FARMERS' PREFERENCE, CHEMICAL COMPOSITION AND *IN VITRO* GAS AND METHANE PRODUCTION OF INDIGENOUS FODDER TREES IN SIDAMA REGIONAL STATE, ETHIOPIA †

[PREFERENCIA DE LOS AGRICULTORES, COMPOSICIÓN QUÍMICA Y PRODUCCIÓN *IN VITRO* DE GAS Y METANO DE ÁRBOLES FORRAJEROS NATIVOS EN EL ESTADO REGIONAL DE SIDAMA, ETIOPÍA]

Adugna Gebregiorgis[1,*], Ajebu Nurfeta[2], Mesele Negash[1] and Merga Bayssa[2]

[1]Wondo Genet College of Forestry and wild life Sciences, Hawassa University, P. O. Box 128, Shashemene, Ethiopia. Email: adusase@gmail.com, meselenegash72@gmail.com*
[2]School of Animal and Range Sciences, College of agriculture, Hawassa University, P. O. Box 5, Hawassa, Ethiopia. Email: ajebu_nurfeta@yahoo.com, mergabayssa@yahoo.com
**Corresponding author*

SUMMARY

Background. Indigenous fodder trees (IFT) are grown in Sidama Ethiopia, for different purposes. However, information on farmers' preferences, chemical composition, and *in vitro* gas production of IFT is limited. **Objective**. To identify farmers' preferences, chemical composition, methane production, and their indigenous knowledge used for selecting quality IFT compared with laboratory indicators. **Methodology**. Three districts were purposively selected based on their agroecological characteristics. Nine kebeles and 273 households were randomly selected for the household survey. Three focus group discussions, representing all community groups, were conducted. The chemical composition, in vitro gas production, and Methane (CH_4) production were determined. **Results**. The main criteria used by farmers to select IFT were multifunctionality, availability, biomass yield, fodder value, and ease of propagation. By using these criteria, farmers selected 4, 5, and 4 IFTs from the highland, midland, and lowland areas, respectively. *Erythrina brucei* had high crude protein (CP) (20.95%) content in the highland and midland. The neutral detergent fiber (NDF) contents varied from 43-60%, 34.9-59.9% and 43.4-54% in the highland, midland and lowland, respectively. *Vernonia amygdalina* had the highest ADF and ADL content compared to *Hagenia abyssinica* in the highland. In the midlands, the highest ADF and ADL contents were found in *Cordia africana* and *V. amygdalina,* respectively. The highest IVOMD was observed for *Vernonia amygdalina, Dracaena steudneri* and *Balanites aegyptiaca* in the highland, midland and lowland, respectively. A strong relationship was observed between laboratory results and farmers' feed value score. Farmers were able to differentiate IFT that had high and low protein content using their indigenous knowledge for feed evaluation. Total gas production (GP) trends of IFT during the 94 h of incubation period increased with increasing incubation time. The total GP and CH_4 production was highest for *V. amygdalina*, *D. steudneri* and *B. aegyptiaca* in the highland, midland and lowland, respectively. The lowest CH_4 concentration was observed for *E. brucei, V. amygdalina* and *B. aegyptiaca* in the highland, midland and lowland, respectively. **Implication.** *D. steudneri, E. brucei, B. aegyptiaca* and *V. amygdalina* showed relatively lower CH_4 concentration and had a considerable amount of CP. **Conclusion.** IFT can be used to supplement poor-quality feed; however, laboratory analysis of anti-nutritional factors and feeding trials are necessary.
Key words: Indigenous knowledge; fodder trees; farmers' preference; methane; Ethiopia.

RESUMEN

Antecedentes. Los árboles forrajeros nativos (IFT) se cultivan en Sidama, Etiopía, para diferentes propósitos. Sin embargo, la información sobre la preferencia de los agricultores, la composición química y la producción de gas *in vitro* de IFT es limitada. **Objetivo**. Identificar la preferencia de los agricultores, la composición química, la producción

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ORCID = A. Gebregiorgis: http://orcid.org/0009-0003-9552-5861; **A. Nurfeta**: http://orcid.org/0000-0003-3286-4789; **M. Negash**: http://orcid.org/0000-0003-4329-614X; **M. Bayssa**: http://orcid.org/0000-0002-3820-5453

de metano y el conocimiento indígena utilizado para seleccionar IFT de calidad en comparación con indicadores de laboratorio. **Metodología**. Tres distritos fueron seleccionados intencionalmente con base en la agroecología. Nueve kebeles y 273 hogares fueron seleccionados aleatoriamente para la encuesta de hogares. Se utilizaron tres discusiones grupales focales que representaban a todos los grupos de la comunidad. Se determinó la composición química, y la producción de gas *in vitro* y de metano (CH_4). **Resultados**. Los principales criterios utilizados por los agricultores para seleccionar IFT fueron la multifuncionalidad, la disponibilidad, el rendimiento de la biomasa, el valor del forraje y la facilidad de propagación. Mediante el uso de estos criterios, los agricultores seleccionaron 4, 5 y 4 IFT, de tierras altas, tierras medias y tierras bajas, respectivamente. *Erythrina brucei* tuvo un alto contenido de proteína cruda (PC) (20.95%) en las tierras altas y medias. Los contenidos de fibra detergente neutra (FDN) variaron entre 43-60%, 34.9-59.9% y 43.4-54% en las tierras altas, medias y bajas, respectivamente. *Vernonia amygdalina* tuvo el mayor contenido de FDA y LAD que *Hagenia abyssinica* en las tierras altas. En las tierras medias, los mayores contenidos de FDA y LAD fueron para *Cordia africana* y *V. amygdalina*, respectivamente. El IVOMD más alto se observó para *V. amygdalina*, *Dracaena steudneri* y *Balanites aegyptiaca* en las tierras altas, medias y bajas, respectivamente. Se observó una fuerte relación entre los resultados de laboratorio y la puntuación del valor del alimento de los agricultores. Los agricultores pudieron diferenciar los IFT que tenían un contenido alto y bajo de proteína utilizando su conocimiento indígena para la evaluación del alimento. Las tendencias de producción total de gas (GP) de los IFT durante las 94 h del período de incubación incrementaron con el aumento del tiempo de incubación. La producción total de GP y CH_4 fue más alta para *V. amygdalina*, *D. steudneri* y *B. aegyptiaca* en las tierras altas, medias y bajas, respectivamente. La concentración más baja de CH_4 se observó en *E. brucei*, *V. amygdalina* y *B. aegyptiaca* en las tierras altas, medias y bajas, respectivamente. **Implicaciones**: *D. steudneri, E. brucei, B. aegyptiaca* y *V. amygdalina* mostraron una concentración relativamente menor de CH_4 y una cantidad considerable de PC. **Conclusión**: La IFT puede utilizarse para complementar piensos de baja calidad; sin embargo, es necesario realizar análisis de laboratorio de factores antinutricionales y experimentos de alimentación.

Palabras clave: Conocimiento indígena; árboles forrajeros; preferencia de los agricultores; metano; Etiopía.

