Indigenous legume fodder trees and shrubs with emphasis on land use and agroecological zones: Identification, diversity, and distribution in semi-humid condition of southern Ethiopia

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Abstract

Background: Fodder trees and shrubs are among the strategic feed resources that complement the dry season feed supply in the tropics. They are an integral element of the farming system incorporated into different land uses and deliver multiple functions, even though their diversity relies on various anthropogenic, physiographic, and agroecological factors.

Objective: The study aimed to identify indigenous legume fodder trees and shrubs (ILFTS) and estimate their diversity in terms of land use and agroecological zones in southern Ethiopia’s Gamo landscape.

Method: Respondent households were selected using a stratified multistage sampling procedure. Information about the ILFTS was gathered through key informant interviews conducted in each agro-ecological zone. A total of 273 households from three agro-ecological zones were selected and interviewed using a semi-structured questionnaire to assess ILFTS. The information acquired by the questionnaire survey was complemented with a focus group discussion held with 10 respondents in each agro-ecological zone. Herbarium samples were collected for each of the species for identification and confirmation of the botanical names. Sixty randomly selected sampling plots of each with a dimension of 20 m × 20 m were created, and inventories of ILFTS species were performed and recorded on species inventory sheets. The Shannon–Wiener diversity index (H) was used to determine the species diversity.

Result: The study identified 21 ILFTS that have been an integral constituent of the land uses recognised for their multiple functions in all agroecological zones. The mean species richness and diversity indices of the ILFTS differed significantly with land use and agroecological zones, where the lowland area closure exhibited the highest, and the highland homesteads and highland grazing land revealed the least.

Conclusion: Farmers’ indigenous knowledge and previous experience determined the species richness and diversity of ILFTS in farmlands and homesteads; however, the
1 | INTRODUCTION

Livestock production is an essential element of agriculture for smallholder farmers in many tropical countries. Besides its role in the livelihood and economy, it is the key component in farm diversification which enhances the resilience against risks and ensures sustainable agricultural production (Herrero et al., 2013). However, its contribution has been threatened by frequent phenomena such as recurrent drought and seasonal vegetation changes which impair the sustainable feed supply.

Ethiopia is among the tropical countries having the largest livestock population in Africa (CSA, 2020). Yet, various technical and institutional constraints challenge the productivity of the animals (Shapiro et al., 2017). Among other things, scarcity and fluctuating feed supply, which results in a negative feed balance, particularly during the dry season, is a major technical issue that hinders the sustainable performance of ruminant livestock (FAO, 2018; Shapiro et al., 2017).

Ruminant farming in many areas of Ethiopia is increasingly dependent on supplementary feeding, especially in high-energy breeding seasons and critical periods of drought. However, like most farmers in the tropics and subtropics, small farmers in Ethiopia cannot afford concentrated feeds and therefore rely almost exclusively on locally available alternative feeds to supplement their herd of ruminants (Franzel et al., 2014; Kodzo et al., 2018; Shapiro et al., 2017). Filleau et al. (2018) noted the need to use new alternative feeds for livestock feeding to improve feed supply and address feed billing and other feed production challenges for ruminants.

Fodder trees and shrubs are important for ruminant nutrition in the tropics due to their intrinsic advantages such as acceptance, adaptability, sustainability, and multifunctionality (Fadiyimu et al., 2011; Franzel et al., 2014). Most forage trees and shrubs have broad ecological adaptation and can grow in a variety of soils with different land use (Franzel et al., 2014; Lawal et al., 2020). They have a deep root system that can exploit water far from the soil surface and keep their leaves green during critical dry periods and contribute to a sustainable forage supply (Franzel et al., 2014). They have multiple functions, providing products such as masts and/or poles for construction, firewood, charcoal, rubber, and so forth and services such as shade, stability, soil fertility, and so forth, making them an integral part of the agricultural system (Franzel et al., 2014; Yisehak & Janssens, 2013). The leaves and pods/fruits of forage trees and shrubs are rich in nutrients and are valued by various ruminants (Ali et al., 2020; Woldemariam & Gebremichael, 2015) and therefore have the potential to partially or completely replace feed concentrate (Franzel et al., 2014). Several studies have shown that the inclusion of the leaves and pods/fruits of fodder trees and/or shrubs in the fibre-based diet of ruminants improves feed intake, digestibility, growth, and productivity performance (Hlatini et al., 2016; Makau et al., 2020; Shenkute et al., 2012).

Ethiopia has a diverse agroecological zones blessed with a variety of indigenous legume fodder trees and shrubs (ILFTS) integrated into various land uses (Franzel et al., 2014; Tesema et al., 1993). Farmers and herdsmen have a long tradition of using ILFTS as an integral part of their way of life for forage and other purposes. Yet, these plants were not rated due to the insufficiency of information. Therefore, this study was done to identify ILFTS and to assess their diversity and distribution in terms of agroecology and land use systems in the Gamo landscape in Ethiopia.

