temaa	Bolu	Leaf, twig	Goats
Oxytenanthera abyssinica (A.Rich.) Munro	Lowland bamboo	Usuntta	Usuntta		Leaf, shoot	Cattle, shoats and equine
Ficus benjamina L.	Weeping fig			Balut	Leaf	Cattle, goats
Hypericum hirsutum L.	Hairy St John's-wort			Tirshech	Leaf, twig	Goats
Ficus thonningii Blume	Strangler Fig			Oshkut	Leaf	Cattle, goats
Acacia albida (Delile) A. Chev.	White acacia	Odoruwaa	Odoruwaa		Leaf and twig	Goats
Ligustrum sinense Lour.	Chinese Privet			Kolekole	Leaf and twig	Goats
Steganotaenia araliacea Hochst.	Carrot tree				Leaf	Goats
Acacia oerfota (Forssk.) Schweinf.	Gum Arabic tree	Kana achaa			Leaf	Goats
Rhus natalensis Krauss	Natal rhus	Ongaforiyaa			Leaf, twig	Goats
Grewia bicolor Juss.	White raisin	Tawayiyaa			Leaf	Cattle, goats
Dovyilas abyssinica (A.Rich.) *Warb*	African gooseberry	Haglaa			Leaf	Goats
Balanites aegyptiaca (L) Delile	Desert date	Badanaa			Leaf, twig, fruit	Cattle, goats
Dodonea angustifolius L.F.	Sand olive	Sankaraa			Leaf	Goats

Table 3. Grass species identified in south western Ethiopia.

Scientific name	Common name	Vernacular name			Livestock species
		Wolaita	Dawro	Menit	
Cultivated forage grasses					
Pennisetum purpureum Schm.	Napier grass				Cattle
Pennisetum glaucifolium H.	Desho grass	Dashuwaa	Dashuwaa	Desho	Cattle, sheep
Natural pasture grasses					
Natural pasture grass mixed spp.	Natural pasture	Ottaa	Ottaa		Cattle, shoats and equine
Stephania abyssinica (Dill. & A. Rich.) Walp	Moon seed	Turaa			Cattle, sheep and equine
Paspalum fimbriatum Kunth	Crown grass			Gorut	Cattle
Panicum spp.	Panic grass			Habai	Cattle and sheep
Setaria palmifolia (J. Koenig) Stapf	Palm grass			Tabal	Cattle
Setaria verticillata (L.) P.Beauv**.**	Bristle grass	Magaa			Cattle, sheep, equines
Cynodon dactylon Pers.	Bermuda grass	Suraa		Bizit	Cattle, sheep and equine
Hyparrhenia hirta (L.) Stapf	Common thatching grass	Albuwaa			Cattle
Eleusine indica (L.)	Goose grass	Hatitiyaa			Cattle, sheep
Molinia caerulea (L.) Moench	Moor-grass		Doginiyaa		Cattle, sheep, equines

Table 4. Rank of sampled households on major livestock feed resources in highland, midland and lowlands of south western Ethiopia.

Altitude	Feed resources	Rank of respondents							Index	Rank
		1st	2nd	3rd	4th	5th	6th	7th		
Highland										
	Natural pasture	24	36	0	0	0	0	0	0.23	2nd
	Crop residue	36	24	0	0	0	0	0	0.24	1st
	Browses	0	0	28	23	7	1	1	0.15	3rd
	Improved fodder	0	0	15	14	10	15	6	0.12	4th
	Agro-industrial by-products	0	0	2	1	19	16	22	0.07	7th
	Enset leaf, vegetable and fruit by-products	0	0	11	8	7	23	11	0.10	5th
	Hay	0	0	4	14	17	5	20	0.09	6th
Midland										
	Natural pasture	47	18	7	1	1	0	0	0.23	1st
	Crop residue	21	29	15	9	0	0	0	0.21	2nd
	Browses	0	16	25	10	15	5	3	0.15	3rd
	Improved fodder	1	1	6	31	19	14	2	0.12	4th
	Agro-industrial by-products	5	7	2	4	5	8	43	0.09	6th
	Enset leaf, vegetable and fruit by-products	0	3	14	5	11	24	17	0.10	5th
	Hay	0	0	5	14	23	23	9	0.10	5th
Lowland										
	Natural pasture	41	19	4	0	0	0	0	0.23	1st
	Crop residue	16	27	13	5	3	0	0	0.21	2nd
	Browses	4	14	35	6	5	0	0	0.18	3rd
	Improved fodder	0	3	3	30	28	0	0	0.13	4th
	Agro-industrial by-products	3	1	6	9	3	7	35	0.08	6th
	Enset leaf, vegetable and fruit by-products	0	0	1	4	7	25	27	0.07	7th
	Hay	0	0	2	10	18	32	2	0.09	5th

Index: [(7 × number of respondents for 1st rank) + (6 × number of respondents for 2nd rank) + (5 × number of respondents for 3rd rank) + (4 × number of respondents for 4th rank) + (3 × number of respondents of the 5th rank) + (2 × number of respondents for the 6th rank) + (1 × number of respondents of the 7th rank)] divided by [(7 × total responses for 1st rank) + (6 × total responses for 2nd rank) + (5 × total responses for 3rd rank) + (4 × total responses for 4th rank) +(3 × total responses for 5th rank) + (2 × total responses for 6th rank) + (1 × total responses for 7th rank)]; n: number of respondents.

and ADF contents while, *Ricinus communis* has the lowest NDF and ADF contents in the midland agro-ecological zone. *Oxytenanthera abyssinica* and *Ficus sycomorus* had the highest NDF and ADF contents, respectively in the lowlands. In the highland, the acid detergent lignin (ADL) content of browse species ranged between 50.7 (*Arundinaria alpine*) and 203.5 g kg^{-1} DM (*Lantana camara*). In the midland, it varied from 99.9 (*Steganotaenia araliacea*) to 243.1 g kg^{-1} DM (*Piliostigma thonningii*) whereas, the ADL content was highly varied between 62.4 (Oxytenanthera abyssinica) and 261.1 g kg^{-1} DM (*Piliostigma thonningii*) in the lowlands.

The IVOMD and ME of browse species in the highland ranged from 382.2 to 597.8 g kg^{-1} DM and 5.73 to 8.97 MJ kg^{-1} DM, respectively. *Vernonia amygdalina* had the highest IVOMD and ME. In the midland, the IVOMD and ME of the browse species ranged from 426.9 (*Lantana camara*) to 660.1 g kg^{-1} DM (*Ricinus communis*) and from 6.4 (*Lantana camara*) to 9.9 MJ kg^{-1} DM (*Ricinus communis*), respectively. Whereas, in the lowlands, IVOMD and ME was varied from 450.4 to 681.4 g kg^{-1} DM and 6.76 to 10.22 MJ kg^{-1} DM, respectively. The highest IVOMD as well as ME was for both *Acacia oerfota* and *Rhus natalensis* in the lowlands, whereas the lowest IVOMD and ME was recorded for *Ligustrum sinense.*

Table 5. Chemical composition, *in vitro* organic matter digestibility (IVOMD) and metabolizable energy (ME) of the leaves of commonly used browse species in the three agro-ecological zones of south western Ethiopia.