INTRODUCTION

The livestock sector is contributing a considerable portion to the country's economy and is promising to rally around the country's economic development (CSA, 2021). Although Ethiopia has a large number of livestock, productivity is very low due to feed shortages in terms of both quality and quantity, low genetic potential, and the prevalence of diseases (Kebede *et al.*, 2015). Feed resources are critically short of essential nutrients, such as protein and minerals, and cannot meet the maintenance requirements of ruminant animals, as reflected in weight loss when fed alone without supplementation (Tekliye *et al.*, 2018). Moreover, livestock fed nutritionally poor feed resources, such as crop residues, release a high amount of CH4 to the environment. Ruminants fed native pastures; aftermath and crop residues produce more CH4 than ruminants fed on high-quality forage diets (Opio *et al.*, 2013).

Therefore, indigenous fodder trees (IFT) can be used as a source of protein because most browse plants have high crude protein content, ranging from 11 to 25% on a dry matter basis (Bayssa *et al.*, 2016; Sisay *et al.*, 2018) and have the potential to reduce CH4 emission (Berhanu *et al.*, 2019). A variety of fodder trees and shrubs grow in different parts of Ethiopia, mainly due to the suitability of the environment and the need to utilise them for multiple purposes (Berhanu *et al.*, 2019). It is also common practice to use indigenous fodder trees and shrubs as a supplementary feed to cattle, goat and sheep in different parts of Ethiopia (Ayenew *et al.*, 2021). Farmers in the country possess valuable knowledge about IFT that can lead to the identification of the best fodder trees using different criteria. Hence, the efficient utilisation of such IFT is possible when the available and most preferred browse species are identified, and their nutritional status, farmers' interest, and utilisation practices are known (Ayenew *et al.*, 2021).

In the Sidama Regional State, Ethiopia, the agroforestry system is the dominant land-use practice, and IFT is one of the main components of this system, which can make a significant contribution to livestock feed and ecosystem maintenance. However, limited scientific empirical knowledge is available to assess the relationship between farmers' preferences for IFT and the nutrient content of those species. Thus, the objectives of this study were to identify farmers' preference criteria and the most preferred IFT, as well as the indigenous knowledge used for selecting quality fodder, compared with laboratory indicators, chemical composition, and methane production of selected indigenous forage tree species.

MATERIALS AND METHODS

Description of study area

Sidama National Regional State is located in south-central Ethiopia, 275 km from Addis Ababa (the capital city of Ethiopia). This region features highland (2,500-3,700 m), midland (1,500-2,300 m), and lowland (< 1,500 m) agroecologies. The annual rainfall in highlands, midlands, and lowlands ranges from 1,600 to 2,000 mm, 1,200 to 1,599 mm, and 400 to 800 mm, respectively. Mean monthly temperatures for highland, midland and lowland are from 12 to 14.5 °C, 15 to 19.9 °C and 20 to 24.9 °C, respectively (SNRSAB, 2022).

Data Collection and Sampling Methods

A multi-stage sampling technique was applied to select the study sites. First, one district was selected from each agroecology purposively based on the availability of IFT and road accessibility. Accordingly, Hulla, Aleta Chuko, and Boricha districts were selected for the highlands, midlands, and lowlands, respectively. Then, nine kebeles (3 from each district, the lowest administrative unit in Ethiopia) were randomly selected. Then, a proportional sample of households was used for each kebele, and a total of 273 sample households were randomly selected using the Yamane (1967) formula at a 95% confidence level. The information collected included the most commonly used IFT, the farmers' preferences toward IFT, and the score of IFT based on the criteria used. Three focus group discussions (FGDs), each comprising eight participants and totalling 24 participants representing all community groups (women, extension workers, elders, and youth), were conducted to identify the criteria used to select the most important and commonly used IFT. The ranking of farmers' perceptions towards IFT was undertaken on an individual basis. Scoring was conducted based on the procedure used by Ayenew et al. (2021) and Mekoya et al. (2008), where 1 indicated poorly preferred, 2 indicated preferred, 3 indicated moderately preferred, and 4 indicated highly preferred. Finally, samples from 10-15 plants of each selected IFT from each agroecology were collected for laboratory analysis.

Chemical analysis

Leaves and twigs of selected IFT species were hand-plucked at the end of the long rainy season (September- October). The harvested samples from a single species were mixed and subsampled. The samples were air-dried in the shade and then oven-dried at 60 °C for 48 hours. They were subsequently ground using a Wiley mill with a 1 mm sieve size for chemical analysis. The dry matter (DM), ash, and Kjeldahl nitrogen (N) analyses were performed in duplicate on dried samples (AOAC, 1990), and crude protein (CP) was calculated as N × 6.25. Neutral detergent fiber (NDF) was determined by the method of Van Soest *et al.* (1991) whereas acid detergent fiber (ADF) and acid detergent lignin (ADL) were determined according to Van Soest and Robertson (1985) using Ankom220 fiber analyzer (Ankom Technology®, Macedon, NY, USA).

In vitro gas production

In vitro gas production (GP) was measured according to the procedure described by Menke and Steingass (1988). 200mg of feed sample was weighed and transferred into 100 ml calibrated glass syringes, fitted with white Vaseline lubricated glass plunger to ease movement and prevent gas from escaping. A Menkes' buffer solutions (media solution) were prepared as described in Goering and Van Soest (1970) and maintained in a water bath at 39 °C under continuous flushing with CO2.

Rumen fluid was collected from two Arsi-Bale sheep which fed grass hay before slaughter (Girma *et al.*, 2023). Rumen fluid was collected in a pre-warmed thermos flask (39 ◦C) early in the morning, immediately after slaughter in the abattoir, following the procedure described by Wang et al. (2017). It was then immediately transported to the laboratory and purged with CO2 to maintain an anaerobic condition. The rumen fluid was added to the buffer solution (1:2 v/v) under constant stirring. Syringes were incubated in a water bath at 39°C, where a transparent plastic lid with holes held the syringes upright. Also, three blank syringes with the rumen liquid and culture media solution were incubated. Thirty mL of buffered rumen fluid was injected into each syringe. Gas volume was recorded before incubation (0 h) and after 3, 9, 12, 24, 48, 72 and 96 h of incubation. The volume of the gas was recorded after 3, 6, 12, 24, 48, 72 and 96 hours. Gas production (ml/200 mg) at t hours was calculated as:

$$Gt = [(Vt–V0–G0) \times 200]/Ws$$

Where: Gt = gas production value (ml/200 mg) at t hours, G0 = gas production of blank syringes (ml), V0 = volume in ml at begin, Vt = volume in ml at t hours, Ws = weight of dried sample in mg.

In vitro organic matter digestibility (OMD) at 24 hours was calculated from the equation:

OMD (%) = 14.88 + 0. 889* GP + (0.45 *CP %) + (0.651*Ash%)

Where:
OMD = organic matter digestibility,
CP = crud protein content of feed samples,
GP = gas produced at 24 hours.

Metabolisable energy (ME) was calculated from the equation:

ME (KJ/kgDM) = 2.20 + 0.136*GP + 0.057*CP (Dijkstra *et al.*, 2005)

Where:
GP = gas production over 24 hours of incubation,
CP = crude protein content of feed sample.

