Pastoralism
Research, Policy and Practice

TYPE Original Research
PUBLISHED 21 October 2026
DOI 10.3389/past.2026.16541

Check for updates

OPEN ACCESS

EDITED BY
Srijana Joshi,
International Centre for Integrated Mountain Development, Nepal

*CORRESPONDENCE
Tesfaye Edjem,
nadukotedjem@gmail.com
Yisehak Kechero,
yisehak.kechero@amu.edu.et

RECEIVED 07 March 2026
REVISED 02 July 2026
ACCEPTED 05 October 2026
PUBLISHED 21 October 2026
CORRECTED 29 October 2026

CITATION
Edjem T, Kechero Y and Guja A (2026) Diversity, seasonal availability, and nutritional value of indigenous cattle forages in pastoral and agro-pastoral systems of the Omo–Woito River Basin, southern Ethiopia.
Pastoralism 16:16541.
doi: 10.3389/past.2026.16541

COPYRIGHT
© 2026 Edjem, Kechero and Guja. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Diversity, seasonal availability, and nutritional value of indigenous cattle forages in pastoral and agro-pastoral systems of the Omo–Woito River Basin, southern Ethiopia

Tesfaye Edjem[1,2]*, Yisehak Kechero[2]* and Asrat Guja[2]

[1]South Omo Zone Administration Office, Dimeka, Ethiopia, [2]Department of Animal Sciences, College of Agricultural Sciences, Arba Minch University, Arba Minch, Ethiopia

This study evaluated the nutritional composition, digestibility, and seasonal dynamics of indigenous cattle forage resources in the pastoral and agro-pastoral systems of the Omo - Woito River belts, southern Ethiopia. A total of 371 households were surveyed, and forage samples from 20 key species - categorized as grasses, legumes, shrubs, and fodder trees - were analyzed for chemical composition and *in vitro* digestibility across wet and dry seasons. Perennial grasses, including *Cenchrus ciliaris* and *Brachiaria mutica*, yielded the highest dry matter (up to 11.2 t ha^{-1}), whereas crude protein content and *in vitro* organic matter digestibility were significantly greater during the wet season ($p < 0.01$). Fiber fractions (NDF, ADF) increased markedly in the dry season, corresponding to reduced digestibility in grasses. In contrast, browse species such as *Moringa stenopetala* maintained high crude protein (23.5% DM) and *in vitro* dry matter digestibility (77.7%) during feed-scarce periods, underscoring their role as strategic protein and energy supplements. Strong positive correlations were observed between crude protein and digestibility measures ($r > 0.81$), while fiber fractions were negatively associated with digestibility. These findings highlight the complementary nutritional roles of indigenous forage functional groups and support the integration of drought-tolerant browse species into seasonal feeding regimes to improve feed quality and maintain feed availability under variable climatic conditions in semi-arid production systems.

KEYWORDS
browse species, feeding systems, *in vitro* digestibility, indigenous forages, seasonal nutrition

Introduction

Livestock production in Ethiopia remains fundamentally dependent on natural and indigenous feed resources, including communal rangelands, browse species, and crop residues. National estimates indicate that over 50%–60% of livestock feed is derived from natural grazing lands, particularly within pastoral and agro-pastoral systems where reliance on communal pastures is highest (Central Statistical Agency (CSA), 2021; Food and Agriculture Organization of the United Nations (FAO), 2021). Indigenous forage species are ecologically adapted to local conditions and valued for their drought tolerance, palatability, and multifunctional roles in rangeland ecosystems, including soil conservation and

traditional medicinal uses (Mengistu et al., 2020; International Livestock Research Institute (ILRI), 2022).

In southern Ethiopia, pastoral and agro-pastoral communities along the Omo–Woito River belts rely heavily on cattle for livelihoods, food security, and socio-cultural stability. These systems contribute substantially to regional and national meat and live animal markets, while supporting ecosystem services in arid and semi-arid landscapes (Food and Agriculture Organization of the United Nations (FAO), 2022; Gebremedhin et al., 2021). However, rangeland productivity and forage diversity are increasingly threatened by climate variability, recurrent droughts, bush encroachment, agricultural expansion, and land-use changes, which collectively intensify feed shortages and compromise pastoral resilience (IPCC, 2022; Jiso et al., 2023).

Nutritional sufficiency is a critical determinant of cattle productivity, health, and reproductive performance; yet seasonal fluctuations in forage quality - particularly declines in crude protein and digestibility during dry periods - pose major constraints to animal performance in these systems. Despite the central role of indigenous forages, detailed information on their nutritional composition, seasonal digestibility, and potential as strategic supplements remains sparse, especially in remote pastoral areas of southern Ethiopia (Yayneshet, 2010; International Livestock Research Institute (ILRI), 2023; Tadesse et al., 2024). This knowledge gap limits the development of evidence-based feeding strategies that can sustain cattle nutrition year-round under variable climatic conditions.

Unlike previous studies that have focused on individual aspects of forage resources, this research presents a comprehensive evaluation of indigenous cattle forages in the Omo–Woito River Basin by integrating forage diversity, biomass production, seasonal availability, nutritional composition, and *in vitro* digestibility. It provides location-specific evidence from pastoral and agro-pastoral production systems where detailed information on forage nutritive value remains limited. Accordingly, the study aimed to: (1) characterize the nutritional composition and *in vitro* digestibility of key forage species used in cattle feeding; (2) assess seasonal variation in their nutritive value; and (3) examine relationships between chemical composition and digestibility parameters. By generating species-specific and seasonally explicit data, the study contributes to the development of targeted supplementation practices and more efficient feed management in semi-arid livestock production systems. The findings further offer practical guidance for pastoral and agro-pastoral households seeking climate-resilient feeding strategies based on locally available forage resources.

Materials and methods

Study area

The study was conducted in the Omo–Woito River belts of South Omo and Konso zones, southern Ethiopia. Geographically, the area lies between 4°27′–6°26′N latitude and 34°57′–37°49′E longitude (Figure 1). The region encompasses predominantly lowland and midland agro-ecological zones characterized by high temperatures, bimodal rainfall patterns, and pronounced inter-annual rainfall variability. Extensive rangelands along the Omo and Woito rivers support pastoral, agro-pastoral, and mixed crop–livestock production systems, with livestock rearing forming the main livelihood activity.

Sampling procedure and sample size determination

A multi-stage stratified sampling approach was employed to ensure representative coverage of production systems, agro-ecologies, and indigenous forage resources across the study area.

First stage: Four districts - Dasenech, Nyangatom, Salamago, and Kolume - were purposively selected based on their high dependence on cattle production, diversity of indigenous forage resources, and representation of both pastoral and agro-pastoral systems.

Second stage: A total of 12 kebeles (the lowest administrative units) were purposively selected from the four districts. Household lists for the selected kebeles were obtained from local administrative offices.

The household survey sample size was determined using Yamane's simplified formula for finite populations at a 95% confidence level and a 5% margin of error: The equation is now presented as:

$$n = N / (1 + N \times e^2)$$

Where: n = required sample size, N = total population size, e = level of precision (0.05).

Where, *n* is the required sample size, N is the total number of households in the selected kebeles, and *e* is the margin of error (0.05). The calculated sample size was 371 households, which were proportionally allocated to kebeles using probability proportional to size (PPS) sampling to ensure representativeness. For forage sampling, purposive and systematic approaches were applied to capture seasonal and ecological variation. Twenty key indigenous forage species were selected based on local knowledge and previous pastoral surveys, covering four functional groups: grasses, legumes, shrubs, and fodder trees. Samples were collected during both wet and dry seasons to capture seasonal nutritional dynamics.

Plant identification, voucher specimens, and collection permits

Plant collection complied with Ethiopian Biodiversity Institute (EBI) guidelines and national access and benefit-sharing regulations. Prior to field sampling, collection permits were obtained from the South Omo and Konso District Agricultural Offices, and all scientific names were subsequently reviewed, with author citations standardized and nomenclature verified using the *Flora of Ethiopia and Eritrea* and World Flora Online.