2 | MATERIALS AND METHODS

2.1 | Description of the study area

Gamo zone is among the 13 zones in SNNPRS in Ethiopia located at 437 km south of Addis Ababa and 275 km south west of Hawassa. The total area of the zone is estimated to be 12,581.4 km$^2$ and consists of 14 districts and four town administrations. The total population of the zone is estimated about 1,597,767 with average population density of 80 inhabitants/km$^2$. The zone lies at 5°57’–6°71’ N and 36°37’–37°98’ E and an altitude ranging between 746 and 3478 m above sea level, with mean minimum and mean maximum temperature ranging between 10 and 20°C and 25 and 30°C, respectively. The area is characterised by a bimodal rainfall with a mean annual rainfall above 900 mm. The terrain has undulating feature that favours the existence of different agro-climatic zones in the near proximity ranging from dry lowland to wet highland.

2.2 | Sample site selection and sample size determination

A multistage sampling procedure was held to select respondent households. In the first stage, a representative three agroecological zones were selected following stratified purposive sampling technique. In the second step, 18 farmers’ administrations (study sites) were chosen based on livestock population and diversity, retentiveness of mixed crop-livestock farming systems, crop diversification, proximity, and transportation infrastructure. Respondent households were chosen in the third stage based on the results of a preliminary survey, which revealed the households practice the feeding of ILFTS. Using the
probability proportional to size sampling technique, the sample size was determined (Cochran, 1977) as follows:

\[ n_0 = \frac{Z^2 \times (P \times q)}{d^2}, \]

where

- \( n_0 \) = desired sample size according to Cochran when population is greater than 10,000;
- \( Z \) = standard normal deviation (1.96 for 95% confidence level);
- \( P \) = 0.2 (proportion of population to be included in sample, i.e. 20%);
- \( q = 1 - P \);
- \( N \) = total number of populations;
- \( d \) = degree of accuracy desired (0.05).

### 2.3 Identification of ILFTS species

Data collection was performed after a verbal agreement was made with the agricultural and locality administrative offices and target farmers of the research. In each agroecological zone, an interview was conducted with key informants (model farmers, elders, and development agents) to produce information about ILFTS and their respective socio-economic values in the region. The study involved land uses (grazing land, farmland, area closures, and homestead) commonly used for animal feed production. A household survey was used because it provides more information about ILFTS and their socio-economic value than the field survey (Okoli et al., 2003). Data on socio-economic characteristics of households and information related to ILFTS such as the major types of ILFTS, the feeding practice of ILFTS to ruminants, the type and parts of ILFTS preferred by livestock, the propagation and management method of ILFTS, the purpose of feeding ILFTS to ruminants and other livestock, and patterns on the use of ILFTS during different seasons of the year were collected with a semi-structured questionnaire. Focus group discussions with a group of farmers (10 participants) selected based on their best breeding performance in each agroecological zone were organised separately to supplement the questionnaire-based data. In addition, a field study was conducted and herbarium samples were collected per species for identification and/or confirmation of scientific names.

### 2.4 The diversity of ILFTS

#### 2.4.1 Sampling technique and data collection

The study area is divided into four tiers within each agroecological zone, namely homestead, farmlands, area closure, and communal grazing area, according to land use for the location of the sample plot. Five 20 m × 20 m main plots and 1 m × 1 m subplots were randomly established in each land use in each agricultural zone with a minimum distance of 100 m between any two plots (Jimoh & Lawal, 2016). Numbers of individual ILFTS with a diameter at breast height (DBH) ≥5 cm were counted in the main plot and those below 5 cm DBH were counted in 1 m × 1 m subplots and recorded on a species diversity sheet. The species richness index was calculated using the following equation, which is the number of ILFTS species present in a particular plot:

\[ S = \sum n, \]

where \( S \) is species richness and \( n \) is the number of ILFTS species in a given plot. Species diversity was computed using the Shannon–Wiener diversity index as follows:

\[ H' = -\sum_{i=1}^{n} P_i \ln(P_i), \]

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

### 2.5 Statistical analysis

The collected data were coded and tabulated for analysis. Data about the household socio-economic characteristics, the major ILFTS species and their niches, significant ILFTS goods and services, and the propagation and management of ILFTS were analysed by using descriptive statistics. Data about the species richness and diversity indices of ILFTS were subjected to one-way analysis of variance (ANOVA) with the following model:

\[ Y_{ij} = \mu + \alpha_i + \beta_j + \epsilon_{ij}, \]

where \( Y_{ij} \) is the diversity of ILFTS, \( \mu \) is the overall mean, \( \alpha_i \) is the \( i \)th effect of altitude/agroecological zone, \( \beta_j \) is the \( j \)th effect of land uses, and \( \epsilon_{ij} \) is the experimental error. When the analysis of variance revealed the existence of significant difference among means, Tukey pairwise comparison test was used to separate significant means. Significant difference was declared at \( p < 0.05 \). R statistical software version 4.0.2 program with vegan package version 2.5-7 and AOV1R package version 0.1.0 were used for ANOVA of the diversity and species richness of ILFTS, respectively.