Short-chained fatty acids (SCFA) were estimated as:

SCFA (mmol) = 0.0239*GP - 0.0601(Goering and Van Soest, 1970)

Where:
GP = net gas volume at 24 hours of incubation.

The kinetics of the gas production were estimated using the following equation:

$Y=a+b\ (1-e^{-ct})$ described by (Ørskov and McDonald, 1979)

Where:
Y= the volume of gas produced with time (t),
a = the gas produced from soluble fraction (ml),
b= the gas produced from insoluble but fermentable fraction (ml), (a +b) = the potential gas production,
c= the gas production rate, t = time.

Methane Production

Methane production at 24 h of incubation was measured using the procedure described by Fievez *et al.* (2005). For measuring methane production at the end of incubations, after recording the final gas volume, the lower end of the syringe was connected to the lower end of another syringe containing 4.0 mL of 10 M sodium hydroxide (NaOH). Sodium hydroxide was then introduced from the latter into the incubated contents, thereby avoiding gas escape. Mixing the contents with NaOH allowed for the absorption of CO2, and the gas volume remaining in the syringe was considered to be CH_4.

The percentage of CO_2 was calculated as follows:

CO_2% = (V1-V2)/V1*100.

Where,
V1 is the volume of gas before removal of CO_2 (mL),
V2 is the volume of methane and the other gases after removal of CO_2 (mL).

The percentage of CH_4 was estimated from the percentage of CO_2 as follows:

CH_4 (%) = 100%-[CO_2%+0.2% (other gases)]

Statistical analysis

Data were analyzed using SPSS for qualitative and SAS Version 19.0 for quantitative variables. The scores of preference ranking were used as quantities measured on a continuous scale (Kuntashula and Mafongoya, 2005). Means were calculated, and ANOVA tests were conducted on in vitro gas and CH4 production, ME, SCFA, and farmers' evaluation criteria within agroecology using the GLM. Duncan's mean comparison test was used for mean comparison. Spearman correlation analysis was used to determine the relationship between farmers' assessments of IFT feed value scores and laboratory results for different nutrients of IFT.

RESULTS

Most preferred indigenous fodder tree species

The most preferred IFT species which were prioritized and frequently used for different purposes (including as animal feed) are listed in Table 1. By applying the different criteria outlined in Table 2, farmers selected 4, 5, and 4 IFTs from the highland, midland, and lowland areas, respectively, resulting in a total of 13 IFTs being selected. Accordingly, *E. brucei, A. alpine, H. abyssinica* and *V. amygdalina* were the most preferred species in the highland. *M. ferruginea, D. steudneri, C. africana, E. brucei and V. amygdalina* were preferred in the midland. In the lowland, *B. aegyptiaca, A. tortilis, C. africana* and *E. racemose* were the most preferred IFT species. *E. brucei and V. amygdalina* were common in both highland and midland agroecologies, whereas C. africana was the species preferred in midland and lowland areas.

Table 1. Farmers' preferred indigenous fodder tree species in Sidama regional state, Ethiopia.

Scientific Name	Family Name	Vernacular Name	Agro Ecology		
			Highland	Midland	Lowland
Dracaena steudneri	Dracaenaceae	Lanticho		✓	
Mellettia ferruginea	Fabaceae	Hengedicho	✓	✓	
Erythrina brucei	Fabaceae	Welako	✓	✓	
Vernonia amygdalina	Asteraceae	Hecho	✓	✓	
Cordia africana	Boraginaceae	Wadicho		✓	✓
Balanites aegyptiaca	Balanitaceae	Baddana			✓
Acacia tortilis	Fabaceae	Tadacha			✓
Hagenia abyssinica	Rosaceae	Daadako	✓		
Arundinaria alpina	Poaceae	Leemicho	✓		
Euclea racemose	Ebenaceae	Me'essa			✓

Farmers' indigenous fodder tree evaluation criteria and their ranking

Farmers evaluated indigenous fodder tree species based on plant characteristics and animal preference (Table 2). The criteria slightly varied among the agroecologies. Respondents in the highlands used multi-functionality, availability, and biomass yield as the top three criteria in order of importance. Whereas biomass yield, multifunctionality, and compatibility with other crops were primary criteria used to select IFT in the Midlands. In the lowlands, fodder value, availability, and multi-functionality were the most important criteria for ranking the IFT. The most standard criteria across the three agroecologies included the ease of propagation and the growth and coppicing ability of the fodder trees.

E. brucei in the highland, *D. steudneri* in the midland, *E. racemose* and *Cordia Africana* in the lowland were rated as highest ($p<0.05$) for biomass yield. *E. brucei*, *D. steudneri, and Mellettia ferruginea, as well as C. Africana, had the highest values for availability in the highland, midland,* and lowland, respectively. Similarly, a high score was observed for palatability in the highland, midland, and lowland for E. brucei, V. amygdalina, and A. tortolis, in descending order. Likewise, *E. brucei* in the highland and midland and *C. Africana* in the lowland were ranked high for fodder value. Moreover, in the highlands, midlands, and lowlands, A. alpine, D. steudneri, and A. tortolis were rated highest for growth and regrowth ability, respectively. Besides, *A. alpine*, *M. ferruginea* and *A. tortolis* were graded highest ($p<0.05$) for multi-functionality in the highland, midland and lowland, respectively.

Table 2. Farmers' indigenous fodder tree species selection criteria across the three agroecologies in Sidama regional state, Ethiopia.

Criteria used to select IFT	Highland		Midland		Lowland	
	Index	Rank	Index	Rank	Index	Rank
Biomass yield	0.15	3	0.17	1	0.13	4
Palatability	0.14	4	0.11	5	0.12	5
Availability	0.16	2	0.12	4	0.15	2
Fodder value	0.09	6	0.10	6	0.22	1
Growth and re growth ability	0.08	7	0.09	7	0.09	7
Multi functionality	0.22	1	0.16	2	0.14	3
Compatibility with other crops	0.11	5	0.15	3	0.10	6
Easy of propagation	0.07	8	0.08	8	0.06	8

Index = [(8 × number of responses for 1st rank) + (7 × number of responses for 2nd rank) + (6 x number of respondents of the 3rd rank) + (5 x number of respondents of the 4th rank) + (4 x number of respondents of the 5th rank) + (3 x number of respondents of the 6th rank) + (2 x number of respondents of the 7th rank) + (1 x number of respondents of the 8th rank)] divided by (8 × total responses for 1st rank) + (7 × total responses for 2nd rank) + (6 x total responses for 3rd rank) + (5 x total responses for 4th rank) +(4 x total responses for 5th rank) + (3 x total responses for 6th rank) + (2 x total responses for 7th rank) + (1 x total responses for 8th rank)

Table 3. Farmers' scoring of indigenous fodder tree species against the evaluation criteria across the three agroecologies in Sidama regional state, Ethiopia.