Browse species/ agro-ecological zones	DM	Chemical composition (g kg^{-1} DM)				IVOMD (g kg^{-1} DM)	ME (MJ kg^{-1} DM)
		CP	NDF	ADF	ADL		
Highland (>2,300 m.a.s.l)							
Erythrina abyssinica.	294^{a}	152.8^{bc}	475.2^{ab}	409.1^{a}	114.1^{bc}	498.2^{b}	7.47^{b}
Cordia africana	258^{ab}	207.7^{ab}	420.2^{b}	402.9^{a}	175.2^{ab}	471.8^{bc}	7.08^{bc}
Arundinaria alpine	285^{a}	173.3^{bc}	563.6^{a}	284.2^{b}	50.7^{c}	561.4^{ab}	8.42^{ab}
Vernonia amygdalina	244^{ab}	246.2^{a}	406.9^{b}	268.8^{b}	104.8^{bc}	597.8^{a}	8.97^{a}
Lantana camara	287^{a}	105.2^{c}	445.4^{ab}	343.9^{ab}	203.5^{a}	382.2^{c}	5.73^{c}
Mussaenda erythrophylla	219^{b}	200.1^{ab}	413.6^{b}	356.2^{ab}	166.3^{ab}	543.9^{ab}	8.16^{ab}
Acanthus pubescens	261^{ab}	200.5^{ab}	414.1^{b}	283.8^{b}	128.9^{abc}	536.4^{ab}	8.05^{ab}
SEM	1.13	1.49	2.87	2.21	1.63	1.94	0.29
p-value	0.0034	0.0003	0.018	0.0015	0.0002	<0.0001	<0.0001
Midland (1,500–2,300 m.a.s.l)							
Erythrina brucei	299^{abc}	127.3^{def}	465.1^{ab}	410.1^{ab}	109.6^{gh}	517.3^{cdef}	7.76^{cdef}
Cordia africana	265^{c}	199.2^{c}	390.2^{bcdef}	358.1^{bcd}	172.8^{cd}	477.3^{efg}	7.16^{efg}
Vernonia amygdalina	281^{bc}	248.7^{b}	349.2^{defg}	274.1^{e}	137.8^{efg}	580.3^{abcd}	8.70^{abcd}
Ficus sycomorus	277^{c}	149.1^{d}	424.2^{bcde}	365.1^{bc}	145.4^{de}	551.9^{bcde}	8.28^{bcde}
Piliostigma thonningii	287^{abc}	114.5^{ef}	523.1^{a}	451.2^{a}	243.1^{a}	456.9^{fg}	6.85^{fg}
Bridelia micrantha	276^{c}	98.6^{fg}	453.1^{abc}	357.7^{bcd}	213.4^{ab}	499.4^{defg}	7.49^{defg}
Acokanthera schimperi	354^{ab}	77.3^{g}	449.7^{abc}	276.8^{de}	241.2^{a}	580.2^{abcd}	8.70^{abcd}
Ricinus communis	274^{c}	287.8^{a}	273.4^{g}	185.5^{f}	103.8^{h}	660.1^{a}	9.90^{a}
Lantana camara	297^{abc}	115.3^{ef}	413.1^{bcdef}	344.7^{bcde}	184.6^{bc}	426.9^{g}	6.40^{g}
Acanthus pubescens	335^{abc}	193.5^{c}	428.8^{bcd}	304.0^{cde}	112.7^{fgh}	529.7^{bcdef}	7.95^{bcdef}
Ficus benjamina	358^{a}	138.2^{de}	339.0^{efg}	278.3^{de}	173.0^{cd}	600.9^{abc}	9.01^{abc}
Hypericum hirsutum	266^{c}	240.0^{b}	370.4^{cdef}	282.5^{cde}	144.0^{def}	510.8^{defg}	7.66^{defg}
Ficus thonningii	304^{abc}	204.3^{c}	448.2^{abc}	398.9^{ab}	169.2^{cde}	552.0^{bcde}	8.28^{bcde}
Steganotaenia araliacea	291^{abc}	178.3^{c}	326.2^{fg}	277.9^{fg}	99.9h	605.9^{ab}	9.09^{ab}
SEM	1.46	0.56	1.69	1.61	0.63	1.65	0.25
p-value	0.005	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Lowlands (<1,500 m.a.s.l)							
Erythrina brucei	294^{bcdef}	182.8^{abcd}	436.6^{de}	367.2^{abcd}	110.9^{fgh}	516.5^{cdef}	7.75^{cdef}
Cordia africana	244^{ef}	221.4^{a}	369.0^{e}	324.5^{bcdef}	150.6^{def}	489.8^{efg}	7.35^{efg}
Oxytenanthera abyssinica	412^{a}	133.3^{efg}	654.9^{a}	367.4^{abc}	62.4^{h}	510.6^{defg}	7.66^{defg}
Vernonia amygdalina	210^{f}	185.8^{abcd}	381.0^{e}	313.5^{cdef}	178.3^{cd}	518.2^{cdef}	7.77^{cdef}
Ficus sycomorus	381^{ab}	138.5^{def}	503.0^{bcd}	413.8^{a}	161.1^{cdef}	526.5^{bcdef}	7.90^{bcdef}
Piliostigma thonningii	201^{f}	114.3^{fgh}	562.6^{ab}	404.6^{ab}	261.1^{a}	492.8^{efg}	7.39^{efg}
Bridelia micrantha	380^{ab}	86.7^{gh}	448.5^{cde}	359.5^{abcd}	189.3^{bcd}	574.7^{bc}	8.62^{bc}
Acokanthera schimperi	355^{abcd}	75.6^{h}	454.0^{cde}	269.4^{ef}	242.1^{ab}	584.9^{b}	8.78^{b}

Table 5. Continued…

Browse species/ agro-ecological zones	DM	Chemical composition (g kg^{-1} DM)				IVOMD (g kg^{-1} DM)	ME (MJ kg^{-1} DM)
		CP	NDF	ADF	ADL		
Lantana camara	382^{ab}	164.9^{bcde}	403.3^{e}	318.1^{cdef}	167.6^{cde}	474.9^{fg}	7.12^{fg}
Acanthus pubescens	307^{bcdef}	212.8^{ab}	408.8^{e}	285.6^{def}	121.5^{efg}	550.3^{bcde}	8.26^{bcde}
Acacia albida	274^{cdef}	202.2^{abc}	439.2^{de}	369.0^{abc}	204.0^{bcd}	559.6^{bcd}	8.39^{bcd}
Ligustrum sinense	344^{abcde}	183.7^{abcd}	460.1^{cde}	370.1^{abc}	238.8^{ab}	450.4^{g}	6.76^{g}
Acacia oerfota	327^{abcde}	206.5^{ab}	380.6^{e}	360.5^{abcd}	157.6^{def}	659.7^{a}	9.90^{a}
Rhus natalensis	272^{def}	207.4^{ab}	421.3^{de}	350.8^{abcde}	171.2^{cde}	681.4^{a}	10.22^{a}
Grewia bicolor	259^{def}	224.9^{a}	535.7^{bc}	357.0^{abcd}	167.2^{cdef}	588.0^{b}	8.82^{b}
Dovyilas abyssinica	284^{bcdef}	155.6^{cdef}	439.4^{de}	368.6^{abc}	214.2^{abc}	484.4^{fg}	7.27^{fg}
Balanites aegyptiaca	285^{bcdef}	147.6^{def}	273.6^{f}	256.9^{f}	92.1^{g}	682.2^{a}	10.23^{a}
Dodonea angustifolius	301^{bcdef}	149.3^{def}	265.8^{f}	255.6^{f}	164.4^{cdef}	532.5^{bcdef}	7.99^{bcdef}
SEM	2.02	0.90	1.74	1.54	1.06	1.19	0.18
p-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Means labeled by different superscript letters in the columns are significantly different according to Tukey's Student Range Test (*p<0.05*) within agro-ecology; SEM: standard error of means; CP: crude protein; NDF: neutral detergent fiber; ADF: acid detergent fiber; ADL: acid detergent lignin; IVOMD: *in vitro* organic matter digestibility; ME: metabolizable energy; *p-value*: probability value and m.a.s.l: meters above sea level.

Chemical composition of common grass species

Table 6 presents chemical composition and *in vitro* organic matter digestibility (IVOMD) (g kg^{-1} DM) and ME (MJ kg^{-1} DM) of commonly used grass species in the three agro-ecological zones. The CP content of the grass species for highland, midland and lowlands ranged from 62.2 g kg^{-1} DM (natural pasture grass mixed species) to 144.8 g kg^{-1} DM (*Molinia caerulea*), from 57.2 g kg^{-1} DM (*Cynodon dactylon*) to 151.9 g kg^{-1} DM (*Paspalum fimbriatum*) and from 34.7 g kg^{-1} DM (*Eleusine indica*) to 99.3 g kg^{-1} DM (*Pennisetum purpureum*), respectively. The NDF and ADF of grass species in the highland ranged from 464.9 (*Setaria verticillata*) to 710 g kg^{-1} DM (*natural pasture*) and 329.6 (*Setaria verticillata* to 478.8 g kg^{-1} DM (*natural pasture*), respectively. In the midland, the NDF and ADF contents of the grasses ranged from 425.3 (*S. abyssinica*) to 758.7 g kg^{-1} DM (natural pasture) and from 328.5 (*Paspalum fimbriatum*) to 463.2 g kg^{-1} DM (*Cynodon dactylon*), respectively. While, in the lowlands, the NDF and ADF contents varied from 630.4 (*Setaria palmifolia*) to 785.1 g kg^{-1} DM (*Hyparrheni**a** hirta*) and 396.4 (*Setaria palmifolia*) to 518.4 g kg^{-1} DM (*Hyparrheni**a** hirta*), respectively. The ADL content of common grass species in south western Ethiopia ranged from 47.1 to 133.4 g kg^{-1} DM; from 50.7 to 9.89 g kg^{-1} DM and from 48.7 to 106.3 g kg^{-1} DM for highland, midland and lowlands, respectively. The highest ADL content was recorded for Natural pasture grass mixed species whereas; the lowest was for *Setaria verticillata* in the highlands. Both *Cynodon dactylon* and *Stephania abyssinica* had high ADL contents in the midland agro-ecological zones. Though, in the lowlands, the highest ADL content was for *Hyparrheni**a** hirta.*