### 3 RESULT

#### 3.1 Socio-economic characteristics of the respondents

A total of 273 herders with extensive knowledge of native forage and legumes (ILFTS) were interviewed for the study, of whom 95.2% were male and 4.8% were female, although no female respondent was representing the highland (Table 1). Likewise, the profile of the respondents’ age categories showed a gap, with the majority (41.8%) being 41–50 years, followed by those over 51 years. Similarly, the diverse educational background was detected among the respondents in the study where the majority were in grade 5–8 (24.5%), followed by...
illiterate (23.1%), and only 1.8% were above grade 12. The land holdings of the majority of the respondents of the study were greater than 1 ha (33.7%), of which most were lowland dwellers (21.6%), followed by 0.51–1 ha (28.9%) where the midland inhabitants were dominant, and 28.2% of the respondents had 0.26–0.5 ha of landholdings.

### 3.2 Identified ILFTS

The study identified approximately 21 native legume fodder trees and shrubs (ILFTS), of which 16 were trees and the remaining five were shrubs (Table 2). Most ILFTS have broad agro-climatic adaptation and are therefore grown in multiple niches (Table 3). In the study, nine ILFTS species, namely *Acacia tortilis*, *Tamarindus indica*, *Aeschynomene elaphroxylon*, *Acacia senegal*, *Acacia sieberiana*, *Dichrostachys cinerea*, *Acacia nilotica*, *Acacia drepanolobium*, and *Acacia brevispica* grew only in the lowlands; however, *Acacia seyal*, *Acacia albida*, *Acacia polyacantha*, *Acacia hockii*, *Acacia mellifera*, *Piliostigma thonningii*, and *Acacia lahai* were common in both the lowlands and the midlands. [Correction added on 4 July 2022, after first online publication: The term ‘highlands’ was changed to ‘midlands’ in the preceding sentence.] Five species, namely *Acacia abyssinica*, *Millettia ferruginea*, *Albizia schimperi*, *Aeschynomene gal*, and *Erythrina brucei*, and *Erythrina abyssinica*, inhabited the middle and upper regions (Table 3).

The study found that most of the ILFTS provide multiple functions such as nutrition, local construction posts and poles, firewood, charcoal, traditional medicine, fencing, bee feed, the tool handler, soil fertility and stability, farming tools, shad, local furniture, canoeing, animal shelters, construction, and mulch, and thus are an integral part of the agricultural system in all agroecological zones (Table 2). Incorporating ILFTS into farmland has increased yields through improved soil fertility and stability, as the study shows. In particular, the respondents who planted *Acacia albida* (low and medium land) and *Acacia abyssinica* (medium and high land) trees in their farmland reported improved crop yields without any negative effect on the crops grown below. Also, lowland interviewees reported that ILFTS, namely *Acacia tortilis*, *Acacia polyacantha*, *Tamarindus indica*, *Acacia senegal*, *Acacia nilotica*, and *Acacia mellifera*, had a shading effect on farmland so that branch pruning was necessary to ensure high crop yield; however, they were successful in home growing, as they were often needed for the shed (Table 3).

A wide experience with the use of ILFTS for local construction depending on the nature of the tree/shrub was reported by the respondents. The woods of *Acacia lahai*, *Acacia nilotica*, *Acacia senegal*, *Acacia mellifera*, *Acacia brevispica*, and *Dichrostachys cinerea* resist decay and termite and hence preferred to make pole and/or post for local construction as reported by the respondents in lowland and midland districts (Table 2). Moreover, the tough *Acacia bark* was used to make fibre for local construction. The light dry wood of *Aeschynomene elaphroxylon* was used for making canoes, and fishing boats in Mirab-Abaya and Ariba-Minch zuria districts. It was also used to make local furniture and house utensils. *Acacia lahai*, *Acacia nilotica*, *Acacia mellifera*, *Acacia senegal*, and *Tamarindus indica* have been used to make implement handles and/or farm implements such as the plow and yoke of an ox.