Species	BMY	AV	PAL	FV	GRGP	MF	EP	CWC
Highland								
Arundinaria alpina	1.9[c]	2.8[b]	3.4[a]	3.5[a]	3.3[a]	3.3[a]	2.9[a]	1.0[c]
Hagenia abyssinica	2.7[b]	1.8[c]	2.7[b]	2.9[b]	1.2[c]	2.4[b]	3.0[a]	3.4[a]
Erythrina brucei	3.4[a]	3.5[a]	3.5[a]	3.6[a]	3.0[a]	3.2[a]	1.6[b]	3.4[a]
Vernonia amygdalina	1.6[d]	2.0[c]	2.8[b]	1.9[c]	1.9[b]	1.9[c]	1.5[b]	2.6[b]
SE	0.1	0.2	0.3	0.2	0.3	0.2	0.1	0.1
Midland								
Cordia africana	2.9[b]	3.1[b]	2.7[a]	3.0[b]	3.3[a]	3.1[a]	1.9[c]	3.4[ab]
Dracaena steudneri	3.4[a]	2.1[c]	2.0[b]	1.9[d]	3.6[a]	1.3[d]	1.3[d]	3.6[a]
Erythrina brucei	1.8[c]	3.4[a]	1.8[b]	3.3[a]	2.9[b]	2.4[b]	2.8[b]	3.3[b]
Mellettia ferruginea	1.5[d]	3.4[a]	2.9[a]	3.0[b]	2.0[c]	3.3[a]	3.4[a]	3.2[bc]
Vernonia amygdalina	2.0[c]	2.3[c]	2.9[a]	1.5[d]	3.6[a]	1.9[c]	1.4[d]	3.0[c]
SE	0.2	0.1	0.1	0.2	0.2	0.1	0.3	0.2
Lowland								
Balanites aegyptiaca	1.5[c]	2.0[c]	2.9[b]	2.1[c]	2.9[b]	3.3[b]	3.3[a]	3.4[b]
Euclea racemose	3.6[a]	1.5[d]	2.0[c]	2.0[c]	2.0[c]	3.2[b]	2.0[c]	1.5[c]
Cordia africana	3.5[a]	3.7[a]	2.9[b]	3.6[a]	2.9[b]	3.6[a]	3.1[b]	3.7[a]
Acacia tortilis	3.0[b]	3.2[b]	3.4[a]	2.9[b]	3.7[a]	3.7[a]	3.4[a]	3.5[ab]
SE	0.2	0.1	0.3	0.2	0.1	0.2	0.1	0.3

Means in a column and within agro-ecology with different letters refer to significant differences at $p < 0.05$,; SE= standard error, BMY= Biomass yield, AV= Availability, PAL= Palatability, FV= Fodder value, GRGP= Growth and re growth ability, MF= Multi functionality, CWC = Compatibility with other crops and EP= Easy of propagation.
Index = [(8 × number of responses for 1st rank) + (7 × number of responses for 2nd rank) + (6 x number of respondents of the 3rd rank) + (5 x number of respondents of the 4th rank) + (4 x number of respondents of the 5th rank) + (3 x number of respondents of the 6th rank) + (2 x number of respondents of the 7th rank) + (1 x number of respondents of the 8th rank)] divided by (8 × total responses for 1st rank) + (7 × total responses for 2nd rank) + (6 x total responses for 3rd rank) + (5 x total responses for 4th rank) +(4 x total responses for 5th rank) + (3 x total responses for 6th rank) + (2 x total responses for 7th rank) + (1 x total responses for 8th rank)

Chemical composition of the selected indigenous fodder trees

The chemical compositions of the major IFT in the study area are given in Table 4. *E. brucei* had the highest while A. *alpine* had the lowest CP content in the highland. In the midlands, E. brucei had a higher ($p < 0.05$) CP content, followed by *M. ferruginea*. Higher CP was observed for *A. tortilis*, but E. racemose had the lowest CP in the lowland. The NDF contents varied from 43-60%, 34.9-59.9% and 43.4-54% in the highland, midland and lowland, respectively.

The ADF and ADL content differed among IFT ($p < 0.05$), with the highest mean value observed in V. amygdalina, while the lowest was in *H. abyssinica* in the highland. Likewise, in the midlands, the highest ADF and ADL contents were observed for C. africana and V. amygdalina, respectively. In contrast, the lowest values of ADF and ADL were observed for *D. steudneri*. *E. racemose* had the highest ADF and ADL in the lowland. *V. amygdalina* had the highest IVOMD, followed by *E. brucei* in the highland. Similarly, *D. steudneri* had the highest IVOMD, followed by *V. amygdalina* and *E. brucei* in the midland. In the lowlands, B. aegyptiaca had the highest IVOMD, followed by *C. africana*.

Correlation analysis of farmers' preferences for nutritional composition of fodder trees

Correlation analysis of farmers feed value score and laboratory values (CP, fiber and IVOMD) are presented in Table 5. The ranking scores of highland and midland were significantly correlated ($p < 0.05$) with laboratory indicators of IFT. However, not all laboratory indicators of lowland were significantly correlated with the farmers' ranking score value. In the highland, the CP content and IVOMD of IFT were positively correlated ($p < 0.05$) with farmers' feed value score, but NDF was negatively correlated. As farmers' scoring for feed value increases, there is an increasing trend in CP content and IVOMD, but NDF shows a decreasing trend. Similarly, the CP content of IFT was positively correlated ($p<0.05$) with the feed value score in the midland, and other laboratory indicators were not significant. In the lowlands, the laboratory indicators (CP, NDF, ADF, and ADL) were positively correlated but not significantly ($p > 0.05$) with the farmers' feed value score.

Complementarity between indigenous knowledge and laboratory assessment

Farmers' feed value score and their corresponding nutrient composition values of IFT are presented in Figures 1, 2 and 3. Except for *E. brucei* in the highlands and *D. steudneri* and *C. africana* in the midlands, farmers were able to discriminate well between IFT species with high and low CP content using their indigenous knowledge for all pairwise comparisons. In the lowlands, farmers were able to distinguish IFT species, except for *E. racemosa*, which had high and low CP content, using their indigenous feed value indicator system for all pairwise comparisons.

Table 4. Chemical composition (%DM) and IVOMD (% DM) of the leaves of the major indigenous fodder tree in Sidama regional state, Ethiopia.