The IVOMD and ME contents of the grasses varied widely across the agro-ecological zones, with the IVOMD content ranging from 465.2 (Natural pasture grass) to 608.1 g kg^{-1} DM (*Setaria verticillata*), from 458.1 (*Cynodon dactylon*) to 571.5 g kg^{-1} DM (*Paspalum fimbriatum*) and from 417.8 (*Hyparrheni**a** hirta*) to 535.1 g kg^{-1} DM (*Pennisetum glaucifolium*) in the highland, midland and lowlands, respectively. The ME varied between 6.98 (Natural pasture grass) and 9.12 MJ kg^{-1} DM (*Setaria verticillata*) in the highlands; 6.87 (*Cynodon dactylon*) and 8.57 MJ kg^{-1} DM (*Paspalum fimbriatum*) in the midlands; and between 6.27 (*Hyparrheni**a** hirta*) and 8.03 MJ kg^{-1} DM (*Pennisetum glaucifolium*) in the lowland.

Chemical composition of non-conventional feeds

Chemical composition (g kg^{-1} DM), *in vitro* organic matter digestibility (IVOMD) and ME (MJ kg^{-1} DM) of non-conventional feeds are shown in Table 7. The crude protein CP contents of non-conventional feeds varies between 62 (Maize grain screening) and 156.5 g kg^{-1} DM (traditionally fermented beverage residue; borde atella). The NDF and ADF contents ranged from 245.9 (mixed grain screening) to 418.1 g kg^{-1} DM (processed rice grain screening) and from 66.5 (Mixed grain screening) to 252.9 g kg^{-1} DM (processed rice grain screening), respectively. The ADL content was ranged from 10.6 g kg^{-1} DM (Mixed grain screening) to 69.4 g kg^{-1} DM (borde atella). Whereas the IVOMD and ME contents ranged from 512.4 to 634.4 g kg^{-1} DM and from 7.69 to 9.52 MJ kg^{-1} DM, respectively. The lowest IVOMD and ME was recorded for processed rice grain screening.

Chemical composition of crop residues, enset leaf, vegetable and fruit by-products

Chemical composition (g kg^{-1} DM) and *in vitro* organic matter digestibility (IVOMD) (g kg^{-1} DM) of some crop residues, enset leaf, vegetable and fruit by-products are presented in Table 8. The CP content of crop residues ranged between 26.9 (wheat (*Triticum aestivum* L.) straw) and 65.7 g kg^{-1} DM (teff (*Eragrotis teff* (Zucc.) Trotter) straw), while the NDF content varied between 736.9 (barley (*Hordeum vulgare* L.) straw) and 794.3 g kg^{-1} DM (teff straw). The ADF content lied between 475 (barley straw) and 535 g kg^{-1} DM (wheat straw). The highest ADL content was recorded for wheat straw whereas, the lowest ADL content was for barley straw. The IVOMD content of crop residue ranged from 224.1 (wheat straw) to 463.1 g kg^{-1} DM (barley straw).

Table 6. Chemical composition, *in vitro* organic matter digestibility (IVOMD) and metabolizable energy (ME) of commonly used grass species in the three agro-ecological zones of south western Ethiopia.

Grass species/ agro-ecological zones		Chemical composition (g kg^{-1} DM)				IVOMD	ME
	DM	CP	NDF	ADF	ADL	(g kg^{-1} DM)	(MJ kg^{-1} DM)
Highland (>2,300 m.a.s.l)							
Natural pasture grass mixed species	310^{a}	62.2^{c}	710.0a	478.8^{a}	79.3^{b}	465.2^{c}	6.98^{c}
Pennisetum purpureum	277^{ab}	127.3^{b}	560.8^{c}	392.6^{b}	52.1^{bc}	554.1^{b}	8.31^{b}
Pennisetum glaucifolium	239^{ab}	70.4^{c}	655.0^{b}	413.2^{b}	53.3^{bc}	495.0^{c}	7.42^{c}
Molinia caerulea	265^{ab}	144.8^{ab}	513.7^{c}	371.0^{bc}	68.9^{bc}	580.2^{ab}	8.70^{ab}
Setaria verticillata	219^{b}	138.1^{ab}	464.9^{d}	329.6^{c}	47.1^{c}	608.1^{a}	9.12^{a}
SEM	1.63	1.02	1.01	1.09	0.60	0.82	0.12
p-value	0.0234	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Midland (1,500–2,300 m.a.s.l)							
Natural pasture grass mixed species	275	88.1^{bc}	758.7^{a}	430.6^{ab}	71.8^{b}	501.8^{c}	7.53^{c}
Pennisetum purpureum	317	128.4^{ab}	586.4^{c}	380.9^{bcd}	62.4^{b}	522.4^{bc}	7.84^{bc}
Pennisetum glaucifolium	302	84.4^{bc}	650.2^{b}	425.8^{ab}	57.5^{b}	517.4^{bc}	7.76^{bc}
Stephania abyssinica	302	135.3^{b}	425.3^{e}	407.6^{bc}	98.9^{a}	540.8^{abc}	8.11^{abc}
Setaria palmifolia	262	130.6^{b}	554.0^{cd}	371.6^{cd}	56.6^{b}	555.0^{ab}	8.33^{ab}
Paspalum fimbriatum	242	151.9^{a}	513.3^{d}	328.5^{d}	50.7^{b}	571.5^{a}	8.57^{a}
Cynodon dactylon	294	57.2^{c}	716.0^{a}	463.2^{a}	98.7^{a}	458.1^{d}	6.87^{d}
SEM	2.21	0.52	1.14	1.11	0.52	0.89	0.13
p-value	0.3064	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Lowland (<1,500 m.a.s.l)							
Pennisetum purpureum	369^{a}	99.3^{a}	638.0^{c}	414.2^{b}	56.0^{b}	498.8^{bc}	7.48^{bc}
Pennisetum glaucifolium	316^{bc}	85.1^{ab}	651.5^{c}	415.1^{b}	48.7^{b}	535.1^{a}	8.03^{a}
Panicum spp.	277^{d}	67.3^{bc}	736.4^{b}	487.7^{a}	73.2^{b}	466.0^{cd}	6.99^{cd}
Setaria palmifolia	350^{ab}	82.6^{ab}	630.4^{c}	396.4^{b}	51.2^{b}	528.0^{ab}	7.92^{ab}
Cynodon dactylon	282^{cd}	71.1^{b}	759.2^{ab}	428.0^{b}	77.7^{ab}	479.1^{cd}	7.19^{cd}
Hyparrhenia hirta	303^{cd}	45.2^{cd}	785.1^{a}	518.4^{a}	106.3^{a}	417.8^{e}	6.27^{e}
Eleusine indica	268^{d}	34.7^{d}	780.8^{a}	479.2^{a}	69.2^{b}	452.3^{de}	6.78^{de}
SEM	0.72	0.53	0.89	0.88	0.66	0.74	0.11
p-value	0.0083	<0.0001	<0.0001	<0.0001	0.0004	<0.0001	<0.0001

Means labeled by different superscript letters in the columns are significantly different according to Tukey's Student Range Test ($p<0.05$) within agro-ecology; SEM: standard error of means; CP: crude protein; NDF: neutral detergent fiber; ADF: acid detergent fiber; ADL: acid detergent lignin; IVOMD: *in v*itro organic matter digestibility; ME: metabolizable energy; *p-value*: probability value and m.a.s.l.: meters above sea level.

Table 7. Chemical composition, *in vitro* organic matter digestibility (IVOMD) and metabolizable energy (ME) of non-conventional feeds.