All identified ILFTS species provide food for bees, as reported by respondents (Table 2). However, *Acacia mellifera*, *Acacia senegal*, *Acacia tortilis*, and *Acacia abyssinica* were very popular with bees and yielded high-quality honey. The use of ILFTS for animal feed depends on the availability and preference of animal species in the study area. Nearly all ILFTS species were valued by goats, although sheep enjoyed a
| Botanical name          | Family name     | Vernacular name          | Plant habit | Favoured plant part | Livestock species          | Feeding method | Major products and services          |
|------------------------|-----------------|--------------------------|-------------|---------------------|---------------------------|----------------|--------------------------------------|
| *Acacia tortilis*      | Fabaceae        | Shara/Caca/Odoro         | Tree        | Leaf and pod        | Goat, sheep, and cattle    | Lop, RB, SheP | FuelW, Char, BeeFo, SheT, pole, post, ToolH, SoilF, SoilS |
| *Acacia seyal*         | Fabaceae        | Pule/Pulesa/Polanto      | Tree        | Leaf, twigs, and pod | Goat and sheep             | Lop, RB        | FuelW, BeeFo, Char, SoilS, FenceM, SoilF, post |
| *Acacia albida*        | Fabaceae        | Odoro                    | Tree        | Leaf and pods       | Cattle, goat, and sheep    | Lop, RB SheP   | FuelW, SoilF, BeeFo, SheT, Char, SoilS, pole, post |
| *Tamarindus indica*    | Fabaceae        | Kori                     | Tree        | Leaf, twigs, and fruit | Goat, sheep, and cattle    | CC, Lop, RB    | FuelW, Tim, Char, SheT, ToolH, BeeFo, SoilF, food, FarmU, SoilS, pole, post |
| *Aeschynomene elaphroxylon* | Fabaceae                | Soakke                   | Tree        | Leaf, twigs         | Goat and sheep             | Lop, RB, CC    | FishingC, carving, Furniture, SoilS, Con |
| *Acacia polyacantha*   | Fabaceae        | Dalame/Damale            | Tree        | Leaf, twig, and pods | Goat and sheep             | Lop, CC, RB    | FuelW, Char, Tim, TradM, SheT, BeeFo, SoilF, SoilS, post, FenceM |
| *Acacia senegal*       | Fabaceae        | Gamo Chaliga/Chalike     | Tree        | Leaf and pod        | Goat and sheep             | Lop, CC, RB    | FuelW, Char, Tim, Pole, Post, ToolH, TradM, SheT, BeeFo, SoilF, FenceM, AmiEn |
| *Acacia sieberiana*    | Fabaceae        | Chaliga                  | Tree        | Leaf, twig, and pod | Goat and sheep             | Lop, CC, RB    | FuelW, Char, Tim, TradM, SheT, BeeFo, SoilF, FenceM, post |
| *Acacia hockii*        | Fabaceae        | Kichinda                 | Shrub       | Leaf and pod        | Goat and sheep             | Lop, CC, RB    | FuelW, Char, pole, post, TradM, SheT, BeeFo, SoilF |
| *Dichrostachys cinerea* | Fabaceae          | Gargaro                  | Shrub       | Leaf, twigs, and pods | Cattle, goat, and sheep    | Lop, CC, RB    | FuelW, post, FarmT, ToolH, TradM, BeeFo, SoilF, SoilS |
| *Acacia mellifera*     | Fabaceae        | Elanje                   | Shrub       | Leaf, twigs, and pod | Goat and sheep             | Lop, SheP, RB  | FuelW, SoilF, SoilS, BeeFo, SheT, AnimEn, post, pole, ToolH. |
| *Acacia nilotica*      | Fabaceae        | Sata                     | Tree        | Leaf and pods       | Goat and sheep             | Lop, RB        | FuelW, Char, SheT, BeeFo, SoilF, Con, FarmU, ToolH, post, pole |
| *Acacia drepanolobium* | Fabaceae        | Chacha/Gugunta           | Shrub       | Leaf, twigs, pods, and young galls | Goat and sheep | Lop, RB | FuelW, TradM, BeeFo, pole SoilS, SoilF, fenceM |
| *Piliostigma thonningii* | Fabaceae                | Kalkala/Galigathe/Yekola waniza | Tree       | Leaf, twigs, and pods | Cattle, sheep, and goat    | Lop, CC, RB    | FuelW, Con, FarmU, TradM, SoilF, shedT, Cattle, BeeF, pole, mulch, BeddingLS |
| *Acacia lahai*         | Fabaceae        | Burigudo                 | Tree        | Leaf, twig, and pod | Goat and sheep             | Lop, RB        | FuelW, Char, Tim, SoilF, FarmU, toolH, TradM, Con, shedT, BeeF, pole, post |
| *Acacia brevispica*    | Fabaceae        | Hota/Wortafa/Zerigene    | Shrub       | Leaf and pod        | Cattle, sheep, and goat    | Lop, RB        | FuelW, stick, BeeFo, LiveF, SoilF, SoilS |

(Continues)
significant number of species [Correction added on 4 July 2022, after first online publication: The preceding sentence was updated]. However, cattle mainly eat the leaves of the less thorny species, pods, and fruits of ILFTS (Table 2). It is reported that some ILFTS have been used for feeding livestock for unique purpose. Farmers in the Mirab-Abaya district, for example, believe that feeding *Dichrostachys cinerea* leaves to cows increases milk production and helps expel the placenta so that they can collect manually and provide it immediately after delivery.