Species Name	Ash	CP	NDF	ADF	ADL	IVOMD
Highland						
Arundinaria alpine	16^{a}	10.5^{d}	60^{a}	33.65^{ab}	12.33^{c}	41.45^{d}
Hagenia abyssinica	7.3^{c}	11.6^{c}	43^{d}	20.4^{c}	6.85^{d}	50.81^{c}
Erythrina brucei	7.5^{c}	20.95^{a}	51.9^{c}	27.3^{bc}	17.95^{b}	56.47^{b}
Vernonia amygdalina	13^{b}	17.8^{b}	53.4^{b}	37.3^{a}	32.15^{a}	62.29^{a}
SE	0.4	0.1	5	3	4	2
Midland						
Erythrina brucei	9.15^{b}	21.2^{a}	54.4^{b}	27.85^{c}	16.9^{c}	51.83^{c}
Cordia africana	11.35^{ab}	13.5^{d}	59.1^{a}	43.3^{a}	26.8^{b}	50.17^{cd}
Dracaena steudneri	12.95^{a}	13.4^{d}	34.9^{c}	21.4^{d}	6.5^{d}	68.25^{a}
Mellettia ferruginea	9.5^{b}	18.6^{b}	59.9^{a}	30.35^{b}	18.25^{c}	48.44^{d}
Vernonia amygdalina	10.7^{ab}	16.6^{c}	56.9^{b}	44.1^{a}	36.9^{a}	60.63^{b}
SE	1	0.1	2.7	0.9	2.5	3
Lowland						
Cordia africana	12.8^{a}	12.8^{a}	54^{a}	35.1^{b}	23.65^{b}	56.01^{b}
Balanites aegyptiaca	13.9^{a}	9.6^{ab}	36.5^{d}	22^{c}	14.2^{c}	60.12^{a}
Euclea racemose	6.1^{c}	6.7^{b}	48.6^{b}	43^{a}	33.3^{a}	33.03^{d}
Acacia tortilis	8.6^{b}	13.85^{a}	43.4^{c}	18.6^{c}	12.5^{c}	39.57^{c}
SE	0.4	1	0.4	1.5	3	2.4

Means in a column and within agro-ecology with different letters refer to significant differences at $p < 0.05$, and similar letter show not significant differences between groups; CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; ADL= acid detergent lignin; IVOMD = in vitro Organic digestibility; SE= standard error.

Table 5. Correlations between laboratory parameters and farmers' feed value score in different agroecologies of Sidama regional state, Ethiopia.

Feed value score	Laboratory parameters				
	CP	NDF	ADF	ADL	IVOMD
Highland	0.80**	-0.40**	0.39	0.72	0.95**
Midland	0.74**	-0.50	-0.90	-0.88	0.25
Lowland	0.62	0.40	0.45	0.30	-0.96

CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; ADL= acid detergent lignin; IVDMD = in vitro DM digestibility; ** Significant at $P < 0.05$.

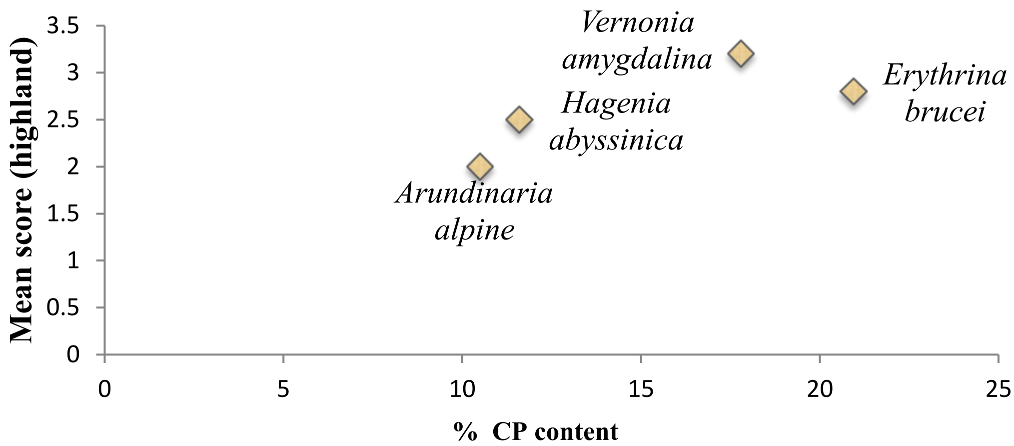

Figure 1. Complementarity between farmers' rankings for feed value and correlated laboratory crude protein contents of indigenous fodder tree species in the highland of Sidama regional state, Ethiopia.

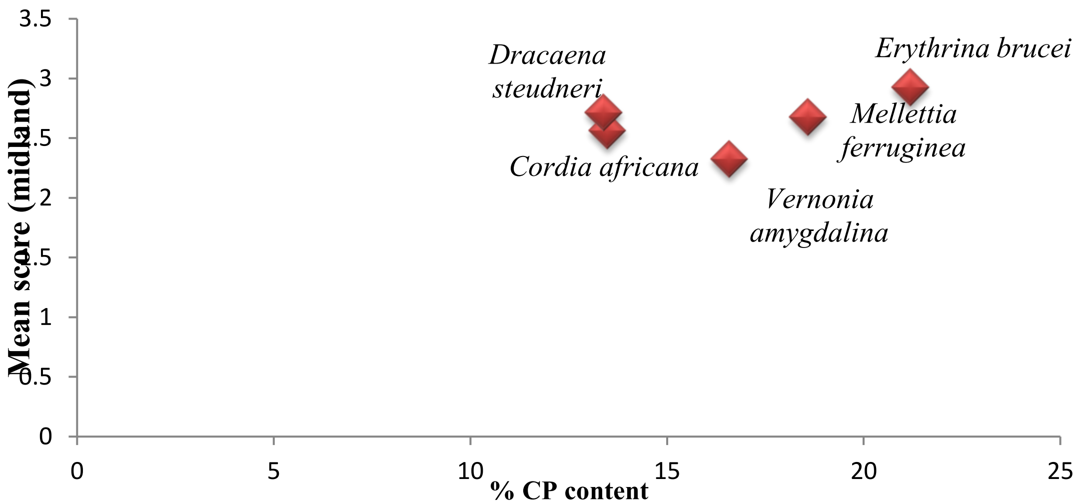

Figure 2. Complementary between farmers' rankings for feed value and correlated laboratory crude protein contents of indigenous fodder tree species in the midland of Sidama regional state, Ethiopia.

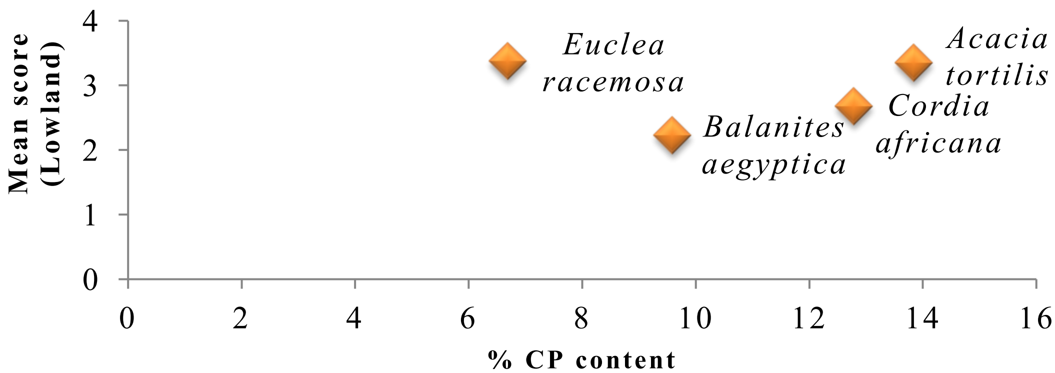

Figure 3. Complementarity between farmers' rankings for feed value and correlated crude protein contents of indigenous fodder tree species in the lowland of Sidama regional state, Ethiopia.