Types of feed stuff	DM	Chemical composition (g kg^{-1} DM)				IVOMD (g kg^{-1} DM)	ME (MJ kg^{-1} DM)
		CP	NDF	ADF	ADL		
Cereal grain mill by-products							
Mixed grain screening	899^{a}	107.4^{b}	245.9^{c}	66.5^{c}	10.6^{b}	634.4^{a}	9.52^{a}
Maize grain screening	909^{a}	62.0^{c}	350.2^{b}	118.4^{c}	24.6^{b}	582.8^{a}	8.74^{a}
Processed rice grain screening	916^{a}	105.9^{b}	418.1^{a}	252.9^{a}	67.1^{a}	512.4^{b}	7.69^{b}
Local beverage by-products							
Katikalla residue (Areke atella)	201^{c}	122.8^{a}	299.0^{bc}	121.6^{bc}	42.1^{ab}	588.0^{a}	8.82^{a}
Traditionally fermented beverage residue (Borde atella)	257^{b}	156.5^{a}	406.3^{a}	207.1^{a}	69.4^{a}	614.8^{a}	9.22^{a}
SEM	0.94	0.94	1.17	1.90	0.71	1.44	0.22
p-value	0.0024	0.0005	<.0001	0.0003	0.0005	<.0014	<.0014

Means labeled by different superscript letters in the columns are significantly different according to Tukey's Student Range Test ($p<0.05$) within agro-ecology; SEM: standard error of means; DM: dry matter; CP: crude protein; NDF: neutral detergent fiber; ADF: acid detergent fiber; ADL: acid detergent lignin; IVOMD: *in vitro* organic matter digestibility; ME: metabolizable energy; *p-value*: probability value.

Table 8. Chemical composition, *in vitro* organic matter digestibility (IVOMD) and metabolizable energy (ME) of some crop residues and horticultural by-products in southwestern Ethiopia.

Feed type	DM	Chemical composition (g kg^{-1} DM)				IVOMD (g kg^{-1} DM)	ME (MJ kg^{-1} DM)
		CP	NDF	ADF	ADL		
Crop residue							
Wheat (*Triticum aestivum* L.) straw	942.3^{a}	26.9^{b}	777.7^{a}	535.0^{a}	93.7^{a}	424.1^{b}	6.36^{b}
Barley (*Hordeum vulgare* L.) straw	940.2^{a}	39.9^{b}	736.9^{b}	475.0^{b}	66.0^{c}	463.1^{a}	6.95^{a}
Tef (*Eragrotis tef* (Zucc.) Trotter) straw	939.8^{b}	65.7^{a}	794.3^{a}	484.7^{b}	75.7^{b}	433.4^{b}	6.50^{b}
SEM	0.05	0.56	1.27	1.09	0.30	0.60	0.07
p-value	0.0073	0.0012	0.0103	0.0031	0.0003	0.0016	0.0005
Enset leaf, vegetable and fruit by-products							
Sugar cane (*Saccharum officinarum L.*) leaf	303^{a}	84.6^{c}	640.4^{a}	450.3^{a}	74.6^{b}	467.0^{d}	7.00^{d}
Enset (*Enset ventricosum* (Welw.) Cheesem) leaf	227^{bc}	190.6^{a}	371.9^{c}	303.2^{b}	59.9^{b}	570.2^{c}	8.55^{c}
Taro (*Colocasia esculenta* L.) leaf	171^{d}	203.7^{a}	321.2^{d}	235.2^{c}	77.4^{b}	590.4^{b}	8.85^{b}
Sweet potato (*Ipomoea batatas* L.) leaf	207^{bcd}	161.5^{b}	351.0^{cd}	317.0^{b}	128.3^{a}	610.4^{a}	9.16^{a}
Sweet potato (*Ipomoea batatas* L.) vine	242^{b}	89.8^{c}	550.5^{b}	415.9^{a}	78.8^{b}	620.8^{a}	9.31^{a}
Banana (*Musa accuminata*) peel	196^{cd}	55.4^{d}	369.9^{c}	322.2^{b}	72.7^{b}	594.9^{b}	8.92^{b}
SEM	1.16	0.43	1.01	1.29	0.62	0.46	0.07
p-value	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001

Means labeled by different superscript letters in the columns are significantly different according to Tukey's Student Range Test ($p<0.05$) within agro-ecology; SEM: standard error of means; DM: dry matter; CP: crude protein; NDF: neutral detergent fiber; ADF: acid detergent fiber; ADL: acid detergent lignin; IVOMD: *in vitro* organic matter digestibility; ME: metabolizable energy; *p-value*: probability value.

The CP content of vegetable and fruit by-products ranged from 55.4 to 203.7 g kg^{-1} DM. The highest (*p<0.01*) CP was for both taro (*Colocasia esculenta* L.) and enset [*Enset ventricosum* (Welw.) Cheesem] leaf, whereas the lowest (*p<0.01*) was recorded for banana (*Musa accuminata*) peel. The NDF content of vegetable and fruit by-products varied from 321.2 g kg^{-1} DM in taro to 640.4 g kg^{-1} DM in sugar cane (*Saccharum officinarum* L.) leaf. The ADF content ranged between 235.2 g kg^{-1} DM in taro leaf to 450.3 g kg^{-1} DM in sugar cane leaf. The ADL content ranged from 59.9 to 128.3 g kg^{-1} DM. The highest (*p<0.01*) ADL content was in sweat potato (*Ipomoea batatas* L.) leaf, whereas the lowest (*p<0.01*) ADL content was in enset leaf. The IVOMD and ME contents of vegetable and fruit by-products varied from 467 (sugar cane leaf) to 620.8 g kg^{-1} DM (sweet potato vine) and from 7 (sugar cane leaf) to 9.31 MJ kg^{-1} DM (sweat potato vine), respectively.

DISCUSSION

Types of feed resources

According to the current result, natural pasture, crop residue, browse species, improved forage, agro-industrial by-products and vegetable and fruit by products were the main livestock feed resources in the study areas which is consistent with the findings of Mengistu *et al*. (2017) which reported that livestock feed resources in Ethiopia are mainly natural grazing and browse, crop residues, improved pasture, forage crops and agro-industrial by-products. Crop residue followed by natural pasture was the most important feed resource in the highlands as larger proportion of land is allocated for cultivation of food crop than other land use types, which agrees with the reports from the other highland areas of Ethiopia (Dawit *et al.*, 2013). Land use, size of land ownership and cropping pattern during the production season determines the types and amount of feed obtained per household. Likewise, the trend of land scarcity testifies that smallholder livestock production in the mixed crop-livestock system is likely to continue to rely upon crop residue, which comprised the major portion of annual feed supply (Tahir *et al.*, 2018). Similarly, as a result of grazing lands deterioration in the highlands of study areas, crop residue generated from production of food-feed crops comprise the largest proportion of livestock feed resources. Bogale *et al.* (2008) also reported the progressive decline of grazing land and the use of crop residue as the major source of livestock feed especially during the dry season in the mixed farming system of the Bale highlands of Ethiopia. On the other hand, natural pasture was the dominant component of livestock feed in midlands and lowlands particularly, for the agro-pastoralists in the West Omo zone. Similarly, Tolera and Abebe (2007), and Worku and Lisanework (2016) noted that grazing on natural pasture; browsing on communal grazing land and stubble following crop harvest are the main components of animal fodder in South Omo zone, South Western Ethiopia. A similar finding was reported by Gizaw *et al.* (2017) where the proportion of grazing resources to total land area was 56.5 %, 48.2 % and 40.5 % in dry lowland, dry highland and dry midland compared to 24.6 % in moist lowland, 28.5% in moist highland, 29.3 % in wet highland and 30.5 % in the wet midland. However, the productivity of natural pasture in Ethiopia is very low, owing to agricultural expansion, population pressure, drought and overgrazing (Admasu *et al.*, 2010). Consequently, this condition leads to low dry matte (DM) production, and therefore, creates a critical imbalance in year-round livestock feed supply. This would be alleviated by using various improved forage innovations in the country.

In the current study area, it was noted from group discussion that the area is rich in tree browse and shrubs species which are being used as livestock feed resource especially in dry season. Similarly, FAO (2018) clearly described that browses could constitute a bulk of feed for livestock at times of severe drought. However, these feed resources are rich in anti-nutritional factors (tannins) that limit nutrient availability and decrease nutrient utilization in animals. Hence, for areas rich in browses, placement of multi-nutrient blocks containing a commonly used tannin-inactivating agent such as polyethylene glycol (MW 4000) in rangelands could enhance the use of browses as animal feed and help prevent livestock mortality. Availability of agro-industrial by-product was very limited in the areas particularly in the highlands and midlands of Bench Sheko and West Omo zones as the agro-industries as well as feed processing plants limited to few industries, located long kilometers away, at Addis Ababa and there around (FAO, 2018).