Forage samples were collected from twelve kebeles across four districts: Dasenech (5°10′N, 36°45′E), Nyangatom (5°25′N, 35°55′E), Salamago (6°10′N, 36°30′E), and Kolume (5°15′N, 37°10′E). All plant materials were wild-harvested from non-protected communal rangelands and riverine grazing areas within the Omo–Woito River basin, Southern Ethiopia (4°27′–6°26′N; 34°57′–37°49′E). No cultivated or commercially sourced seeds were used in this study.

A total of twenty forage species were collected and studied, including *Cenchrus ciliaris* L. (1753), *Brachiaria mutica* (Forssk.) Stapf (1919), *Panicum virgatum* L. (1753), *Chloris gayana* Kunth

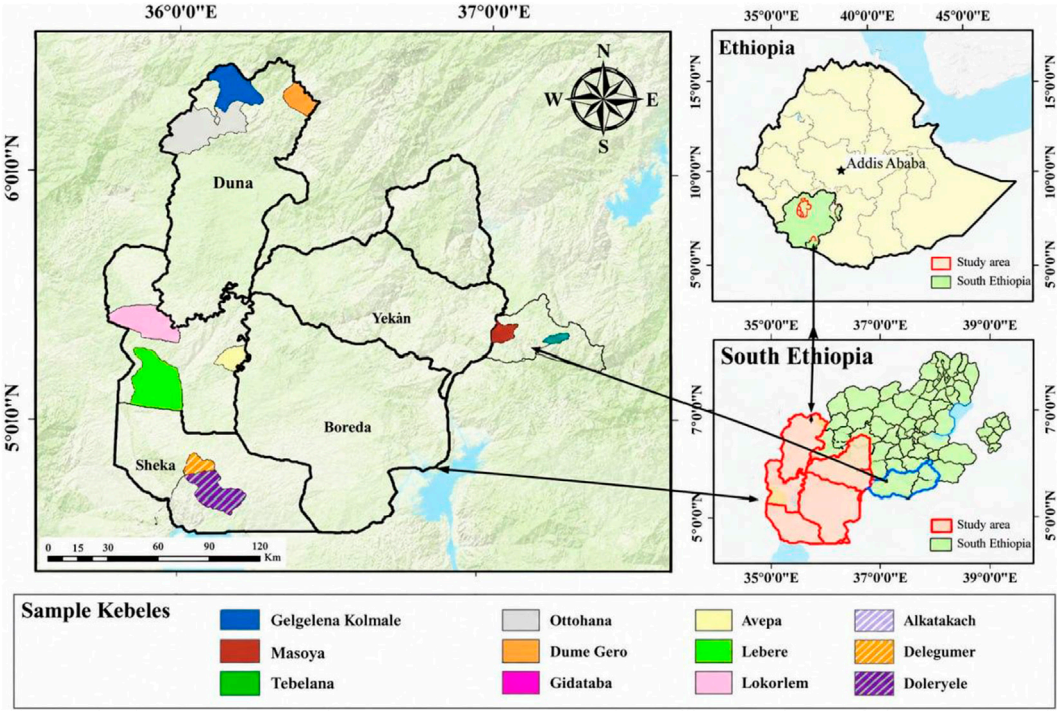


FIGURE 1
Location of the study area in South Ethiopia and spatial distribution of the sampled kebeles. The inset maps show the location of the study area within Ethiopia and South Ethiopia, while the main map illustrates the study-area boundaries and the sampled kebeles, distinguished by colours and patterns.

(1829), *Eragrostis superba* Peyr. (1859), *Sporobolus indicus* (L.). R.Br. (1810), *Melilotus albus* Medik. (1787), *Stylosanthes hamata* (L.). Taub. (1894), *Indigofera spicata* Forssk. (1775), *Vigna luteola* (Jacq.) Benth. (1859), *Celtis ehrenbergiana* (Klotzsch) Liebm. (1851), *Grewia bicolor* Juss. (1789), *Cadaba farinosa* Forssk. (1775), *Acalypha fruticosa* Forssk (1775), *Triadica sebifera* (L.). Small (1903), *Moringa stenopetala* (Baker f.) Cufod. (1955), *Cordia africana* Lam. (1792), *Vachellia tortilis* (Forssk.) Galasso & Banfi (2008), and *Ficus sycomorus* L. (1753).

Species identification was carried out by Dr. Temesgen Dingamo and Dr. Tizazu Gebre, Plant Taxonomists in the Department of Biology at Arba Minch University. Scientific names were verified using the *Flora of Ethiopia and Eritrea* and the World Flora Online database. Voucher specimens for all twenty forage species were prepared and deposited at the Arba Minch University Herbarium (AMUH) under accession numbers AMUH-OF-001 to AMUH-OF-020, with voucher codes available upon request.

The study fully adhered to national and institutional guidelines for plant research. None of the collected species are listed as threatened under the IUCN Red List or regulated under CITES. All samples were obtained from non-protected communal grazing lands with prior permission from local administrative authorities and community leaders.

Ethics and consent to participate

Plant collection complied with national and local regulations governing research on wild plant species in Ethiopia. Permission was obtained from district agricultural offices and kebele administrations prior to sampling. No protected or endangered species were collected. Sampling involved non-destructive harvesting of leaves and above-ground biomass from communal grazing lands.

Data collection

Primary data were collected using household surveys, key informant interviews, focus group discussions, and direct field observations. Structured questionnaires were administered to household heads to obtain information on indigenous cattle feed resources, their seasonal availability, and utilization practices.

Key informant interviews were conducted with community elders, experienced herders, and livestock development agents with extensive knowledge of rangeland resources and traditional feeding practices. Focus group discussions were employed to triangulate household-level information and to rank indigenous feed species based on locally defined criteria, including palatability, availability, and perceived nutritional value.

Identification of indigenous forage species was conducted using participatory approaches involving herders and elders. Plant samples were collected during both wet and dry seasons and identified using standard botanical keys and field guides to ensure taxonomic accuracy.

Biomass and fodder yield estimation

Herbaceous biomass yield was estimated using a quadrat sampling technique following standard rangeland assessment procedures (Cook and Stubbendieck, 1986). A total of

260 quadrats (1 m × 1 m) were randomly established within representative grazing areas across the study sites during both dry and wet seasons. All above-ground biomass within each quadrat was harvested and weighed fresh in the field. Subsamples were collected from each quadrat and oven-dried at 105 °C to constant weight for dry matter (DM) determination. Biomass yield was subsequently expressed on a dry matter basis per hectare (t DM ha^{-1}). For each forage species, five representative samples were collected per season for nutritional analysis. Laboratory analyses of crude protein, neutral detergent fiber, acid detergent fiber, ash content, and *in vitro* digestibility were conducted in triplicate to ensure analytical precision and reliability. Edible biomass yield of shrubs and fodder trees was estimated using established allometric equations based on stem diameter, plant height, and canopy measurements (Le Houérou, 1980; Alemayehu, 2006). Only edible fractions relevant to cattle feeding, namely leaves and tender twigs, were considered.

Chemical composition and *in vitro* digestibility

Representative forage samples were air-dried, ground to pass through a 1-mm sieve, and analyzed for chemical composition. Crude protein (CP) content was determined using the Kjeldahl method according to AOAC procedures (AOAC, 2019). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) concentrations were analyzed following the detergent system of Van Soest et al. (1991). Ash content was determined by combustion at 550 °C according to AOAC methods (AOAC, 2019).

In vitro organic matter digestibility (IVOMD) was determined using a two-stage rumen fluid–pepsin technique as described by Tilley and Terry (1963), simulating ruminal and post-ruminal digestion. Digestibility values were expressed as a percentage of dry matter.

Statistical analysis

Data were coded and analyzed using the Statistical Package for the Social Sciences (SPSS), version 20 (IBM Corp., Armonk, NY, USA). Descriptive statistics were used to summarize indigenous feed resource diversity, biomass yield, seasonal availability, and chemical composition.Prior to inferential analysis, data were examined for compliance with the assumptions of parametric testing. Normality of residuals was assessed using the Shapiro–Wilk test and visual inspection of Q–Q plots, while homogeneity of variances was evaluated using Levene's test. Variables that did not meet these assumptions were log-transformed prior to analysis.