***In vitro* gas and methane production of the indigenous fodder tree**

Total gas production (GP) trends of IFT during a 94-hour incubation period are shown in Figure 4. The GP of IFT during the incubation period increased with increasing incubation time. *D. steudneri* produced higher GP throughout the incubation period, followed by B. aegyptiaca and C. africana in the midlands. However, the lowest GP trend was observed in *E. racemose* and *A. alpine*.

The total gas production (GP), CH_4 production and concentration of IFT varied significantly ($p < 0.05$) within agroecology (Table 6). The total gas volume after 24 h incubation ranged from 12.7 to 33.9 mL, 21.9 to 42.9 mL, and 7.5 to 30.5 mL in the highland, midland, and lowland, respectively. Whereas CH4 production after 24 h ranged from 8.4 to 17.9 mL, 13.3 to 21.8 mL, and 5.3 to 16.8 mL in the highland, midland, and lowland, respectively. The total GP and CH_4 production was highest for *V. amygdalina* and lowest for *A. alpine* in the highland. However, in the midlands, D. steudneri exhibited the highest GP and CH4, while *E. brucei*, *C. africana* and *M. ferruginea* had the lowest value. *B. aegyptiaca* and *C. africana* had the highest, whereas *E. racemose* had the lowest GP and CH_4 production in the lowland. The CH4 concentration of *A. alpine* (69.7%) was the highest in the highland. The highest methane concentration in the midlands was found in *C. africana* and *M. ferruginea*. In the lowland, there was no significant difference between *A. tortilis* (71.1%) and *E. racemose* (69.8%), which exhibited higher CH_4 concentration than *C. africana* (59.5%). *V. amygdalina,* and *D. steudneri. C. africana* had the highest ME and SCFA, whereas *A. alpine, M. ferruginea and A. tortilis had* the lowest in the highland, midland and lowland, respectively.

In vitro gas production characteristics of the major IFT species are presented in Table 7. There was a significant ($P<0.05$) difference in gas production from soluble (a) and insoluble (b) fractions, potential gas production (a + b) and rate of gas production (c) among IFT species. Gas production from the immediately

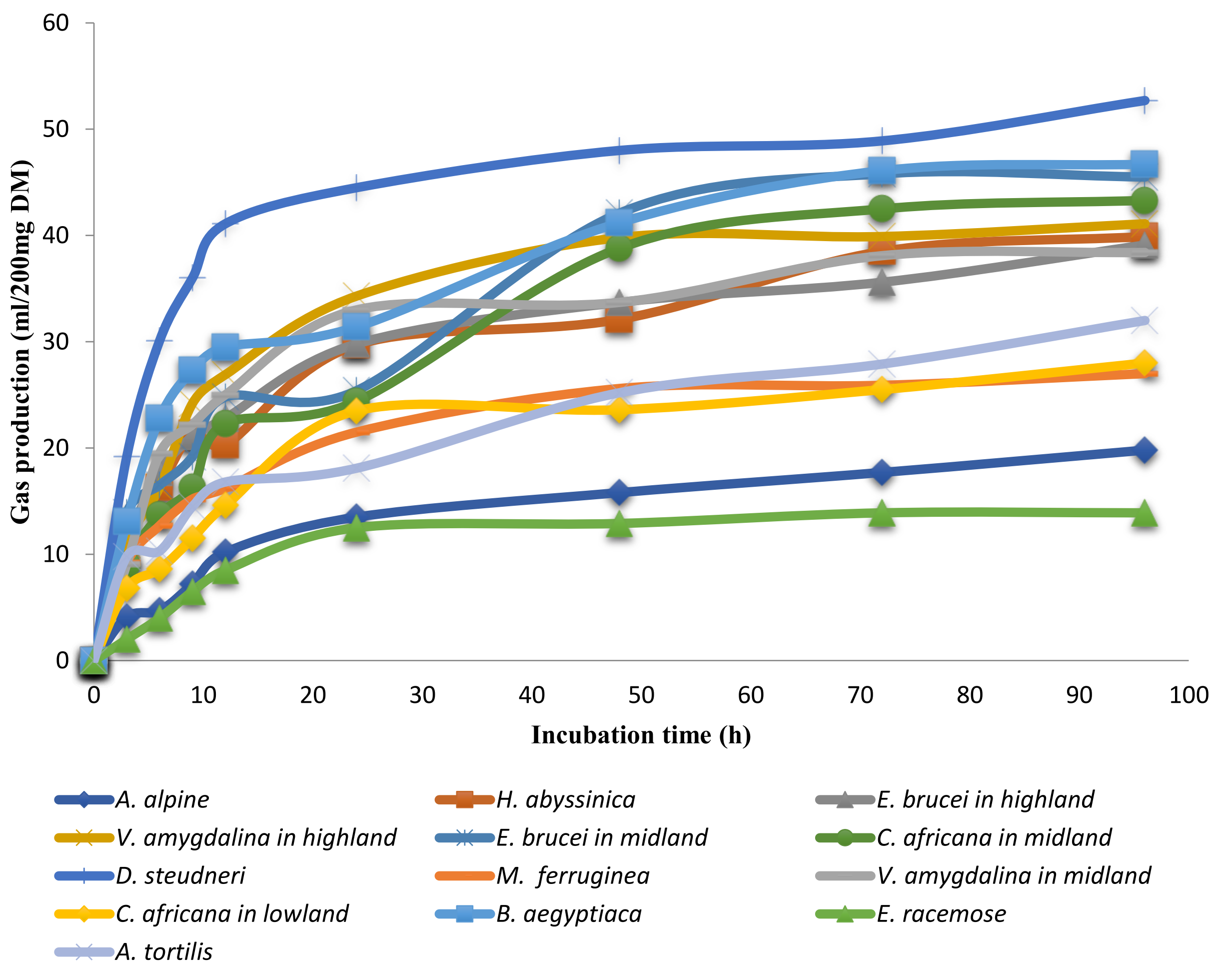

Figure 4. *In vitro* gas production characteristics of indigenous fodder tree in Sidama regional state, Ethiopia.

Table 6. Methane production(ml) and concentration (%), Metabolisable energy and Short chain fatty acids of indigenous fodder trees at 24 hours post incubation in Sidama regional state, Ethiopia.