Chemical composition of common browse species

The chemical composition and *in vitro* organic matter digestibility of the browse species were varied between the species. Crude protein is a good indicator to determine the quality of forage (Amiri and Mohamed Shariff, 2012). The CP contents of the leaves of browse species such as *Erithryna abyssinica, Erythrina brucei, Cordia Africana, Vernonia amygdalina and Piliostigma thonningii*, are comparable to those reported by various authors

(Shinkute *et al.,* 2012; Emana *et al.,* 2017; Fekade *et al.,* 2021; Ayenew *et al.,* 2021). Moreover, the CP content of *Vernonia amygdalina* is higher in highlands and midlands while, its NDF, ADF and ADL contents are lower than the values reported for Ethiopian feeds in Sub-Saharan African (SSA) Feeds database (ILRI, 2021). However, *Erythrina abyssinica*, *Erythrina brucei* (in midland) *Cordia africana* (in the highland and midland) had lower CP, NDF and ADF contents than the figures reported by ILRI (2021) for Ethiopian feeds (SSA Feeds database). Except the CP values for *Lantana camara* in the highland and midland*; Piliostigma thonningii, Bridelia micrantha* and *Acokanthera schimperi* in both midland and lowlands, all the browse species tested contain a CP value above the required CP (110-120 g kg^{-1} DM) for moderate level of ruminant production (ARC, 1980). As a result, the high CP content in the tested browse species suggested that the species have a good potential to be used as a protein supplement to poor quality feeds for ruminants indicating the possibilities of feed resource base improvement from locally available feed resource under all the three agro-ecological zones. Except *Arundinaria alpine* in the highland and *Oxytenanthera abyssinica* in the lowland, the NDF contents of all the browse species lie below the critical level (550 g kg^{-1} DM) that limit appetite and digestibility (Van Soest and Robertson, 1985). In addition, almost all of the browses tested contain ADF value less than the threshold value of 400 g kg^{-1} DM reported by Kellems and Church (1998), believed to have high quality feed. IVOMD of the browses was within the range of IVOMD value (422 - 580.8 g kg^{-1} DM) reported by Bayissa *et al.* (2016) for the browse species from Boran rangeland. However, the IVOMD value of the browse species in the current study was below the range (631 – 751 g kg^{-1} DM) reported by Fekade *et al.* (2021) for the browse species in East Dembia. The variation in IVOMD values could be due to differences in fiber fraction (Van Soest, 1991) and organic matter content (Isaac *et al.,* 2008) of the tested browse species. As Mugerwa *et al*. (1973) reported the digestibility values more than 650 g kg^{-1} DM show good nutritive value and values below these level results in reduced in take. Accordingly, except *Ricinus communis* in midlands and; *Acacia oerfota, Rhus natalensis* and *Balanites aegyptiaca* in the lowlands, all the remaining browses tested in the current study had lower digestibility values than the critical level (650 g kg^{-1} DM), indicating that there a need of strategic supplementation for efficient utilization. Several factors such as harvesting regime, season, location, differences in morphology and lignin content affect chemical composition, digestibility, intake and nutrient utilization (Mengistu, 2001; Beyene, 2009). In order to exploit these browses fully, there is a need of in-depth studies on anti-nutritional factor, digestibility and animal response besides chemical composition. In the current result, the high variability in the nutrient content of browse species could be associated with the inherent nature of the species. Digestible organic matter is important for ruminal microbial protein synthesis as an energy source (Costa *et al.,* 2013; Bakr, 2019). Most of the browses and vegetable by products used in our study were low in fiber. Hence, the *in vitro* organic matter digestibility and ME in the current study applies to camels and donkey as they are more efficient in low fiber feeds.

Chemical composition of common grass species

Wide variation observed in the nutritive value of the grass species along the agro-ecological zones in the present study was as expected that is attributed to several factors including species, stage of maturity and location. Moreover, Ludwig *et al.* (2004) reported that difference in the quality of forage species is mainly due to the species type, phenology of a species and the above-ground biomass. The CP concentration in *Pennisetum purpureum* both in the highland, mid land and lowlands of the present study is consistent with reports of Melesse *et al.* (2017) and ILRI (2021) for Ethiopian feeds in SSA feeds data base. But, the CP value for *Cynodon dactylon* is lower than the values reported by the same authors. All of the grass species evaluated in the current study had the CP below the critical limit of 106 g kg^{-1} DM (Minson, 1990) except *Molinia caerulea*, *Setaria verticillata*, *Pennisetum purpureum* in the highland and; *Paspalum fimbriatum, Stephania abyssinica, Setaria palmifolia* and *Pennisetum purpureum* in midlands. In general, lower CP contents in the grasses than in the browses were consistent with the reports of Abebe *et al.* (2012) for the grass species in Boran rangeland and Tesfaye *et al.* (2009) for the exclosure forages in the semi-arid region of northern Ethiopia. As a result, it is obvious that majority of the grass species evaluated in this study inadequate levels of nitrogen for the effective microbial synthesis and hence intake may fall down. The NDF and ADF contents of *Pennisetum purpureum* and *Pennisetum glaucifolium* in all the studied agro-ecologies are lower than the average values reported in Sub-Saharan African Feeds (SSA Feeds) database, for Ethiopian feeds, (ILRI, 2021). However, the NDF concentrations of natural pasture grass mixed species in highland and midlands are higher than the figures reported for natural pasture grass harvested during wet season (ILRI, 2021). On the other hand, CP and

NDF contents in *Hyparrhenia hirta* are comparable to the values reported for the same species in Sub-Saharan African Feeds (SSA Feeds) database (ILRI, 2021). In general, all grass species (except, *Pennisetum purpureum*, *Trifolium species*, *Molinia caerulea*, *Setaria verticillata*, *Stephania abyssinica*, *Setaria palmifolia* and *Paspalum fimbriatum* both in the highland and midland) had higher NDF values than the threshold level (600g kg^{-1} DM) in tropical grasses suggested by Meissner *et al.* (1991) above which intake is affected. Moreover, the grass species evaluated in the current study were highly fibrous and, the IVOMD as well as ME values of the grasses apply to cattle, sheep and goats as they are more efficient in feeds with high fiber. But it does not apply to milk production, since milk production needs a lot of energy. The energy in those feeds was insufficient for milk production.

Chemical composition of non-conventional feeds

The lower CP and NDF content, but higher IVOMD and ME contents than the current study has been reported by Feyissa *et al.* (2015) for mixed cereal grain screenings. Moreover, Gebremariam and Belay (2021) reported comparable CP content, but higher NDF and ME contents for food mill waste than the figures recorded for mixed grain screenings in this study. ILRI (2021) reported higher CP and NDF contents for maize bran than the present values for maize grain screening. The higher fiber contents of maize grain screening was associated with the low proportion of germ and flour in maize grain screening than in mixed grain screenings. Maize grain screening is made by screening maize grain flour by using a sieve in order to separate the finest flour and the fibrous outer layer of maize grain.