ILFTS have been used for traditional medicine, as reported by respondents. For example, extracts from a young shoot of *Erythrina brucei* and *Erythrina abyssinica* have been used to treat lice and itching in cattle in the Geresse district. An infusion of the bark or leaves of *Dichrostachys cinerea* is used to treat intestinal disorders and tonsilitis in humans, while the leaves are used for the treatment of internal parasites in cattle in Mirab-Abaya district. Similarly, the leaves of *Acacia nilotica*, *Acacia polyacantha*, and *Acacia senegal* have been used to treat internal parasites of livestock in lowland and mid-altitude areas. An infusion made from the fruit of *Tamarindus indica* was used as a drink to expel roundworms in humans, while the leaf was used to treat internal parasites in cattle. An infusion of *Piliostigma thonningii* leaves was used to treat gastritis and heartburn in humans, while the bruised leaves were used mixed with water to treat the cattle swollling. The leaves of *Erythrina abyssinica*, *Erythrina brucei*, *Albizia schimperiana*, and *Millettia ferruginea* were used for mulching and bedding for livestock. *Erythrina abyssinica* and *Erythrina brucei* were commonly used as fences and hedges in lowland and midland areas, while the seeds of *Millettia ferruginea* were used to poison fish.

According to the respondents, ILFTS have given year-round fodder to cattle, albeit some shade their leaves seasonally. *Acacia albida* and *Acacia mellifera*, for example, shade their leaves in June and August, respectively, whereas *Erythrina abyssinica* and *Erythrina brucei* in January and February. However, all respondents stated that the best time to utilise ILFTS for cattle feeding was from December to June when the grass begins to wither owing to the dry season. Lowland and midland responders, in particular, stated that ILFTS were crucial in sustaining significant feed shortages throughout the dry season (Table 2).

### 3.3 Propagation method and management practice of ILFTS

The study indicated seed, seedling, stem cutting, and wilding were the prominent propagation methods of ILFTS in Gamo landscape. The term ‘wilding’ is used to express the plants that are not cultivated (grow naturally). Among the identified ILFTS, 17 species were propagated via wilding, and two species, namely *Millettia ferruginea* and *Albizia schimperiana*, via seed and seedling in the study area. *Erythrina abyssinica* and *Erythrina brucei* have been wildly propagated via stem cutting and hence used for live fence and hedgerow in the midland and highland areas. All respondents reported that except for the above mentioned species (*Millettia ferruginea*, *Albizia schimperiana*, *Erythrina abyssinica*, and *Erythrina brucei*), farmers usually did not plant ILFTS; however, they managed the seedlings that emerged to grow and take advantage of it ultimately. Similar results were reported by Meaza and Demssie (2015), who stated that natural seedlings from soil seed banks and

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**TABLE 2** (Continued)

| Botanical name     | Family name | Vernacular name               | Plant habit | Favoured plant part | Livestock species             | Feeding method       | Major products and services |
|--------------------|-------------|--------------------------------|-------------|---------------------|-------------------------------|----------------------|-----------------------------|
| *Acacia abyssinica*| Fabaceae    | Odoro/Chacha/ Dhaze/Bazra grar | Tree        | Leaf and fruit      | Cattle, goat, and sheep       | Lop, RB SheP         | FuelW, Char, post, TradM, pole, post, SheT, BeeFo, SoilF, FenceM |
| *Millettia ferruginea* | Fabaceae | Zaage/Birbira               | Tree        | Leaf                | Cattle, goat, and sheep       | Lop, CC, RB           | FuelW, Tim, con, BeeF, shedT, FarmU, ToolH, fishing, pole, post, mulch, BeddingLS |
| *Albizia schimperiana* | Fabaceae | Pezo/Pishto/ Sesa            | Tree        | Leaf and pod        | Cattle, sheep, and goat       | Lop, CC, RB           | FuelW, FarmU, post, Char, TradM, SheT, BeeFo, SoilF, LiveF, Tim, ShedT |
| *Erythrina brucei* | Fabaceae    | Borto/Korch                  | Tree        | Leaf, fruits, and twigs | Cattle, goat, and sheep       | Lop, CC              | FuelW, carving, TradM, mulch, shedT, LiveF, SoilF, BeeF, mulch, BeddingLS |
| *Erythrina abyssinica* | Fabaceae | Borto/Korch                 | Tree        | Leaf, fruits, and twigs | Cattle, goat, and sheep       | Lop, CC              | FuelW, carving, TradM, mulch, shedT, LiveF, SoilF, BeeF, mulch, BeddingLS |