Scientific Name	GP (ml)	CH_4(ml)	CH_4 (%)	ME (MJ/kg DM)	SCFA (mmol)
Highland					
Arundinaria alpine	12.7^{c}	8.4^{b}	69.7^{a}	4.57^{c}	0.21^{c}
Hagenia abyssinica	29.1^{b}	16.3^{a}	56.4^{b}	6.72^{b}	0.55^{b}
Erythrina brucei	28.8^{b}	16.2^{a}	56.4^{b}	7.35^{ab}	0.63^{ab}
Vernonia amygdalina	33.9^{a}	17.9^{a}	52.8^{b}	7.98^{a}	0.75^{a}
SE	4.5	2.7	4.6	0.23	0.1
Midland					
Erythrina brucei	23.1^{c}	14.0^{c}	60.8^{a}	6.5^{c}	0.49^{c}
Cordia africana	22.1^{c}	13.7^{c}	62.5^{a}	6.3^{c}	0.47^{d}
Dracaena steudneri	42.9^{a}	21.8^{a}	51.4^{b}	8.81^{a}	0.97^{a}
Mellettia ferruginea	21.9^{c}	13.3^{c}	60.9^{a}	6.4^{c}	0.46^{d}
Vernonia amygdalina	32.6^{b}	16.8^{b}	51.6^{b}	7.84^{b}	0.72^{b}
SE	5.4	2.7	4.4	0.13	0.10
Lowland					
Cordia africana	25.4^{a}	15.0^{a}	59.5^{b}	7.44^{a}	0.67^{a}
Balanites aegyptiaca	30.5^{a}	16.8^{a}	56.4^{b}	6.92^{b}	0.58^{b}
Euclea racemose	7.5^{c}	5.3^{c}	69.8^{a}	4.96^{c}	0.29^{c}
Acacia tortilis	14.4^{b}	10.2^{b}	71.1^{a}	3.93^{d}	0.18^{d}
SE	6.2	2.8	4.9	0.21	0.11

Means in a column and within agro-ecology with different letters refer to significant differences at $p < 0.05$, and similar letter show not significant differences between groups GP = gas production (ml/200mg DM) at 24 hrs, CH4= Methane production, CH4% = Methane concentration, ME = metabolizable energy (MJ/kg DM), SCFA = Short chained fatty acids (mmol) and SE = standard error.

soluble component (a) varied from 14.7 for *B. aegyptiaca* to 1.6 for *V. amygdalina* (M). Gas production from the insoluble but potentially degradable portion (b) ranged between 43.8 for *D. steudneri* and 15.9 for *E. racemose.* The gas production potential varied from 51.8 for *E. brucei* in the midlands and 18.0 for E. racemose in the lowlands. The rate of gas production (c) ranged between 0.13 for *D. steudneri* and 0.02 for *A. toritolis.* The shortest ($P<0.05$) lag time was observed for *E. brucei in midland,* and the longest lag time was observed for *E. racemosa*.

DISCUSSION

Farmers' preference criteria and evaluation of indigenous fodder tree

In this study, farmers used different criteria to rank IFT, which is similar to the study by Mekoya *et al.* (2008) and Ayenew *et al.* (2021), which reported that biomass yield, availability, feed value, multi-functionality, growth and regrowth potential and palatability were used by farmers as criteria to evaluate IFT in Ethiopia. Likewise, Evelyne (2007) indicated that local farmers used several evaluation criteria for rating IFT. Also, Upreti and Devkota (2017) reported that farmers prefer important fodder trees based on availability during the dry season. Moreover, Begashaw (2018) reported that farmers used availability as the first-prioritised criterion to select IFT. In the midlands of the current study, compatibility with other crops was the third criterion used by farmers to evaluate IFT, which could be related to competition for available soil moisture and nutrients, as well as shade for coffee. *E. brucei* and *A. alpine* were the most preferred IFT, which is consistent with the study by Kindu et al. (2006), who reported that this species was the most preferred IFT species and has multipurpose uses in the central highlands of Ethiopia. Similar to the current result, Kindu et al. (2006) indicated that H. abyssinica was preferred by farmers for its fodder value, ease of propagation and compatibility with other crops. Mekoya *et al* (2008) also reported that farmers' preferences for M. ferrugina and C. africana are more based on compatibility with different crops in Sidama, south Ethiopia. Furthermore, *A. tortilis* was more preferred by farmers due to its multifunctionality, which is consistent with Azene (2007), who reported that the species is used for firewood, charcoal, timber, poles, fodder, bee forage, shade, nitrogen fixation, soil conservation, and fencing in Ethiopia.

Table 7. ***In vitro*** **gas production characteristics of indigenous tree species from Sidama Regional State, Ethiopia.**

Species of browse plants	Gas production parameters				
	a	b	a+b	c	Lag time
Arundinaria alpine	3.3^{h}	17.1^{j}	20.4^{j}	0.03^{b}	1.02^{b}
Hagenia abyssinica	12^{c}	31.6^{f}	43.6^{e}	0.02^{b}	0.22^{fg}
Erythrina brucei (in the highland)	7.4^{e}	29.5^{g}	36.9^{g}	0.06^{ab}	0.58^{de}
Vernonia amygdalina (in the highland)	2.3^{i}	38.1^{c}	40.4^{f}	0.09^{ab}	0.23^{fg}
*Erythrina brucei(*in the midland*)*	12.5^{b}	39.3^{b}	51.8^{a}	0.02^{b}	0.19^{g}
Cordia africana	6.5^{f}	39.2^{b}	45.6^{d}	0.03^{b}	0.24^{fg}
Dracaena steudneri	5.5^{g}	43.8^{a}	49.3^{b}	0.13^{a}	0.26^{f}
Mellettia ferruginea	6.2^{f}	20.4^{i}	26.6^{i}	0.06^{ab}	0.89^{c}
Vernonia amygdalina (in the midland)	1.6^{j}	35.2^{d}	36.8^{g}	0.10^{ab}	0.54^{e}
Balanites aegyptiaca	14.7^{a}	32.9^{e}	47.6^{c}	0.03^{b}	0.24^{fg}
Euclea racemose	2.1^{i}	15.9^{k}	18.0^{k}	0.09^{ab}	1.23^{a}
Acacia tortilis	9.2^{d}	26.3^{h}	35.5^{h}	0.02^{b}	0.61^{d}
SE	0.2	0.3	0.4	0.04	0.03

Means in a column and within agro-ecology with different letters refer to significant differences at $p < 0.05$, and similar letters show not significant differences between groups; a= gas production from immediately soluble component; b=gas production from insoluble but potentially degradable portion; a+b=gas production potential; c = gas production rate constant.

Chemical composition of selected indigenous fodder tree species

In this study, all IFTs, except E. racemose, had a higher CP content than the threshold level (7%) for maintaining ruminant animals (Arelovich *et al.*, 2008). Moreover, the range of CP (6.6% - 21.2%) contents in the IFT is similar to the findings reported by many researchers in Ethiopia (Ahmed et al., 2017; Sisay et al., 2018; Ayenew *et al.*, 2021). Thus, IFT could be used to supplement poor-quality feed sources and increase the productivity of ruminant livestock (Geta et al., 2014; Sisay et al., 2018; Berhanu et al., 2019), indicating an opportunity to improve feed resources using IFT available in the study area.

The NDF content of all IFT was < 55%, except *A. alpine, C. africana* and *M. ferruginea.* This level of NDF can be suitable for maintaining a good appetite and improving digestibility (Van Soest and Robertson 1985). On the other hand, all IFT in all agroecologies had < 40% content of ADF, which is believed to have high-quality feed (Kellems and Church, 1998). The ADL affect feed intake in ruminant animals (Reed *et al.,* 1985). The ADL content of IFT in the current study was greater than 10%, except for *H. abyssinica* and *D. steudneri*. In agreement with the current research, Berhanu *et al.* (2019) reported that tropical forages are known for their higher lignin contents. Lignin represents an undigested portion of the forage and is associated with fiber. Therefore, the greater the concentration of lignin in a plant, the lower the digestibility of the forage and the less dry matter an animal can consume (Berhanu *et al.*, 2019). Nevertheless, the chemical composition alone is an inadequate indicator of nutritive value, as the availability of nutrients from browse species is variable, and their digestibility may also be affected by anti-nutritional factors (Ayenew *et al.*, 2021). Hence, additional information on the secondary plant compounds, along with animal performance trials of these IFT, is needed.