The effects of season (wet vs. dry) and agro-ecology (lowland vs. midland) on biomass yield and nutritive parameters of selected forage species were analyzed using two-way analysis of variance (ANOVA). When significant main effects or interaction effects were detected, mean comparisons were performed using Tukey's honestly significant difference (HSD) test. Statistical significance was declared at $p < 0.05$.

Relationships between chemical composition parameters (crude protein, fiber fractions, and ash) and *in vitro* digestibility indices were evaluated using correlation analysis. Pearson's correlation coefficient was applied when both variables satisfied assumptions of normality and linearity. When these assumptions were not met, Spearman's rank correlation coefficient was used as a non-parametric alternative. Correlation strength and direction were interpreted following standard statistical conventions.

Results

Distribution of sample households by district, production system, and agro-ecology

A total of 371 households were sampled from 12 kebeles across the South Omo and Konso administrative zones (Table 1). In South Omo Zone, the Dasenech district contributed 92 households from the Direyelere, Delenyemur, and Alkatakach kebeles, all of which practiced a pastoral production system in lowland areas. Similarly, the Nyangatom district also provided 92 households from the Lokorlam, Lebere, and Aypa kebeles, predominantly engaged in pastoral livelihoods in lowland agro-ecology. In contrast, the Salamago district comprised 92 households from Omo Hana, Dakuba, and Gero kebeles, representing a combination of pastoral, agro-pastoral, and mixed production systems spanning lowland to midland agro-ecologies. In the Konso Zone, the Kolume district contributed 95 households from the Gelgelo-Qolmala, Tebela, and Massoya kebeles, where mixed and agro-pastoral systems were dominant in midland to lowland areas. Overall, the sampled households reflected diverse production systems, with pastoralism being most common, and covered a range of lowland to midland agro-ecologies.

Major indigenous cattle feed species identified in the Omo–Woito River belts

A total of 20 major indigenous cattle feed species (Table 2) were identified in the Omo-Woito River belts, classified into four functional groups: grasses (6 species), legumes (4 species), shrubs (4 species), and trees (6 species). The distribution of these species varied across production systems, feeding seasons, and nutritional roles.

Grasses were predominantly used in pastoral and agro-pastoral systems, with most species utilized during the wet season (e.g., *Cenchrus ciliaris*, *Panicum virgatum*, *Chloris gayana*). They mainly served as energy and fiber sources, forming the basal diet for cattle. Notably, *Eragrostis superba* was reported to be drought-tolerant, extending its availability into the early dry season.

Legumes were primarily found in agro-pastoral and mixed systems and were mostly consumed during the wet season. These species (*Melilotus albus*, *Stylosanthes hamata*, *Indigofera spicata*, *Vigna luteola*) were noted for their high protein content, contributing significantly to diet quality, growth, and soil fertility improvement. Shrubs were mostly utilized in pastoral systems during the dry season and functioned as drought reserves or survival feed (*Celtis ehrenbergiana*, *Cadaba farinosa*), while some provided moderate protein and minerals (*Acalypha fruticosa*, *Grewia bicolor*). Trees were important dry-season

TABLE 1 Distribution of sampled households by administrative zone, district, production system, and agro-ecology.

Administrative zone	District	Kebeles (FA)	Production system	Agro-ecology	Sample households (n)
South Omo	Dasenech	Direyelere, Delenyemur, Alkatakach	Pastoral	Lowland	92
South Omo	Nyangatom	Lokorlam, Lebere, Aypa	Pastoral	Lowland	92
South Omo	Salamago	Omo Hana, Dakuba, Gero	Pastoral/Agro-pastoral/ Mixed	Lowland–Midland	92
Konso	Kolume	Gelgelo-Qolmala, Tebela, Massoya	Mixed/Agro-pastoral	Midland–Lowland	95
Total	—	12 kebeles	—	—	**371**

Bold values indicate statistically significant differences at the specified significance level.

TABLE 2 Major indigenous cattle feed species identified in the Omo - Woito River belts, their production systems, feeding seasons, and nutritional roles.

Functional group	Local name	Scientific name	Production systems	Primary feeding season	Main nutritional role
Grass	Edakapuseru	*Cenchrus ciliaris*	Pastoral, agro-pastoral	Wet and dry	Energy and fiber source; basal diet
Grass	Kujiji (Ejawo)	*Sporobolus indicus*	Pastoral, mixed	Wet	Fiber and maintenance feed
Grass	Amuriat-nachupa	*Panicum virgatum*	Pastoral	Wet	Energy source; moderate fiber
Grass	Sere	*Chloris gayana*	Pastoral, agro-pastoral	Wet	Energy and fiber; good palatability
Grass	Woyibo	*Brachiaria mutica*	Agro-pastoral, mixed	Wet	Energy-rich forage; supports milk production
Grass	Daka	*Eragrostis superba*	Pastoral	Wet and early dry	Fiber and energy; drought-tolerant grass
Legume	Emariat	*Melilotus albus*	Agro-pastoral, mixed	Wet	High protein; improves diet quality
Legume	Chibara	*Stylosanthes hamata*	Agro-pastoral	Wet	Protein supplement; soil fertility improvement
Legume	Korkora	*Indigofera spicata*	Pastoral, mixed	Wet	Protein-rich forage; growth support
Legume	Abela	*Vigna luteola*	Mixed	Wet	Protein and mineral source
Shrub	Edome	*Celtis ehrenbergiana*	Pastoral	Dry	Drought reserve; fiber and browse
Shrub	Karsa	*Grewia bicolor*	Pastoral, agro-pastoral	Dry	Browse feed; energy and minerals
Shrub	Dembi	*Cadaba farinosa*	Pastoral	Dry	Drought reserve; survival feed
Shrub	Seko	*Acalypha fruticosa*	Pastoral	Dry	Browse with moderate protein
Tree	Lalipach	*Triadica sebifera*	Pastoral, agro-pastoral	Dry	Emergency feed; energy and fiber
Tree	Haleko/Mida	*Moringa stenopetala*	Agro-pastoral, mixed	Dry	High protein, vitamins, and minerals
Tree	Wanza	*Cordia africana*	Mixed	Dry	Supplementary browse; fiber
Tree	Qarar	*Vachellia tortilis*	Pastoral, agro-pastoral	Dry	Protein-rich pods; key drought reserve
Tree	Seraw	*Ficus sycomorus*	Mixed	Dry	Emergency forage; moisture and fiber

feeds, with species like *Moringa stenopetala* and *Vachellia tortilis* supplying high protein, vitamins, and minerals, while others (*Triadica sebifera*, *Ficus sycomorus*) acted as emergency or supplementary feed. Overall, trees played a critical role as drought reserves and nutritional supplements during feed-scarce periods.

Mean dry matter (DM) yield of selected indigenous feed species

The mean dry matter (DM) yield of commonly used indigenous feed species differed significantly among functional groups and agro-ecological zones (Table 3).

10.3389/past.2026.16541

TABLE 3 Mean dry matter yield of commonly used indigenous feed species in the study area.