Currently, there is emerging production of rice crop in the south western Ethiopia, especially in Bench sheko zone. After the rice has been processed for food, the rice bran, hulls and its fragmented grains, which are highly fibrous, are produced as by-products and further re-processed in order to reduce the high fiber content and used mainly as livestock feed around Mizan-Aman town. Almost all of cattle fattening, dairy and poultry farms in the town use processed rice residue as major supplement instead of use of other compound feeds due to several factors such as lack of feed processing plant in the town or nearby, a limited access to concentrate feeds, an elevated cost of concentrate feeds (Group discussion). Tolera (2008) reported comparable NDF and lignin, but lower CP contents for rice bran than the values recorded for processed rice screening in this study. Also, ILRI (2021) reported lower CP and higher NDF contents for rice bran than the values obtained in the current study for the processed rice screening. This might be associated with differences in the crop growing environment and method of grain milling processes. Traditional beverage by-products called Katikalla residue (Areke atella) and traditionally fermented beverage residue (Borde atella) are produced in appreciable amounts year round in the south western Ethiopia. The CP and NDF contents of areke atella found in this study were lower than the values reported by various authors (Tolera, 2008; Negesse *et al.*, 2009; Chalchissa *et al.*, 2014; Feyissa *et al.*, 2015), while the NDF was higher than the value reported by Alemayehu and Yaynishet (2011). On the other hand, lower IVOMD and ME were observed in areke atella than the values reported by Feyissa *et al.* (2015) and Chalchissa *et al.* (2014). According to Lonsdale (1989), feeds that have <12%, 12–20%, and >20% CP are classified as low, medium, and high protein sources, respectively. Based on this classification, traditionally fermented beverage residue is considered as medium protein source, and has the potential to serve as protein supplement to poor-quality roughages. ‘Traditionally fermented beverage residue or ‘borde atella’ is a by-product yielded via the production of borde (traditionally fermented beverage) in Wolaita and West Omo zones (Figure 1). A production process of borde includes fermentation of cereals such as wheat and maize grains. A thick coarse paste of wheat or maize flour is roasted on a hot flat metal or clay pan and cooled for an hour, thoroughly blended with ground malt. The whole mixture is further mixed with water and allowed to ferment in ambient temperature for 24 hours (Bacha *et al.*, 1998). Borde atella residue has been less studied compared to other traditional beverage by-products such as Katikalla (areke) and local brewery (tella) residues.

Generally, borde and areke atellas are provided to all species and type of animals in south western Ethiopia (Figure 2). Even if ‘atella’ has reasonable amounts of CP, and could be considered as a protein supplement to non-ruminants, its high fiber content might limit intake and digestibility in broilers (Solomon, 2007). However, Ajebu and Abdo (2014) found improved performance (intake, digestibility and daily weight gain) in sheep fed on a mixture of diet consisting of equal parts of areke atella. Moreover, the nutritional value of these by-products (atella) is influenced by the row materials, such as grains, used and the different fermentation processes (Alemayehu and Yaynishet, 2011).

Figure 1. 'Borde atella' preparation in West Omo zone.

Chemical composition of crop residues, enset leaf, vegetable and fruit by-products

The CP content of barley and teff straws and NDF content of wheat straw are higher than the values reported for Ethiopian feeds in SSA Feeds database (ILRI, 2021). But, comparable CP and higher NDF concentrations than the current values were reported for sugar cane leaf + tops in SSA Feeds database (for Ethiopian feeds). Ruminants require above 7%, (70 g kg^{-1} DM) CP for microbial protein synthesis to satisfy their maintenance requirement (Minson, 1990; Van Soest, 1994). The CP content of Sugar cane leaf was above this minimum level whereas, all the cereal straws and banana peel tested in this study had CP value below the critical level, and hence need protein supplements. The high level of CP in taro leaf makes their use for supplementing low quality roughages. The CP value of taro leaf in this study was comparable with the value reported earlier (Kaensombath and Frankow-Lindberg, 2012) while, the NDF content in our study was much lower than the value in the same report. Higher CP and lower NDF contents were also found in the current result than the values reported by Gemiyo *et al.* (2013) for taro leaf in southern Ethiopia. Moreover, Sreng *et al.* (2020) reported lower CP and NDF in taro leaf than the values in the current result. Taro, often locally found in south western Ethiopia (Figure 3), is directly used by the poultry and dairy farms as animal feed (especially, farms in and around Mizan aman city). Higher CP value was reported for leaf lamina (Nurfeta *et al*., 2008) than value observed in this study. However, the CP content of the enset leaf was higher than earlier reports (Tolera, 2008; 175 g kg^{-1} DM and Gemiyo *et al*., 2013; 175g kg^{-1} DM).

Figure 2. Various type and species of animals consuming borde and areke atellas

In densely populated and land scarce areas, sweet potato (*Ipomoea batatas*) has a promising potential for use as animal feed because of its relatively short vegetative cycle and high yield potential with minimal agricultural practices. The CP of sweet potato leaf tested in this current study was lower than previous studies by Zeru *et al.* (2014) and Melesse *et al.* (2020), but the NDF content was higher than the value in those previous studies. Similarly, ILRI (2021) reported lower NDF and ADF contents in sweat potato leaf and vines than the values obtained in the current study. The CP content of sweet potato vine lies within the range of 82 to 109 g kg^{-1} DM reported by Zeru *et al.* (2014) for sweet potato vine of various varieties. However, higher CP content was reported for sweet potato vine (Sreng *et al.,* 2020) than the values in this study. In general, sweet potato leaf and vine are characterized by high yielding, palatability and CP content. Due to this, they could be used as appropriate protein supplement for farm animals having low quality roughages during drier periods (Megersa *et al.*, 2013).

Figure 3. *Colocasia esculenta* L. used as animal fed in Bench sheko zone.

Due to favorable climatic condition for banana plant production in south western Ethiopia, especially in Bench Sheko zone, large amount of its fresh peel is produced daily and it is part of the solution to the feed shortage in the dry season of the area. Negesse *et al.* (2009) found similar CP to the value in this study while Tolera (2008) reported higher CP content for banana peel. However, the CP content in our study was below the critical level (7% or 70g kg^{-1} DM) for minimum microbial synthesis in ruminants. Thus, it should be provided with suitable protein supplement.

CONCLUSSION

Among the feed resources identified in the south western Ethiopia, maize grain screenings, banana peel, crop residues and most of indigenous grass species across all agro-ecological zones were observed to show CP value below the critical level for optimum microbial function in the rumen. On the other hand, local beverage by-products, enset leaf, vegetable by-products and leaves of browse species possessed moderate to high CP contents and IVOMD values suggesting their potential for strategic supplementation to poor quality roughages. *Colocasia esculenta* and *Enset ventricosum* leaves had highest CP and digestibility values. *Vernonia amygdalina* in the highlands and midlands; *Ricinus communis, Hypericum hirsutum* in the midlands and *Grewia bicolor, Cordia africana* leaves in the lowlands were also tested to show best values in terms of CP and NDF contents. Hence, the browse species as well as vegetable and fruit, and local beverage by-products in south western Ethiopia could be considered as potential source of feed especially during the dry periods. We recommend further study on anti-nutritional factors (especially for browse species) and animal responses while the indigenous grass species and crop residues need strategic supplementation for efficient utilization.

Acknowledgments

We acknowledge zonal and district as well as peasant association experts in the study sites for their valuable support during data collection.

Funding. This work was funded in whole or part by the United States Agency for International Development (USAID) Bureau for Food Security under Agreement no. AID-OAA-L-15-00003 as part of Feed the Future Innovation Lab for Livestock Systems. Additional funding was received from Bill & Melinda Gates Foundation. Any opinions, findings, conclusions, or recommendations expressed here are those of the authors alone.

Conflict of interest. Authors declare no conflict of interest regarding this research work.

Data availability. The data helping the conclusions of this article could be available with the aid of corresponding author. tametade2011@gmail.com.

Author contribution statement (CRediT). T. Tadesse – Conceptualization; Investigation; Methodology; Data curation; Formal analysis; Writing - original draft; Writing review and editing. **A. Nurfeta**- Conceptualization; Investigation; Data curation; Methodology; Validation; Supervision; Writing review and editing. **A. Tolera** – Conceptualization; Methodology; Project administration; Supervision; Writing - review and editing.

REFERENCES

Abebe, A., Tolera, A., Oystein, H., Tormod, A. and Lars, O.E., 2012. Seasonal variation in nutritive value of some browse and grass species in Borana Rangeland, South Ethiopia. *Tropical and Subtropical Agroecosystems* 15, pp. 261-271. https://www.revista.ccba.uady.mx/ojs/index.php/TSA/article/view/786

Admasu, T., Ebro, A. and Tessema, Z., 2010. Livestock-rangeland management practices and community perceptions towards rangeland degradation in South Omo zone of Southern Ethiopia. *Livestock Research for Rural Development*, 2010, 22, p. 5. http://www.lrrd.org/lrrd22/1/tere22005.htm

Ajebu, N. and Abdo, Y., 2014. Feeding value of different levels of malt sprout and katikala atella on nutrient utilization and growth performance of sheep fed basal diet of Rhodes grass hay. *Tropical Animal Health and Production*, 46(3), pp. 541-547. http://doi.org/10.1007/s11250-013-0527-8

Alemayehu, T. and Yayneshet, T., 2011. Comparative chemical composition evaluation of local brewery and liquor byproducts made from different ingredients. *Journal of Drylands*, 4 (2), pp. 307-309

Amiri, F. and Mohamed Shariff, A.R., 2012. Comparison of nutritive values of grasses and legume species using forage quality index. Songklanakarin, *Journal of Science and Technology*, 34, pp.577-586. https://rdo.psu.ac.th/sjstweb/journal/34-5/0475-3395-34-5-577-586.pdf

AOAC (Association of Official Analytical Chemists), 1990. Association of official Analytical chemists. Official methods of analysis. 15th edition, volume 1.