Abbreviations: AniE, animal enclosure; BeddingLS, bedding livestock; BeeF, bee forage; CC, cut and carry; Char, charcoal; Con, construction; FarmU, farm utility; FenceM, fence material; FishingC, fishing canoes; FuelW, fuel wood; LiveF, live fence; Lop, lopping; RB, range browsing; ShedT, shade tree; SoilF, soil fixation; SoilS, soil stabilisation; Tim, timber; ToolH, tool handles; TradM, traditional medicine.
home nurseries are the main sources of seedlings of fodder trees across the communities in the northern highlands of Ethiopia. Conversely, pruning and weeding were the major management practices identified for ILFTS as the study indicated. Both pruning and weeding have been practiced on 16 species of ILFTS, though no management practice has been reported on five species since it did not inhabit the land uses commonly owned by the respondents (Table 4). For instance, *Acacia brevispica*, *Acacia seyal*, *Aeschynomene elaphroxylon*, *Acacia drepanolobium*, and *Dichrostachys cinerea* are usually grown in area closure and other protected areas and hence received no management. Weeding and protection from herbivores are the common management techniques for fodder trees grown in the homestead in the northern highlands of Ethiopia (Meaza & Demssie, 2015).

### 3.4 The diversity of ILFTS with the land uses and agroecological zones

The diversity and species richness of ILFTS varied significantly \((p < 0.05)\) with land uses and agroecological zones in Gamo area (Tables 5 and 6). The mean species richness and diversity indices of the highland observed a significant difference \((p < 0.05)\) with the lowland and midland; however, the lowland observed no significant difference with the midland (Table 6). The highest mean species richness (5.6) and diversity indices (1.59) of ILFTS were exhibited in lowland area closure (LAC) followed by midland area closure (MAC) which valued 1.2 and 4, respectively (Table 5). However, highland homestead (HHS) and highland grazing land (HGL) exhibited no diversity of ILFTS. Similarly, species richness and diversity indices were highest in the plots in LAC, followed by MAC, whereas HHS and HGL plots exhibited the least (Figure 1). The three LAC plots among the five plots exhibited above 1.5 Shannon–Weiner diversity indices, contrary to HHS and HGL where all the plots exhibited no diversity (Figure 1). Area closure exhibited higher diversity and species richness in all agroecological zones followed by the farmlands compared to other land uses in the midland and highland (Table 5). However, LGL exhibited the highest species richness and diversity indices compared to the fellow land uses in the midland and highland, respectively. The least species richness and diversity indices were observed in the homestead and the grazing land of the highlands which exhibited no diversity (Figure 1).

Of the total plots, two-thirds exhibited below mean average species richness (2.38) and diversity indices (0.61); however, only three plots exhibited above 5 species richness and 1.5 diversity indices, of which all allotted in LAC. MAC exhibited above 4 species rich-
TABLE 4  propagation and management of ILFTS in Gamo landscape

| Botanical name          | Propagation method | Management practices |
|-------------------------|--------------------|----------------------|
|                         | Seed   | Seedling | Stem cutting | Wilding | Pruning | Weeding | None  |
| Acacia tortilis         | –      | –       | –            | +       | +       | +       | –     |
| Acacia seyal            | –      | –       | –            | +       | –       | –       | –     |
| Acacia albida           | –      | –       | –            | +       | –       | –       | –     |
| Tamarindus indica       | –      | –       | –            | +       | +       | +       | –     |
| Aeschynomene elaphroxylon| –      | –       | –            | +       | –       | –       | +     |
| Acacia polyacantha      | –      | –       | –            | +       | +       | +       | –     |
| Acacia senegal          | –      | –       | –            | +       | +       | +       | –     |
| Acacia sieberiana       | –      | –       | –            | +       | +       | +       | –     |
| Acacia hockii           | –      | –       | –            | +       | +       | +       | –     |
| Dichrostachys cinerea   | –      | –       | –            | +       | –       | –       | +     |
| Acacia mellifera        | –      | –       | –            | +       | +       | +       | –     |
| Acacia nilotica         | –      | –       | –            | +       | +       | +       | –     |
| Acacia drepanolobium    | –      | –       | –            | +       | –       | –       | +     |
| Piliostigma thonningii  | –      | –       | –            | +       | +       | +       | –     |
| Acacia lahai            | –      | –       | –            | +       | +       | +       | –     |
| Acacia brevispica       | –      | –       | –            | +       | –       | –       | +     |
| Acacia abyssinica       | –      | –       | –            | +       | +       | +       | –     |
| Millettia ferruginea    | +      | +       | –            | +       | +       | +       | –     |
| Albizia schimperiana    | +      | +       | –            | +       | +       | +       | –     |
| Erythrina brucei        | –      | –       | +            | +       | +       | +       | –     |
| Erythrina abyssinica    | –      | –       | +            | +       | +       | +       | –     |

Abbreviations: +, yes; –, no.

ness and 1.1 diversity indices in three plots which were next to LAC (Figure 1).