Local name	Common name	Scientific name	Functional group	Mean DM yield (t ha^{-1})	Agro-ecology
Edakapuseru	Buffel grass	*Cenchrus ciliaris*	Grass	10.7 ± 0.6	Lowland
Kujiji (Ejawo)	Smut grass	*Sporobolus indicus*	Grass	6.3 ± 0.4	Midland
Amuriat-nachupa	Switchgrass	*Panicum virgatum*	Grass	9.7 ± 0.5	Lowland
Sere	Rhodes grass	*Chloris gayana*	Grass	8.4 ± 0.5	Lowland
Woyibo	Para grass	*Brachiaria mutica*	Grass	11.2 ± 0.7	Lowland
Daka	Love grass	*Eragrostis superba*	Grass	7.1 ± 0.4	Lowland
Emariat	Sweet white clover	*Melilotus albus*	Legume	9.6 ± 0.5	Midland
Chibara	Stylo	*Stylosanthes hamata*	Legume	6.8 ± 0.4	Midland
Korkora	Indigofera	*Indigofera spicata*	Legume	5.9 ± 0.3	Lowland
Abela	Wild cowpea	*Vigna luteola*	Legume	5.4 ± 0.3	Midland
Edome	Hackberry	*Celtis ehrenbergiana*	Shrub	3.1 ± 0.3	Lowland
Karsa	Grewia	*Grewia bicolor*	Shrub	3.6 ± 0.3	Lowland
Dembi	Cadaba	*Cadaba farinosa*	Shrub	2.9 ± 0.2	Lowland
Seko	Acalypha	*Acalypha fruticosa*	Shrub	3.3 ± 0.3	Lowland
Lalipach	Chinese tallow tree	*Triadica sebifera*	Fodder tree	2.8 ± 0.3	Lowland
Haleko/Mida	Moringa	*Moringa stenopetala*	Fodder tree	2.2 ± 0.2	Midland
Wanza	Cordia	*Cordia africana*	Fodder tree	2.5 ± 0.2	Midland
Qarar	Umbrella thorn	*Vachellia tortilis*	Fodder tree	3.0 ± 0.3	Lowland
Seraw	Sycamore fig	*Ficus sycomorus*	Fodder tree	3.4 ± 0.3	Mixed

Values are means ± standard error; DM, dry matter. Shrub and tree yields represent edible leaf and tender twig biomass only.

Grasses exhibited the highest DM yields overall, led by *Brachiaria mutica* (Para grass), which recorded the highest mean yield (11.2 ± 0.7 t ha^{-1}), followed by *Cenchrus ciliaris* (Buffel grass; 10.7 ± 0.6 t ha^{-1}) and *Panicum virgatum* (Switchgrass; 9.7 ± 0.5 t ha^{-1}). Relatively lower yields among grasses were observed for *Sporobolus indicus* (Smut grass; 6.3 ± 0.4 t ha^{-1}) and *Eragrostis superba* (Love grass; 7.1 ± 0.4 t ha^{-1}).

Among legumes, *Melilotus albus* (Sweet white clover) produced the highest DM yield (9.6 ± 0.5 t ha^{-1}), whereas *Vigna luteola* (Wild cowpea) recorded the lowest yield within this functional group (5.4 ± 0.3 t ha^{-1}). Shrubs and fodder trees yielded comparatively lower DM production, with *Grewia bicolor* (3.6 ± 0.3 t ha^{-1}) and *Ficus sycomorus* (3.4 ± 0.3 t ha^{-1}) showing moderate yields, while *Moringa stenopetala* recorded the lowest overall DM yield (2.2 ± 0.2 t ha^{-1}).

Agro-ecological effects were evident, as lowland areas predominantly supported higher-yielding grass species, whereas midland areas showed relatively greater legume productivity.

Chemical composition and *in vitro* digestibility of selected indigenous forage species

The chemical composition, *in vitro* dry matter digestibility (IVDMD), and *in vitro* organic matter digestibility (IVOMD) of indigenous forage species in the Omo-Woito River belts varied significantly by species, agro-ecology, and season (Table 4). Crude protein (CP) content was generally higher in legumes and certain tree species compared to grasses and shrubs. For instance, *Moringa stenopetala* had the highest CP at 23.5% DM, followed by *Indigofera spicata* (21.2%) and *Vigna luteola* (20.6%) in the wet season. In contrast, grasses such as *Chloris gayana* and *Sporobolus indicus* had lower CP values ranging from 7.1% to 9.2% DM during the wet season, which further declined in the dry season.

Fiber content, measured as neutral detergent fiber (NDF) and acid detergent fiber (ADF), was higher in grasses, with *Brachiaria mutica* and *Vachellia tortilis* showing NDF values above 60% and ADF values above 40%, while legumes and trees generally had lower fiber, indicating higher digestibility. Ash content ranged from 6.6% to 11.8%, with higher mineral levels observed in tree species such as *Moringa stenopetala* and *Cordia africana*.

Digestibility values followed similar trends to chemical composition. Grasses had moderate IVDMD (54%–64%) and IVOMD (51%–62%), with a notable decline in the dry season. Legumes and trees exhibited higher digestibility, with *Moringa stenopetala* recording the highest IVDMD and IVOMD at 77.7% and 74.5%, respectively. Species like *Melilotus albus* and *Indigofera spicata* also had digestibility values above 69% for both parameters. Overall, legumes and certain trees provided superior protein content and digestibility, while grasses contributed primarily fiber and basal energy.

TABLE 4 Chemical composition, *in vitro* dry matter digestibility (IVDMD), and *in vitro* organic matter digestibility (IVOMD) of indigenous forage species (% DM).

Species	Agro-ecology	Season	CP	NDF	ADF	Ash	IVDMD	IVOMD
Cenchrus ciliaris	Lowland	Wet	10.3	60.2	34.4	8.1	63.6	61.8
		Dry	7.5	67.6	40.8	7.0	56.5	52.4
Sporobolus indicus	Midland	Wet	9.2	62.0	36.1	7.8	63.5	59.1
		Dry	6.6	70.4	42.2	6.6	54.4	51.1
Panicum virgatum	Lowland	Wet	11.7	58.4	32.6	8.5	66.7	63.3
		Dry	8.3	66.2	39.8	7.2	58.5	55.6
Chloris gayana	Lowland	Wet	7.1	65.0	39.4	8.0	57.8	55.6
Brachiaria mutica	Lowland	Wet	9.2	69.8	40.5	7.5	57.4	55.4
Eragrostis superba	Lowland	Wet/Dry	8.6	67.5	40.1	7.3	57.8	55.7
Melilotus albus	Midland	Wet	18.7	46.6	29.3	9.4	71.8	69.6
		Dry	13.2	51.6	34.7	8.2	62.2	60.7
Stylosanthes hamata	Midland	Wet	12.3	49.6	42.2	8.8	64.1	61.3
Indigofera spicata	Lowland	Wet	21.2	45.2	31.7	9.6	71.8	68.5
Vigna luteola	Midland	Wet	20.6	45.6	32.4	9.1	69.3	65.6
Celtis ehrenbergiana	Lowland	Dry	14.5	49.7	30.4	10.1	67.4	65.7
Grewia bicolor	Lowland	Dry	19.9	47.5	36.5	9.4	69.1	65.6
Cadaba farinosa	Lowland	Dry	16.3	52.8	37.9	8.9	62.8	60.4
Acalypha fruticosa	Lowland	Dry	14.7	51.6	37.1	9.2	61.8	59.8
Triadica sebifera	Lowland	Dry	12.8	52.8	34.2	9.6	64.5	62.7
Moringa stenopetala	Midland	Dry	23.5	39.2	25.6	11.8	77.7	74.5
Cordia africana	Midland	Dry	16.2	37.4	28.9	11.0	61.2	57.2
Vachellia tortilis	Lowland	Dry	13.8	61.7	50.4	7.8	62.8	60.3
Ficus sycomorus	Mixed	Dry	16.9	47.5	34.2	10.5	71.5	67.4

CP, crude protein; NDF, neutral detergent fibre; ADF, acid detergent fibre; Ash, mineral content; IVDMD, *in vitro* dry matter digestibility; IVOMD, *in vitro* organic matter digestibility (% DM).

Seasonal availability of major indigenous cattle feed resources

The seasonal availability of indigenous forage species in the Omo-Woito River belts varied considerably among functional groups and species (Table 5). Annual grasses, such as *Sporobolus indicus* and *Eragrostis superba*, had high availability in the wet season (index 4) but low availability in the dry season (index 2), reflecting their strong dependence on rainfall and short growth cycles. Perennial grasses (*Cenchrus ciliaris*, *Panicum virgatum*) maintained moderate to high availability into the early dry season (index 3), indicating drought tolerance and persistence under grazing, while species like *Brachiaria mutica* showed very high wet-season productivity (index 5) but limited dry-season availability (index 2).

Legumes were generally abundant during the wet season, with indices ranging from 4 to 5, but their dry-season persistence varied. For example, *Melilotus albus* and *Stylosanthes hamata* declined sharply (index 2), whereas *Indigofera spicata* maintained moderate availability (index 3). *Vigna luteola* had minimal dry-season survival (index 1).