ARC (Agricultural Research Council), 1980. The nutrient requirements of ruminant livestock, technical review Agricultural Research Council working party. Common wealth Agricultural Bureau, Farnham Royal, UK.

Assefa, G., 2003. Feed Resource Development and Utilization: Possible Options and Recommendations under Ethiopian Condition. Training Handout Prepared For Agricultural Subject Matter Specialists (SMS), Holeta Agricultural Research Centre, Addis Ababa, Ethiopia, pp: 1-37.

Ayenew, A., Tolera, A., Nurfeta, A. and Assefa, A., 2021. Farmers' Preference and Knowledge on Indigenous Multipurpose Browse Species towards their Feed Value in North Western Ethiopia. *Tropical and Subtropical Agroecosystems* 24 (2021), pp. #20. http://dx.doi.org/10.56369/tsaes.3124

Bacha, K., Mehari, T. and Ashenafi, M., 1998. Microbial dynamics of 'borde' fermentation, a traditional Ethiopian fermented beverage. SINET. *Ethiopian Journal of Science*, 1998; 21, pp.195-205. https://doi.org/10.4314/sinet.v21i2.18120

Bakr, A.A., 2019. Impact of partial replacement of alfalfa hay with prickly pear peels (ppps) on productive performance of rabbits. *Egyptian Journal of Nutrition and Feeds*, 22, pp. 535–550. https://ejnf.journals.ekb.eg/article_79445_f7c24a42dfed9988127985fc5c06d71b.pdf

Bekele, T. A., 2007. Useful trees of Ethiopia: identification, propagation and management in 17 agroecological zones. Nairobi: RELMA in ICRAF Project, 552p.

Beyene, T., 2009. Assessment of livestock feed resources, feeding systems and rangeland condition in Assosa Zone, Benishangul-Gumuz Region. [Master's Thesis]. [Hawassa]: Hawassa University, Ethiopia.

Bogale, S., Melaku, S. and Yami, A., 2008. Matching livestock systems with available feed resources in the Bale Highlands of Ethiopia.

Outlook *Agriculture*, 2008; 37, pp. 105–10. https://doi.org/10.5367/000000008784648960.

Chalchissa, G., Mekasha, Y. and Urge, M., 2014. Feed Resources Quality and Feeding Practices in Urban and Peri-Urban Dairy Production of Southern Ethiopia. *Tropical and Subtropical Agroecosystems*, 17, pp. 539 – 546. https://www.revista.ccba.uady.mx/ojs/index.php/TSA/article/view/2008

Costa, R.G., Treviño, I.H., Medeiros, G.R.D., Medeiros, A.N.D., Gonzaga Neto, S., Azevedo, P.S.D., Pinto, T.F., 2013. Feeding behavior and performance of sheep fed cactus pear in substitution of corn. *Revista Brasileira de Zootecnia*, 42, pp. 785–791. https://doi.org/10.1590/S1516-35982013001100004

CSA (Central Statistical Agency), 2017. Agricultural sample survey: Area and production of major crops: private peasant holdings. Statistical bulletin 584, Vol. I. Addis Ababa, Ethiopia.

CSA (Central Statistical Agency), 2022. Agricultural Sample Survey. Livestock and Livestock Characteristics (Private Peasant Holdings).Central Statistical Agency, Addis Ababa, Ethiopia. Statistical bulletin 594, Vol. II; 219p.

Dawit, A., Nurfeta, A. and Banerjee, S., 2013. Assessment of feed resource availability and livestock production constraints in selected Kebeles of Adami. *African Journal of Agricultural Research*, 8, pp. 4067–4073. https://doi.org/10.5897/AJAR2013.7096.

EIAR (Ethiopian Institute of Agricultural Research), 2011. Crops and Agro-ecological zones of Ethiopia. Coordination of National Agricultural Research System, Ethiopia. English and Amharic Version. EIAR, Addis Ababa, Ethiopia.

Emana, M., Ashenafi, M. and Getahun, A., 2017. Nutritional Characterization of Selected Fodder Species in Abol and Lare Districts of Gambella Region, Ethiopia. *Journal of Nutrition and Food Science*, 7, pp. 581. http://dx.doi.org/10.4172/2155-9600.1000581

FAO (Food and Agricultural Organization of the United Nations), 2018. Report on Feed Inventory and Feed Balance; FAO: Rome, Italy, 2018; 160p.

Fekade, M., Bayissa, M. and Nurfeta, A., 2021. Nutritive Value of Major Browse Species in East Dembia District, Central Gondar, Ethiopia. *Agricultural Science Digest* (41), pp. 76-80 https://arccjournals.com/journal/agricultural-science-digest/D-192

Feyissa, F., Kitaw, G. and Assefa, G., 2015. Nutritional Qualities of Agro-Industrial By-Products and Local Supplementary Feeds for Dairy Cattle Feeding. Ethiop. *Journal of Agricultural Science*, 26(1), pp. 13-26. https://www.ajol.info/index.php/ejas/article/view/144684

Gebremedin, T. and Belay, S., 2021. Chemical Composition and Digestibility of Major Feed Resources in Tanqua-Abergelle District of Central Tigray, Northern Ethiopia. *The Scientific World Journal*, 2021, p. 5234831. http://doi.org/10.1155/2021/5234831

Gemiyo, D., Hassen, A., Kocho, T., Birhanu, T., Bassa, Z. and Jimma, A., 2013. Chemical Composition and Digestibility of Major Feed Resources in Mixed Farming System of Southern Ethiopia. *World Applied Sciences Journal*, 26 (2), pp. 267-275. http://dx.doi.org/10.5829/idosi.wasj.2013.26.02.1456

Gizaw, S, Ebro, A., Tesfaye, Y., Mekuriaw, Z., Mekasha, Y., Hoekstra, D., Gebremedihin, B. and Tegegne, A., 2017. Feed resources in the highlands of Ethiopia: A value chain assessment and intervention options. LIVES Working Paper 27. Nairobi, Kenya: International Livestock Research Institute (ILRI). https://hdl.handle.net/10568/82636

Hedberg, I. and Edwards, S., 1989. Flora of Ethiopia, Volume 3. The national herbarium, Addis Ababa University, Ethiopia.

ILRI (International Livestock Research Institute), 2021. Sub-Saharan Africa feeds composition database (‘SSA Feeds’). Website: Nairobi, Kenya: ILRI. https://hdl.handle.net/10568/114170

Isaac, M. O., Carolyne, C. W., Shaukat, A. A., Toshiyoshi, I. and Tsutomu, F., 2008. Evaluation of nutritive value and palatability by goats and sheep of selected browse foliages from semi-arid area of Kenya. *Animal Science Journal*, 79, pp.582–589. http://doi.org/10.1111/J.1740-0929.2008.00567.X

Kaensombath, L. and Frankow-Lindberg, B.E., 2012. Effect of harvesting interval on biomass yield and chemical composition of taro (*Colocasia esculenta* (L.) Schott) for feeding pigs in Laos. *Field Crops Research*, 128, 71-75. http://dx.doi.org/10.1016/j.fcr.2011.12.019

Kellems, R.O. and Church, D.C., 1998. Livestock Feeds & Feeding. (4th ed.). Prentice- Hall, Inc., New Jersey, USA. 573.

Kosgey, I.S., 2004. Breeding objectives and breeding strategies for small ruminants in the Tropics. [Ph. D. Dissertation]. [Netherlands]: Wageningen University. https://hdl.handle.net/10568/79733

Lonsdale, C., 1989. Raw Materials for Animal Feeds Compounders and Farmers, Chalcombe Publications, Great Britain, 1989.