Complementarity between indigenous knowledge and laboratory assessment

A strong association was found between farmers' indigenous knowledge of feed value and laboratory indicators of IFT, indicating that farmers can differentiate between IFT with high and low CP content and select high-quality fodder for feeding livestock. Similar to this study, Sunita (2012) and Ayenew et al. (2021) reported significant complementarities between laboratory results and farmers' assessments of feed value. However, in the lowlands, no significant correlation was observed, which may be due to farmers' use of grazing land and crop residues, as well as their less noticeable experience with the effects of the IFT on livestock performance. The farmers' feed value score, as measured by NDF content, was negatively correlated in the highlands, although the relationship was not significant. This finding is in agreement with Mekoya et al. (2008), who reported a similar result in Sidama, southern Ethiopia. Moreover, Ayenew *et al.* (2021) reported that NDF, ADF and ADL content were negatively correlated with farmers' indigenous knowledge in different parts of Ethiopia. This indicates that the farmers' indigenous knowledge to differentiate the quality IFT confirmed the complementarities of fiber content and farmers feed value score.

***In vitro* gas and methane production of the indigenous fodder tree**

The increasing trend of in vitro gas fermentation of IFT observed in the current study is consistent with the results reported in different parts of Ethiopia (Melesse et al., 2019; Sisay *et al.,* 2018). The higher gas production value of *E. brucei, D. steudneri*, and B. aegyptiaca observed in the current study may be attributed to the soluble carbohydrate content. Melesse *et al.* (2019) reported that there is a strong association between soluble carbohydrate (starch) and gas production of multipurpose trees. The low gas production trend of *E. racemose* and *A. alpine* may be due to the presence of a high content of anti-nutritional factors and fibre. In agreement with this study, Patra and Saxena (2011) reported that the high content of condensed tannins in the feed has a direct toxic effect on methanogens and has the potential to modify rumen fermentation to reduce CH4 production. Gas production after 24 hours of incubation in the current study is comparable with the findings of Sisay et al. (2018), who reported a GP range between 9.8 and 47.8 ml/0.2 g DM in the mid-rift valley of Ethiopia.

Osuga *et al.* (2006) argued that variation in potential gas production of the browse species could be attributed to differences in chemical composition, more importantly to CP and fiber components. The potential gas production and fermentation rate were affected by the species. Bayssa *et al.* (2016) reported that differences in species and their cell-wall constituents, such as NDF, lignin, polyphenolic concentrations and anti-nutritional factors, influence the digestibility and degradation characteristics of feeds. A higher gas production potential in *E. brucei*, D. steudneri, and B. aegyptiaca, and a lower rate of gas production in E. racemose, may indicate better nutrient availability for rumen microorganisms, thereby improving digestibility. Getachew *et al.* (2004) stated that the rate at which different chemical constituents are fermented reflects the microbial growth and accessibility of the feed to microbial enzymes. Moreover, Araiza *et al.* (2023) reported that the intake of feed is primarily determined by the fractional rate of gas production, which influences the rate of passage of feed through the gastrointestinal tract. In contrast, potential gas production (b) is associated with the degradability of the feed. In this study, the fractional rate of gas production exhibited large variability among IFT species, attributed to species-specific differences. Gas production from the slowly fermentable fraction ('b' value) of browse species observed in this study was within the range values (18.18-64.93) reported by Mahala and Elseed (2007).

The CH_4 concentration of IFT of this study is within the range of Berihanu *et al.* (2019), who reported the value of 16.25 to 52.22% in Ethiopia. *A. alpine* and *E. rasemosa* exhibited lowest CH_4 production from all candidates of current study which might be due to the presence of secondary metabolites and their presumed antimicrobial properties as suggested by Kong *et al.* (2009). Moreover, lower CH_4 to gas percentages indicate that a given feed would be better as a rumen modifier for CH4 reduction than those yielding higher percentages (Berhanu *et al.*, 2019). Additionally, CH4 as a portion of total gas can be used as an indicator to determine a plant's capacity to suppress CH4 production (Bhatta *et al.,* 2012). Thus, *D. steudneri, E. brucei, B. aegyptiaca*, and V. amygdalina showed a relatively lower CH4 concentration, which makes them promising species for reducing CH4 production in ruminants in the study area. Additionally, these species have a considerable amount of crude protein (CP), making them a good source of protein supplement in ruminant feed. The range of ME and SCFA in this study aligns with the findings of Sisay et al. (2018), who reported a range of 4.59-7.20 MJ/kg DM and 0.17-0.66 mmol, respectively, for indigenous browse species in the mid-rift valley of Ethiopia. The highest ME and SCFA values for V. amygdalina, D. steudneri, and C. fricana in the current study could be attributed to their high gas production and higher CP contents. Higher gas production can significantly contribute to energy supply through SCFA production (Maheri *et al.,* 2008). Similarly, Aderinboye *et al.* (2016) and Sisay *et al.* (2018) reported a positive correlation between crude protein (CP) and metabolizable energy (ME) for tropical browses with high CP content.

CONCLUSION

From this study, it can be concluded that the main criteria used by farmers to select IFT were multifunctionality, availability, biomass yield, compatibility with other crops, fodder value, ease of propagation and growth, and regrowth ability. By using the above criteria, farmers selected ten IFTs for different purposes. There was a high correlation between laboratory results and farmers' assessment of feed value. Consequently, using farmers' preference criteria and indigenous knowledge is crucial for selecting high-quality IFT. Moreover*, D. steudneri, E. brucei, B. aegyptiaca and V. amygdalina showed a relatively lower CH4 concentration and had a* considerable amount of CP. Therefore, it is recommended that these IFTs be used to supplement poor-quality feed; however, laboratory analysis of anti-nutritional factors and feeding experiments should be conducted to support this recommendation further.

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Data availability. The data supporting the conclusions of this article can be obtained with the aid of the corresponding author's email: adusase@gmail.com

Compliance with ethical standards. The authors confirm that the research was carried out and managed in accordance with ethical standards. Rumen fluid was collected from an abattoir, and therefore the procedure did not require approval by an ethical committee.

Author contribution statement (CRediT). A. Gebregiorgis – Conceptualization, Data curation, Formal analysis, Investigation, Methodology, and Writing-original draft., **A. Nurfeta** – Conceptualization, Investigation, Methodology, supervision, Validation, Writing-review and editing., **M. Negash** – Conceptualization, Methodology, Supervision, Validation, Writing-review and editing., **Merga Bayssa –** Methodology, Supervision, Validation, Writing-review and editing.

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