Shrubs and fodder trees were predominantly available during the dry season, serving as key forage and browse resources when grasses and legumes were scarce. *Celtis ehrenbergiana*, *Grewia bicolor*, *Cadaba farinosa*, and *Acalypha fruticosa* had low to moderate wet-season availability (indices 2–3) but very high dry-season availability (indices 4–5). Similarly, fodder trees such as *Triadica sebifera*, *Moringa stenopetala*, *Vachellia tortilis*, and *Ficus sycomorus* provided reliable dry-season feed, with availability indices of 4–5, highlighting their role as strategic feed reserves.

Relationships between nutritional composition and digestibility of indigenous forages

Spearman correlation analysis indicated significant relationships between chemical composition and digestibility of indigenous forage species (Table 6). Crude protein (CP) was strongly and positively correlated with *in vitro* dry matter digestibility (IVDMD; $r = 0.81$, $p < 0.001$) and *in vitro* organic matter digestibility (IVOMD; $r = 0.83$, $p < 0.001$),

TABLE 5 Seasonal availability index (1–5) of indigenous forage species identified in Table 4.

Functional group	Forage species	Wet season availability	Dry season availability	Remarks
Annual grasses	*Sporobolus indicus*	4	2	Strongly rainfall dependent
	Eragrostis superba	4	2	Short growth cycle
Perennial grasses	*Cenchrus ciliaris*	4	3	Drought-tolerant; grazing continuity
	Panicum virgatum	4	3	Persists into early dry season
	Chloris gayana	3	3	Stable under grazing pressure
	Brachiaria mutica	5	2	Highly productive in wet season
Legumes	*Melilotus albus*	5	2	High-quality protein source
	Stylosanthes hamate	5	2	Seasonal legume
	Indigofera spicata	4	3	Partial dry-season persistence
	Vigna luteola	5	1	Minimal dry-season survival
Shrubs	*Celtis ehrenbergiana*	2	5	Key dry-season browse
	Grewia bicolor	3	5	Maintains foliage in drought
	Cadaba farinosa	3	5	Critical feed buffer
	Acalypha fruticosa	3	4	Reliable dry-season browse
Fodder trees	*Triadica sebifera*	2	5	Strategic feed reserve
	Moringa stenopetala	3	5	Green foliage year-round
	Cordia africana	3	4	Supplementary dry-season feed
	Vachellia tortilis	2	5	Pods and leaves in dry season
	Ficus sycomorus	3	5	Emergency fodder

Seasonal availability index: 1 = very low, 2 = low, 3 = moderate, 4 = high, 5 = very high.
Scores are based on field observations, indigenous knowledge, and published rangeland ecology studies.

TABLE 6 Spearman correlation matrix (r) among chemical composition and digestibility of indigenous forage species.

Variables	CP	NDF	ADF	Ash	IVDMD	IVOMD
CP	1.00	−0.90***	−0.67***	0.84***	0.81***	0.83***
NDF		1.00	0.77***	−0.90***	−0.79***	−0.80***
ADF			1.00	−0.81***	−0.71***	−0.73***
Ash				1.00	0.76***	0.79***
IVDMD					1.00	0.98***
IVOMD						1.00

***Indicates a statistically significant correlation at ($p < 0.001$). Crude protein (CP) showed strong positive correlations with both digestibility measures (IVDMD and IVOMD), whereas fiber fractions (NDF and ADF) were strongly and negatively associated with digestibility. Ash content exhibited moderate positive correlations with digestibility parameters. *In vitro* dry matter digestibility and *in vitro* organic matter digestibility were extremely strongly correlated ($r = 0.98$), indicating close agreement between the two measures.

suggesting that higher protein content was associated with greater digestibility. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were negatively correlated with both IVDMD and IVOMD, with ADF exerting a slightly stronger negative effect than NDF. Ash content showed moderate positive correlations with digestibility (IVDMD: $r = 0.76$; IVOMD: $r = 0.79$). IVDMD and IVOMD were extremely strongly correlated ($r = 0.98$, $p < 0.001$), indicating close agreement between dry matter and organic matter digestibility measurements.

Discussion

Distribution of sample households and production systems

The distribution of sampled households across administrative zones, production systems, and agro-ecological settings reflects the dominant livelihood patterns of the Omo–Woito River belts. The predominance of pastoral households in Dasenech and Nyangatom

districts is consistent with long-established rangeland-based livestock systems in the lowlands of South Omo, where limited rainfall and high temperatures constrain crop production (Gebremedhin et al., 2021; Food and Agriculture Organization of the United Nations (FAO), 2022). These systems rely heavily on communal grazing lands and livestock mobility as adaptive strategies to cope with spatial and temporal variability in forage availability.

In contrast, the presence of agro-pastoral and mixed crop–livestock systems in Salamago and Kolume districts indicates a gradual livelihood diversification driven by agro-ecological heterogeneity, population pressure, and expansion of cultivation in relatively favorable environments. Similar transitions from purely pastoral to mixed systems have been reported in other parts of southern Ethiopia and East Africa, where households integrate cropping to reduce vulnerability to climatic shocks (Yayneshet, 2010; Denbela Hidosa et al., 2017).

The inclusion of both lowland and midland agro-ecologies strengthens the ecological representativeness of the study. Agro-ecological variation strongly influences forage species composition, biomass productivity, and nutritional quality, thereby affecting livestock feeding strategies and performance (International Livestock Research Institute (ILRI), 2023). This diversity provides an important basis for understanding spatial differences in indigenous feed resource availability and utilization.

Functional complementarity of indigenous forages in semi-arid cattle systems

The findings demonstrate the integrated role of forage functional groups in supporting cattle production in semi-arid systems. Grasses, with high DM yield and moderate digestibility, are essential for basal energy and fiber intake, consistent with patterns reported in East African rangelands (Coppock, 1994; Skerman and Riveros, 1990). Their reduced protein and digestibility during the dry season highlight the need for supplementary forage to prevent nutritional deficits (Humphreys, 1995; Whitford et al., 2022).

Legumes provide high-protein supplementation, improving diet quality and supporting growth and milk production. Species like *Melilotus albus* and *Indigofera spicata* combine reasonable biomass with superior nutritional value, making them strategic wet-season forages (Amede et al., 2024; Tadesse et al., 2024). Their ability to fix nitrogen may also improve soil fertility in agro-pastoral systems (Peters et al., 2012).

Shrubs and trees are crucial for dry-season feeding, providing both protein and minerals when herbaceous forages decline. The high CP and digestibility of *Moringa stenopetala*, *Ficus sycomorus*, and *Grewia bicolor* reinforce their role as emergency or drought-resilient feeds (Le Houérou, 1980; Foidl et al., 2001; Alemayehu, 2006). The seasonal shift from grasses and legumes to woody species illustrates the adaptive feeding strategies employed by pastoralists to buffer seasonal feed scarcity (Oba et al., 2001; Amede et al., 2024).

For agro-pastoral households, the integration of high-protein legumes and fodder trees within crop–livestock production systems offers additional opportunities for improving feed quality and reducing seasonal feed deficits. Species such as Moringa stenopetala, Indigofera spicata, and Melilotus albus can be strategically incorporated around homesteads, field borders, and fallow lands to provide supplementary protein during periods when natural pastures decline in quality.

The integration of DM yield, chemical composition, digestibility, and seasonal availability suggests that effective rangeland management should combine high-yielding grasses for energy, legumes for protein, and woody species for dry-season supplementation, optimizing both feed quantity and quality throughout the year (Snyman, 2005; Whitford et al., 2022). The integrated assessment of forage diversity, biomass yield, seasonal dynamics, nutritional composition, and digestibility presented in this study provides new evidence for designing season-specific feeding interventions in pastoral and agro-pastoral systems of southern Ethiopia.

Overall, the data confirm that the functional complementarity of forage groups is a critical determinant of livestock productivity in semi-arid systems, emphasizing the importance of species diversity and seasonally adaptive feeding strategies.

Dry matter yield of indigenous feed species

The DM yield patterns of indigenous forage species reflect functional group differences, agro-ecology, and management implications. Perennial grasses such as *Brachiaria mutica*, *Cenchrus ciliaris*, and *Panicum virgatum* consistently produced high biomass, which is critical for sustaining livestock during the wet season when forage quantity is the limiting factor (Coppock, 1994; Skerman and Riveros, 1990). These species' high DM yield combined with moderate CP and digestibility (Table 4) makes them primary forage sources in lowland grazing systems.