Ludwig, F., De Kroon, H., Berendse, F. and Prins, H.H.T., 2004. The influence of savanna trees on nutrient, water and light availability and the understorey vegetation. *Plant Ecology*, 170, pp. 93-105. https://www.jstor.org/stable/20146535

Megersa, T., Urge, M. and Nurfeta, A., 2013. Effects of feeding sweet potato (*Ipomoea batatas*) vines as a supplement on feed intake, growth performance, and digestibility and carcass characteristics of Sidama goats fed a basal diet of natural grass hay. *Tropical Animal Health and Production*, 45, 593–601. https://doi.org/10.1007/s11250-012-0264-4

Meissner, H.H., Köster, H.H., Nieuwoudt, S.H. and Coertze, R.J., 1991. Effects of energy supplementation on intake and digestion of early and mid-season ryegrass and *Panicum*/ Smuts finger hay, and on *in sacco* disappearance of various forage species. *South African Journal of Animal Science*, 21, pp.33–42. https://goo.gl/ypY7DC

Melesse, A., Chalew, N., and Nurfeta, A., 2020. Effect of sweet potato leaf supplementation on growth and nutrient digestibility in sheep. *Scientia Agriculturae Bbohemica*, 51, 2020 (2), pp. 51–57. https://doi.org/10.2478/sab-2020-0007

Melesse, A., Steingass, H., Schollenberger, M. and Rodehutscord, M., 2017. Screening of common tropical grass and legume forages in Ethiopia for their nutrient composition and methane production profile in vitro. *Tropical Grasslands-Forrajes Tropicales.* 5(3), pp.163–175. https://doi.org/10.17138/tgft(5)163-175

Mengistu, A., Kebede, G., Feyissa, F. and Assefa, G., 2017. Review on Major Feed Resources in Ethiopia: Conditions, Challenges and Opportunities. *Academic Research Journal for Agricultural Science Research*, 5(3), pp. 176-185. https://doi.org/10.14662/ARJASR2017.013.

Mengistu, S., 2001. Evaluation of selected multipurpose trees as feed supplements in teff (*Eragrotis tef*) straw based feeding of Menz Sheep. [Ph.D. Dissertation]. [Berlin]: Germany.

Minson, D. J., 1990. Forage in ruminant nutrition. (Ed. T. J. Conha). pp. 60-263. Academic Press, Inc., Javanorich Publishers, USA.

Mugerwa, J.S., Christianson, J.A. and Ochetin, S., 1973. Grazing behavior of exotic dairy cattle in Uganda. *East African Agricultural Forestry Journal*, 19, pp. 1-11. https://doi.org/10.1080/00128325.1973.11662610

NBE [National Bank of Ethiopia], 2017. Annual Report 2016/17; Addis Ababa: National Bank of Ethiopia.

Negesse, T., Makkar, H.P.S. and Becker, K., 2009. Nutritive value of some non-conventional feed resources of Ethiopia determined by chemical analyses and an in vitro gas method. *Animal Feed Science and Technology*, 154, pp. 204–217. https://doi.org/10.1016/j.anifeedsci.2009.09.010

NMA (National Metrological Agency), 2020. Annual bulletin of National Metrological Agency of Ethiopia. Addis Ababa, Ethiopia.

Nurfeta, A., Lars, O. E., Tolera. and Sundstøl, F., 2008. Chemical composition and *in sacco* dry matter degradability of different morphological fractions of 10 enset (*Ensete ventricosum*) varieties. *Animal Feed Science and Technology*, 146, 55–73. http://doi.org/10.1016/j.anifeedsci.2007.12.003

Robles, A.B., Ruiz-Mirazo, J., Ramos, M.E. and González-Rebollar, J.L., 2008. Role of livestock grazing in sustainable use, naturalness promotion in naturalization of marginal ecosystems of southeastern Spain (Andalusia). In: Agroforestry in Europe, Current status and future prospects. *Advanced Agroforestry*, pp, pp. 6. https://link.springer.com/chapter/10.1007/978-1-4020-8272-6_10

SAS (Statistical Analysis Systems Institute), 2002. SAS Version 9.0. SAS Institute Inc. Cary, North Carolina, USA.

Shapiro, B.I., Getachew, G., Solomon, D., Asfaw, N., Kidus, N., Gezahegn, A. and Henok, M., 2017. Ethiopia livestock sector analysis. ILRI (International Livestock Research Institute) Project Report. Nairobi, Kenya. 103p. https://hdl.handle.net/10568/92057

Shinkute, B., Abubeker, H., Tadese, A., Nura, A. and Ebro, A., 2012. Identification and nutritive value of potential fodder trees and shrubs in the Mid Rift Valley of Ethiopia. *The Journal of Animal and Plant Science*, 22, pp. 1126-1132. https://repository.up.ac.za/handle/2263/56661

SNNPRLFD (Southern Nations Nationalities and Peoples Region Livestock and Fisheries Development office), 2020. An annual report on livestock and fisheries development related activities. Hawassa, Ethiopia.

Solomon, D., 2007. Comparative nutritive value of Atella and industrial brewers grains in chicken starter ration in Ethiopia. *Livestock Research for Rural Development*, 19 (1), p. 8. http://www.lrrd.org/lrrd19/1/deme19008.htm

Sreng, S., Chea, B., Kang, K., Keo, S., Tokach, M.D., Tokach, L.M., Hok, L., Vipham, J.L. and DeRouchey, J.M., 2020. Nutrient analysis of common local feed ingredients used by swine farmers in Cambodia. *Livestock Research for Rural Development*, 32 (7), p. 103. www.lrrd.org/lrrd32/7/mtoka32103.html

Tahir, M.B., Mengistu, A.W. and Tamir, B.M., 2018. Evaluation of livestock feed balance under mixed crop–livestock production system in the central highlands of Ethiopia. *Agriculture and Food Security*, 7, pp.19. https://doi.org/10.1186/s40066-018-0170-8

Tesfaye, Y., Eik, L.O. and Moe, S.R., 2009. Seasonal variation in chemical composition and dry matter degradability of exclosure forages in the semi-arid region of northern Ethiopia. *Animal Feed Science and Technology*. 148, pp. 12–33. https://doi.org/10.1016/j.anifeedsci.2009.09.010

Tolera, A., 2008. Feed resources and feeding management: A manual for feedlot operators and development workers. Ethiopia Sanitary and Phyto-sanitary Standards and Livestock and Meat Marketing Program (SPS-LMM), Addis Ababa, Ethiopia 43 pp.

Tolera, A. and Abebe, A., 2007. Livestock production in pastoral and agro-pastoral production systems of southern Ethiopia. *Livestock Research for Rural Development*, 19, p. 177. http://www.lrrd.org/lrrd19/12/tole19177.htm

Tolera, A., Yami, A., and Alemu, D., 2012. Livestock feed resources in Ethiopia: Challenges, Opportunities and the need for transformation. Ethiopia Animal Feed Industry Association, Addis Ababa, Ethiopia. https://eafia.com/wp-content/uploads/2014/12/

Van Soest, P.J. and Robertson, J.B., 1985. Analysis of forage and fibrous foods. A laboratory manual for animal science. 613 Cornell University, New York, USA.

Van Soest, P.J., Robertson, J.B. and Lewis, B.A., 1991. Methods for dietary fiber, neutral detergent fiber, and non-starch polysaccharides in relation to animal nutrition. *Journal of Dairy Science*, 74, pp.3583–3597. https://doi.org/10.4236/fns.2012.311202

Van Soest, P. J., 1994. *Nutritional Ecology of the Ruminant*, Cornell University Press, London, 2nd edition.

Worku, B. and Lisanework, N., 2016. Pastoral Perceptions towards Livestock and Rangeland Management Practices in Kuraz District of South Omo Zone, South Western Ethiopia. *Journal of Natural Science Research* 6 (1), pp. 60-69. https://core.ac.uk/download/pdf/234656227.pdf

Yamane, T., 1967. Statistics, an Introductory Analysis, 2nd Ed., New York: Harper and Row.

Zeru, G., Negesse, T. and Nurfeta, A., 2014. Chemical Composition and *In vitro* Dry Matter Digestibility of Vines and Roots of Four Sweet Potato (*Ipomoea batatas*) Varieties Grown in Southern Ethiopia. *Tropical and Subtropical Agroecosystems*, 17, pp. 547 – 555. https://www.revista.ccba.uady.mx/ojs/index.php/TSA/article/view/2018

Zewdie, W. and Mekasha, Y., 2014. Feed resources availability and livestock production in the central rift valley of Ethiopia. *International Journal of Livestock Production*, 5(2), pp. 30-35. http://doi.org/10.5897/IJLP2013.0158