The study revealed about one-third (19 plots) of the total plots exhibited no diversity, of which 10 plots were from two land uses, namely HGL and HHS, and the remaining were from HFL, HAC, MGL, LFL, and LGL (Figure 1).

4 DISCUSSION

The study indicated that agroforestry was the common practice where ILFTS were among the preferred trees embraced under the different land uses and it delivers several functions. ILFTS allowed the use of abandoned and marginal areas in land uses and enhanced production via providing multiple products and services and optimising the efficient utilisation of the available resources. However, the availability and diversity of the ILFTS varied depending on the land use and agroecological zones.

The study involved 273 respondents, even though the majorities were males and older age group. Probably the reasoned sampling procedure designed to select the experienced respondents might favour them. Of course, herding is the job of males in the study area, which might explain the reason for the higher proportion of the male respondents in the study. Similarly, the low educational level of the respondents might be due to the collective hurdles such as the distance of schools, poor transport facility, and the poor livelihood condition which trigger the children to serve their families rather than go to school and partially affect their access to education.

The current study identified about 21 species of ILFTS that have been the integral constituent of the land use and recognised for their multiple functions in all agroecological zones. Agroforestry was the common practice in the study area where the ILFTS were among the preferred plants for their multiple benefits. Farmers usually planted and nurtured ILFTS in abandoned areas, marginal lands, sloppy areas, along the boundaries, and other areas in land use as an essential component of the system depending on the plant nature and reaped their multiple benefits. ILFTS enabled efficient use of the limited land resource and contributed to improving productivity. Among other benefits, farmers used ILFTS for the treatment of various illnesses in humans and livestock, as the study revealed. Lelamo (2021) substantiated the medicinal value of some indigenous multipurpose trees in Ethiopia. Tannins and other secondary metabolites in fodder trees and shrubs contribute to the anthelmintic (Assefa et al., 2018; Hoste et al., 2011; Maroyi, 2017) and antimicrobial property (Assefa et al., 2017). Several authors described the multipurpose of legume fodder trees for their services and products such as biological nitrogen fixation, diversification of livestock’s diets, shades, carbon sequestration, bee forage, timber, charcoal, firewood, biodiversity conservation,
### Table 5

| Land use  | Shannon–Wiener diversity index ($H'$) Mean | Richness Mean |
|-----------|------------------------------------------|--------------|
| HGL       | 0.000$^a$                               | 1.000$^a$    |
| HHS       | 0.000$^a$                               | 1.000$^a$    |
| HFL       | 0.179$^{ag}$                            | 1.800$^{ag}$ |
| HAC       | 0.290$^{ag}$                            | 1.600$^{ag}$ |
| MGL       | 0.323$^{ag}$                            | 1.600$^{ag}$ |
| LFL       | 0.393$^{cd}$                            | 1.600$^{cd}$ |
| LGL       | 0.543$^{cd}$                            | 1.800$^{cd}$ |
| MHS       | 0.769$^{cd}$                            | 2.600$^{cd}$ |
| LHS       | 0.874$^g$                               | 2.800$^g$    |
| MFL       | 1.091$^{bc}$                            | 3.200$^{bc}$ |
| MAC       | 1.201$^b$                               | 4.000$^b$    |
| LAC       | 1.588$^a$                               | 5.600$^a$    |
| SD        | 0.534                                   | 1.427        |
| p-value   | 0.000                                   | 0.000        |
| Significance level | ***                | ***          |

Note: The same column bearing different superscript differ significantly.

Abbreviations: HAC, highland area closure; HFL, highland farmland; HGL, highland grazing land; HHS, highland homestead; LFL, lowland farmland; LGL, lowland grazing land; LHS, lowland homestead; MAC, midland area closure; MFL, midland farmland; MGL, midland grazing land; MHS, midland homestead.

**Significant at 0.001 level.**

### Table 6

| Agro-ecology | Shannon–Wiener diversity index ($H'$) Mean | Richness Mean |
|--------------|------------------------------------------|--------------|
| Lowland      | 0.849$^a$                               | 2.95$^a$     |
| Midland      | 0.846$^a$                               | 2.85$^a$     |
| Highland     | 0.117$^b$                               | 1.35$^b$     |
| SD           | 0.534                                   | 1.427        |
| p-value      | 0.000                                   | 0.000        |
| Significance level | ***                | ***          |

Note: The same column bearing different superscript differ significantly.