The observed agro-ecological differences in forage biomass production likely reflect variations in rainfall distribution, soil moisture availability, and vegetation composition between lowland and midland environments. The higher productivity of perennial grasses in lowland areas may be attributed to their adaptation to warmer temperatures and extensive grazing landscapes, which favor rapid biomass accumulation during the rainy season. In contrast, the relatively greater productivity of legumes in midland areas may be associated with more favorable soil conditions and moisture regimes that support nitrogen fixation and vegetative growth. The significant seasonal variation in biomass yield further demonstrates the strong dependence of herbaceous forage production on rainfall, highlighting the vulnerability of pastoral feed resources to climatic fluctuations.

The magnitude of the standard errors associated with dry matter yield estimates provides additional insight into the consistency of forage production among species. Most grasses exhibited relatively small standard errors (±0.4–0.7 t ha^{-1}), indicating stable biomass production across sampled locations and suggesting broad adaptation to prevailing environmental conditions. In contrast, the comparatively greater variability observed among some legumes, shrubs, and fodder trees may reflect differences in local site conditions, plant age, grazing pressure, and micro-environmental factors. Such variability is expected in semi-arid rangelands where forage performance is strongly influenced by spatial heterogeneity in rainfall and soil resources.

Grasses with lower DM yield, such as *Sporobolus indicus*, may play a secondary role, often utilized for early-season grazing or in areas with less rainfall. Seasonal reductions in yield and quality of grasses are consistent with patterns observed in arid and semi-arid rangelands, where senescence, increased fiber content, and lignification reduce both quantity and digestibility during dry periods (Humphreys, 1995; Whitford et al., 2022).

Legumes, although yielding less DM than grasses, contribute high-protein forage (CP 12%–21%; Table 4), supporting animal nutrition during periods when grasses are fiber-rich and low in protein. *Melilotus albus* and *Indigofera spicata* combine moderate biomass with high digestibility (IVDMD >68%), enhancing their strategic role as protein supplements (Amede et al., 2024; Tadesse et al., 2024).

Shrubs and fodder trees produced the lowest DM, yet their contribution to dry-season feed security is substantial due to high protein content and digestibility (e.g., *Moringa stenopetala* CP 23.5%, IVDMD 77.7%) and year-round availability (Tables 4 and 5) (Le Houérou, 1980; Foidl et al., 2001; Alemayehu, 2006). Woody species such as *Ficus sycomorus* and *Grewia bicolor* provide complementary forage during dry seasons when grasses and legumes are scarce, highlighting the importance of functional group complementarity in semi-arid rangeland feeding strategies (Oba et al., 2001; Amede et al., 2024).

Overall, forage management should integrate high-yielding grasses for quantity and legumes/trees for quality, ensuring sustainable livestock nutrition throughout seasonal fluctuations. These findings confirm that DM yield alone does not determine forage value—nutritional quality and seasonal availability are equally critical for planning effective rangeland feeding systems (Snyman, 2005; Whitford et al., 2022).

Nutritional quality and digestibility of indigenous forage species

Seasonal differences in forage quality were closely linked to plant physiological responses to changing environmental conditions. During the wet season, active vegetative growth promoted the accumulation of cellular contents such as proteins and soluble carbohydrates, resulting in higher crude protein concentrations and digestibility values. Conversely, dry-season moisture stress accelerated plant maturation and the deposition of structural carbohydrates, leading to increased NDF and ADF concentrations and reduced digestibility. These seasonal changes were particularly pronounced in grasses, whereas browse species maintained relatively stable nutritional quality because of their deeper root systems and ability to access soil moisture during prolonged dry periods. This adaptive characteristic explains their importance as strategic feed resources in semi-arid pastoral systems.

The variation in chemical composition and digestibility among forage types is consistent with established trends in tropical and semi-arid rangelands. Grasses generally provide moderate CP and digestibility, but their quality declines in the dry season due to senescence and increased fiber content (Coppock, 1994; Snyman, 2005). The observed decrease in IVDMD and IVOMD in dry-season grasses, such as *Sporobolus indicus* and *Cenchrus ciliaris*, is attributed to lignification and accumulation of structural carbohydrates under moisture stress (Humphreys, 1995; Whitford et al., 2022).

Legumes and fodder trees exhibited higher CP, lower fiber, and higher digestibility, making them excellent supplements during periods of low forage quality (Skerman and Riveros, 1990; Foidl, Makkar and Becker, 2001). Notably, *Moringa stenopetala* demonstrated exceptional nutritional value (23.5% CP, 77.7% IVDMD), consistent with studies reporting its multipurpose role as a high-protein feed for livestock and a drought-resilient species (Amede et al., 2024; Tadesse et al., 2024).

Variability in nutritional composition and digestibility among forage species further reflects differences in plant functional traits and ecological adaptation. Species exhibiting consistently high crude protein and digestibility values with relatively limited variation, such as Moringa stenopetala and Indigofera spicata, demonstrate reliable nutritional performance across environmental conditions. Conversely, greater variation in some grass species may be associated with seasonal maturity effects and differences in environmental exposure, which influence fiber accumulation and forage quality. These findings emphasize the importance of considering both mean values and variability when selecting forage resources for sustainable livestock feeding programs.

The seasonal decline in CP and digestibility of grasses underscores the importance of complementary feeding strategies, integrating high-quality browse and legumes during dry periods to maintain livestock nutrition (Oba et al., 2001). Woody species such as *Celtis ehrenbergiana*, *Grewia bicolor*, and *Ficus sycomorus* maintained relatively high CP (14%–17%) and digestibility (>65%) in the dry season, emphasizing their critical role as feed buffers under feed-scarce conditions (Le Houérou, 1980; Alemayehu, 2006).

The results also reflect functional group complementarity: grasses dominate quantity in the wet season but decline in quality during dry periods, while legumes and woody species sustain protein supply and digestibility when herbaceous forage quality deteriorates. Such patterns are vital for designing sustainable feeding systems in semi-arid rangelands (Amede et al., 2024; Whitford et al., 2022).

Overall, the chemical composition and digestibility data highlight species-specific and seasonal variations that are crucial for strategic forage utilization, particularly in dryland pastoral and agro-pastoral systems.

Seasonal availability of indigenous feed resources

The interaction between season and agro-ecology has important implications for livestock feeding strategies. In lowland pastoral areas, forage supply is largely driven by seasonal grass production, resulting in substantial fluctuations in feed quantity and quality between wet and dry periods. In contrast, midland and agro-pastoral areas benefit from a more diverse forage base that includes legumes and fodder trees, which can partially offset seasonal declines in grass quality. This ecological complementarity contributes to greater resilience of livestock production systems by ensuring that different forage functional groups become available at different times of the year. Consequently, maintaining species diversity

within rangelands is essential for stabilizing feed resources under increasing climatic variability.

Beyond their ecological importance, the identified indigenous forage resources have significant socio-economic value for pastoral and agro-pastoral households. Seasonal shifts in forage availability strongly influence grazing management, herd mobility, and household feed planning decisions. During dry periods, the continued availability of browse species such as Grewia bicolor, Cadaba farinosa, Vachellia tortilis, and Moringa stenopetala provides critical feed resources that help households maintain livestock during periods of forage scarcity. The strategic use of these species reflects the importance of indigenous knowledge in managing seasonal feed shortages and reducing vulnerability to fluctuating environmental conditions. Consequently, conservation and sustainable utilization of indigenous forage resources can contribute to more stable livestock production and livelihood support in pastoral and agro-pastoral communities.

The observed seasonal variation in forage availability reflects well-established patterns in arid and semi-arid rangelands. Herbaceous species, especially annual grasses, exhibited high wet-season availability but declined sharply during the dry season, reflecting their strong dependence on rainfall and limited drought resilience (Coppock, 1994; Snyman, 2005; Whitford et al., 2022). This pattern aligns with studies in East African rangelands, where annual grasses dominate during rains but contribute minimally to forage supply in dry periods (International Livestock Research Institute (ILRI), 2006).

Perennial grasses such as *Cenchrus ciliaris*, *Panicum virgatum*, and *Chloris gayana* maintained moderate to high availability across seasons. This supports findings that perennial grasses, with deeper root systems and greater drought tolerance, act as buffers for forage supply in the dry season (Skerman and Riveros, 1990; Whitford et al., 2022). Their persistence is crucial for sustaining livestock grazing when annual species senesce, ensuring continuity of feed (Coppock, 1994).

Leguminous forages were abundant in the wet season, but most declined in availability during the dry season, except *Indigofera spicata*, which maintained moderate availability. This trend is consistent with the sensitivity of herbaceous legumes to moisture stress, as legumes generally senesce earlier under drought conditions (Humphreys, 1995; Peters et al., 2012). Recent studies also highlight the value of drought-tolerant legumes in maintaining forage quality during the dry season (Amede et al., 2024).

In contrast, shrubs and fodder trees showed low wet-season availability but very high dry-season availability. Species such as *Grewia bicolor*, *Cadaba farinosa*, *Vachellia tortilis*, and *Moringa stenopetala* retain leaves, pods, or green biomass during drought, providing essential feed resources when grasses are scarce (Le Houérou, 1980; Alemayehu, 2006; Foidl, Makkar and Becker, 2001). Recent remote sensing studies confirm that woody species maintain both quantity and quality of forage during dry periods in arid rangelands (Tadesse et al., 2024; Whitford et al., 2022).

The observed complementarity among functional groups - herbaceous forages dominating in the wet season and woody species in the dry season - underscores adaptive pastoral strategies for coping with seasonal feed variability (Oba et al., 2001; Amede et al., 2024). With increasing climate variability, the conservation and sustainable use of perennial grasses and drought-tolerant woody species are important for maintaining feed availability and supporting livestock feeding systems under increasing climatic variability (Coppock, 1994; Tadesse et al., 2024).

Relationship between chemical composition and *in vitro* digestibility of indigenous forage species

The significant inverse relationships between CP and fiber fractions (NDF and ADF) reflect well-established nutritional dynamics in forage quality, whereby increased structural carbohydrates dilute metabolic components such as protein, resulting in reduced nutritive value (Van Soest, 1994). Similar patterns of positive associations between protein concentration and digestibility, and negative correlations with fiber content have been documented in native forage species and fodder grasses, reinforcing the relevance of these parameters in forage evaluation (Escobar et al., 2020; Brychkova et al., 2022).

The positive correlations between CP and both IVDMD and IVOMD support the role of nitrogen availability in promoting rumen microbial activity and carbohydrate fermentation. Increased CP enhances microbial growth, leading to greater organic matter degradation and improved digestibility outcomes, a relationship frequently observed across forage studies (Getachew et al., 2004; Sisay et al., 2024).

The negative association of fiber fractions with digestibility metrics underscores that high concentrations of NDF and ADF reduce forage utilization. NDF, representing the bulk of structural carbohydrate, limits voluntary intake and passage rate, whereas ADF indicates less digestible fiber portions, such as cellulose and lignin, which impede microbial access and enzymatic breakdown (Mertens, 1994; Lee, 2018).

The positive relationship between ash content and digestibility suggests that mineral richness may support rumen microbial metabolism and enzymatic processes necessary for effective fermentation and nutrient capture. Minerals such as calcium, phosphorus, and magnesium are essential cofactors in numerous microbial pathways that influence feed degradation and animal energy status (McDowell, 2003).

The extremely strong correlation between IVDMD and IVOMD confirms a close concordance between these two measures of digestibility, indicating that both can be effectively used as proxies for forage nutritive potential *in vitro*. This is consistent with approaches in many forage evaluation protocols where organic matter digestibility systematically parallels dry matter digestion (Tilley and Terry, 1963).

Overall, the correlation structure identified crude protein (CP) and fiber fractions as the primary determinants of forage digestibility. Indigenous forage species with higher CP and ash contents and lower neutral detergent fiber (NDF) and acid detergent fiber (ADF) concentrations exhibited superior nutritive value and are therefore more likely to support improved ruminant performance under extensive and semi-intensive livestock production systems. Although the relationships among CP, fiber fractions, and digestibility are well established in forage science, the present findings confirm that these nutritional principles are also applicable to the diverse indigenous forage species of the Omo–

Woito River basin. The observed correlations thus validate the use of CP and fiber measurements as practical and reliable indicators for assessing the nutritive value of indigenous feed resources in the local production context.

Study limitations

This study provides valuable information on the diversity, seasonal availability, nutritional composition, and digestibility of indigenous forage resources in the Omo–Woito River basin. However, some limitations should be acknowledged. Soil characteristics and grazing intensity were not measured or incorporated as explanatory factors in the analysis. Variations in soil fertility, texture, and moisture status, as well as differences in grazing pressure among locations, may have influenced forage species composition, biomass yield, and nutritional quality. Therefore, part of the observed variation among forage species and study sites may be attributable to these environmental and management factors. Future studies should integrate soil assessments and grazing management indicators to better explain spatial and temporal variation in forage productivity and nutritive value.

In addition, seasonal availability indices were partly derived from indigenous knowledge, focus group discussions, and field observations. Although these approaches were triangulated to improve reliability, some degree of subjectivity may remain in the assessment of forage availability across seasons. Future studies incorporating long-term quantitative monitoring of forage abundance would further strengthen the accuracy of seasonal availability estimates.

In addition, the study was conducted within selected pastoral and agro-pastoral areas of the Omo–Woito River basin, and the results should therefore be interpreted within this geographic context. Although seasonal assessments were undertaken during the study period, the data do not capture interannual variation in rainfall patterns, vegetation dynamics, or forage quality that may occur across years. Consequently, the observed seasonal trends represent conditions during the study period rather than long-term ecological responses. Future research incorporating multiple years and a wider range of agro-ecological settings would strengthen understanding of temporal variability and improve the broader applicability of forage resource assessments in semi-arid livestock production systems.

Furthermore, the present study focused primarily on nutritional composition and *in vitro* digestibility. Potential anti-nutritional factors and secondary plant metabolites, such as tannins, saponins, and alkaloids, were not evaluated. Since these compounds may influence forage palatability, intake, and nutrient utilization, future research should investigate their occurrence and effects in indigenous forage species of the Omo–Woito River basin.

Conclusion

Indigenous forage resources play a pivotal role in sustaining cattle production in the pastoral and agro-pastoral systems of the Omo–Woito River basin. The results demonstrate clear functional complementarity among forage groups, with perennial grasses contributing the majority of dry matter, while legumes, shrubs, and fodder trees supply essential crude protein and maintain higher digestibility, particularly during the dry season. Seasonal declines in forage quality were characterized by reduced crude protein concentrations and increased fiber fractions, leading to lower digestibility of herbaceous species. In contrast, browse species, particularly *Moringa stenopetala*, maintained superior nutritional quality and digestibility under feed-scarce conditions.The strong positive relationships between crude protein and digestibility, together with the negative associations between fiber fractions and digestibility, underscore the importance of forage chemical composition in determining nutritive value. Within the Omo–Woito River basin and comparable semi-arid environments, integrating drought-tolerant, protein-rich browse species with high-yielding grasses offers a practical strategy for enhancing year-round feed availability and nutritional balance. Such integration can improve livestock productivity while strengthening the resilience of production systems to increasing climatic variability. This study provides novel, location-specific evidence on the nutritional characteristics, digestibility, and seasonal dynamics of indigenous forage species, thereby contributing a scientific basis for improved feed resource management. The findings also emphasize the value of indigenous knowledge in supporting adaptive feeding practices and sustainable livestock production in pastoral and agro-pastoral communities.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

Ethics statement

The studies involving humans were approved by Arbaminch University Ethics Committee. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. The animal studies were approved by Arbaminch University Ethics Committee. Written informed consent was obtained from the owners for the participation of their animals in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

TE conceptualized the study, conducted field data collection, laboratory analysis, data analysis, and drafted the manuscript. YK supervised the research, contributed to study design, methodology refinement, and critically reviewed the manuscript.

AG contributed to data interpretation, methodological guidance, and manuscript review. All authors read and approved the final manuscript.

Funding

The author(s) declared that financial support was not received for this work and/or its publication.

Acknowledgments

The authors gratefully acknowledge the pastoral and agro-pastoral communities of the Omo–Woito River basin for their cooperation and willingness to share indigenous knowledge during the study. We thank local administrators, development agents, and field assistants for their logistical support and assistance during data collection. The authors also acknowledge Arba Minch University, Department of Animal Science, for providing institutional support and facilitating the research activities.

Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Correction note

This article has been corrected with minor changes. These changes do not impact the scientific content of the article.

Generative AI statement

The author(s) declared that generative AI was not used in the creation of this manuscript.

Any alternative text (alt text) provided alongside figures in this article has been generated by Frontiers with the support of artificial intelligence and reasonable efforts have been made to ensure accuracy, including review by the authors wherever possible. If you identify any issues, please contact us.

References

Alemayehu, M. (2006). *Range Management for Eastern Africa: Concepts and Practice*. Addis Ababa, Ethiopia: Addis Ababa University Printing Press. 118–119.

Amede, T., Tadesse, A., and Mengistu, A. (2024). Integrating drought-tolerant legumes and browse species into semi-arid livestock systems. *J. Arid Environ.* 218, 104–115.

AOAC (2019). *Official Methods of Analysis*. 21st ed. Association of Official Analytical Chemists.

Brychkova, G., Kekae, K., McKeown, P. C., Hanson, P., Jones, C. S., Thornton, P., et al. (2022). Climate change and land use change impacts on future availability of forage grass species for Ethiopian dairy systems. *Sci. Rep.* 12, 20512. doi: 10.1038/s41598-022-23461-w

Central Statistical Agency (CSA) (2021). Agricultural sample survey 2020/21 (2013 E.C.): volume II, *Report on Livestock and Livestock Characteristics (Private Peasant Holdings). Statistical Bulletin No*. 589. Addis Ababa, Ethiopia: Central Statistical Agency.

Cook, C. W., and Stubbendieck, J. (Eds.). (1986). Range research: Basic problems and techniques, *Relevant chapters include "Experimental Design*," Denver, Colorado: Society for Range Management. 251–276.

Coppock, D. L. (1994). *The Borana Plateau of Southern Ethiopia: Synthesis of Pastoral Research, Development and Change, 1980–91*. International Livestock Centre for Africa.

Denbela Hidosa, D., Haji, J., and Ketema, M. (2017). Determinants of pastoralists' participation in crop cultivation in southern Ethiopia. *Pastor. Res. Policy Pract.* 7 (1), 1–12.

Escobar, A., Arango, J., and Mera, O. (2020). Forage quality and digestibility relationships in tropical grasses. *Trop. Grassl.* 8 (3), 201–210.

Foidl, N., Makkar, H. P. S., and Becker, K. (2001). The potential of *Moringa oleifera* for agricultural and industrial uses. *J. Appl. Bot. Food Qual.* 75, 202–206.

Food and Agriculture Organization of the United Nations (FAO) (2021). Ethiopia: livestock sector brief. *Food Agric. Organ. U. N.*

Food and Agriculture Organization of the United Nations (FAO) (2022). *Africa Sustainable Livestock 2050: Business Models along the Cattle Dairy Value Chain in Ethiopia*. Rome: FAO. Available online at: https://www.fao.org/3/cb8179en/cb8179en.pdf.

Gebremedhin, B., Hirpa, A., and Yami, A. (2021). Livestock and livelihoods in the Omo River basin: challenges and opportunities. *J. Arid Environ.* 185, 104–112.

Getachew, G., Robinson, P. H., DePeters, E. J., and Taylor, S. J. (2004). Relationships between chemical composition, dry matter degradation and *in vitro* gas production of several ruminant feeds. *Animal Feed Sci. Technol.* 111 (1–4), 57–71. doi: 10.1016/S0377-8401(03)00217-7

Humphreys, L. R. (1995). *Tropical Pasture Utilization*. Cambridge University Press.

International Livestock Research Institute (ILRI) (2006). The time is now: safeguarding livestock diversity, *Annual Report 2006*. ILRI. Available online at: https://cgspace.cgiar.org/bitstream/10568/2479/1/AnnualRep2006_Safeguard.pdf

International Livestock Research Institute (ILRI) (2022). *Indigenous Forages in Rangeland Ecosystems: Ecological and Nutritional Roles*. International Livestock Research Institute.

International Livestock Research Institute (ILRI) (2023). *Climate Variability and Livestock Feed Security in Pastoral Systems of Ethiopia*. International Livestock Research Institute.

IPCC (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability*. Intergovernmental Panel on Climate Change.

Jiso, R., Kechero, Y., and Guja, A. (2023). The dromedary camel (*Camelus dromedarius*) feed resources and utilization practices in Borana Plateau, southern Ethiopia. *Cogent Food Agric.* 9 (2). doi: 10.1080/23311932.2023.2270251

Le Houérou, H. N. (1980). *Browse in Africa: The Current State of Knowledge*. International Livestock Centre for Africa.

Lee, M. A. (2018). A global comparison of the nutritive values of forage plants grown in contrasting environments. *J. Plant Res.* 131 (4), 641–654. doi: 10.1007/s10265-018-1024-y

McDowell, L. R. (2003). *Minerals in Animal and Human Nutrition*. 2nd ed. Elsevier.

Mengistu, A., Kebede, G., and Assefa, G. (2020). Indigenous forage species diversity and utilization in Ethiopian rangelands: a review. *Afr. J. Range & Forage Sci.* 37 (2), 89–102.

Mertens, D. R. (1994). "Regulation of forage intake," in *Forage Quality, Evaluation, and Utilization*. Editor G. C. FaheyJr. (American Society of Agronomy), 450–493.

Oba, G., Stenseth, N. C., and Lusigi, W. J. (2001). New perspectives on sustainable grazing management in arid zones of Sub-Saharan Africa. *BioScience* 51 (7), 481–493. doi: 10.1641/0006-3568(2000)050[0035:NPOSGM]2.3.CO;2

Peters, M., Herrero, M., and Fisher, M. (2012). Challenges and opportunities for livestock production in smallholder systems in Sub-Saharan Africa. *Outlook Agric.* 41 (4), 265–271.

Sisay, A., Mekuriaw, Y., and Tegegne, F. (2024). Correlations between forage chemical constituents and digestibility in Ethiopian rangelands. *J. Animal Physiology Animal Nutr.* 108 (2), 345–356.

Skerman, P. J., and Riveros, F. (1990). Tropical grasses. *FAO Plant Production and Protection Series, No. 23*. Rome, Italy: Food and Agriculture Organization of the United Nations. 832.

Snyman, H. A., and du Preez, C. (2005). Rangeland degradation in a semi-arid South Africa: influence on soil quality. *J. Arid Environ.* 60 (3), 483–507. doi: 10.1016/j.jaridenv.2004.06.005

Tadesse, A., Amede, T., and Yisehak, K. (2024). Nutritional dynamics of indigenous browse species in southern Ethiopian rangelands. *Afr. J. Agric. Res.* 19 (1), 45–58. https://doi.org/10.1016/j.jaridenv.2004.06.005

Tilley, J. M. A., and Terry, R. A. (1963). A two-stage technique for the *in vitro* digestion of forage crops. *J. Br. Grassl. Soc.* 18 (2), 104–111. doi: 10.1111/j.1365-2494.1963.tb00335.x

Van Soest, P. J. (1994). *Nutritional Ecology of the Ruminant*. 2nd ed. Cornell University Press.

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. *J. Dairy Sci.* 74 (10), 3583–3597. doi: 10.3168/jds.S0022-0302(91)78551-2

Whitford, W. G., de Soyza, A. G., and Van Zee, J. W. (2022). Rangeland resilience: integrating ecological and social dimensions in dryland management. *J. Environ. Manag.* 310, 114–123.

Yayneshet, T. (2010). *Feed Resources Availability and Livestock Production in the Northern Ethiopian Highlands*. Norwegian University of Life Sciences.