**Significant at 0.001 level.**

Traditional medicine, pole and post for construction, reduction of greenhouse gas emission, and fence, among others (Dubeux Junior et al., 2017; Franzel et al., 2014; Lelamo, 2021; Meaza & Demsie, 2015). Some of the ILFTS identified in the study resemble those characterised by some authors in Ethiopia (Abera & Yasin, 2018; Derero & Kitaw, 2018; Lelamo, 2021; Shenkute et al., 2012; Sisay et al., 2017; Weldemariam & Gebremichael, 2015) and other east Africa countries (Mtengeti & Mhelela, 2006; Rubanza et al., 2007) probably due to the similarity of the agroclimatic zone. Various scholars reported different numbers of fodder trees and shrubs in their research works. For instance, Kodzo et al. (2018) reported 34 multipurpose fodder trees and shrubs in four land uses, which is higher than the current study, though (Ayenew et al., 2021) 16 in two niches, and (Chepape et al., 2011; Marius et al., 2017) 17 species, which is lower. The variation in the number of fodder trees and shrubs in different studies might be associated with the scope of the research, the type of land use, area of land coverage, and agroecological zone of the study. In the current study, ILFTS have been integrated with different land uses, namely homesteads, farmlands, grazing lands, and area closure in all agroecological zone, and they complement the system and improve productivity. Being the important element of the land-use system, fodder trees enhance biodiversity, which in turn promotes productivity via improving ecosystem functioning and increasing the growing season (Altieri, 1999; Oehri et al., 2017). Farmers in Ethiopia (Guyassa et al., 2014; Meaza & Demsie, 2015; Sisay & Mekonnen, 2013) and other sub-Saharan countries (Coulibaly et al., 2021; Lawal et al., 2020) nurture fodder trees and shrubs in various land-use systems, owing to exploit their multiple benefits. Franzel et al. (2014) described East African farmers’ plant fodder trees in abandoned land such as in hedges, around the homestead, along field boundaries, or along the contours to avoid land competition with annual crops. They also noted...
that farmers in the Sahel do not plant fodder trees but purposely allow the seedlings emerged to grow on their farms to exploit the fodder, which agrees with the current finding where the propagation of the majority of ILFTS was via wilding (Table 4).

The current study shows that species richness and diversity of ILFTS varied significantly ($p < 0.05$) for land use and infers the impact of land use on the farmer species preference and utilisation. Farmers' preference of ILFTS in the land use with agroecological zone was based on the plant nature and its intended relative benefit as the study unveiled. Farmers' indigenous knowledge and experience determine the selection and preference of trees species in the agroecosystems (Legesse & Lemage, 2018; Meaza & Demssie, 2015). For instance, in the current study, Erythrina brucei was found dominant in the homestead, farm-land, and grazing land of the highlands since it has been used widely for fences and hedge trees. Furthermore, Acacia tortilis, Tamarindus indica, Acacia senegal, Acacia sieberiana, and Acacia nilotica were managed to grow in the homestead often in the lowlands since they are needed for shelter, whereas Acacia albida and Acacia polyacantha (low-land and midland), Acacia Abyssinica (midland and highland), and Acacia lahah and Albizia schimperiana (midland) were the preferred species in the farmlands due to its spectacular ability to improve soil fertility and stability and increase crop yield. In fact, most ILFTS have the potential to improve soil fertility and stability. In agreement with the current study, Hadgu et al. (2009) reported higher barley yield when incorporating Acacia albida in farmland in Tigray, whereas Acacia abyssinica was prominent in crop-livestock farming in Borodo watershed for its ability to enhance soil fertility and provide additional services such as shade, bee forage, and products such as dietary gum (SiSAY & Mekonnen, 2013). Legume plants enrich soil fertility via fixing atmospheric nitrogen through symbiotic rhizobia soil bacteria which enables them to tolerate infertile sites and produce protein-rich fodder without high inputs of artificial nitrogen fertiliser (Singh et al., 2018). The biological nitrogen fixation by tree legumes is estimated from 24 to 304 kg N/ha/year for different species and locations; however, the typical range is from 50 to 150 kg N/ha/year (Dubeux Junior et al., 2017).

The midland farmlands in the current study exhibited higher species richness and diversity indices compared with grazing areas and home-steads in midland and highland areas, which might be associated with the typical physiognomies of legume plants improve soil fertility and stability which enhances crop yield persuades the farmers to incorporate ILFTS into the farmland leverage for higher diversity. Acacia abyssinica, Acacia albida, Albizia schimperiana, and Erythrina brucei were the preferred trees that improve soil fertility and stability in the farmlands in the midland and highland. Habte et al. (2021) found a higher diversity of indigenous tree species in home gardens and cropland compared with the grazing land and woodlots in southwest Ethiopia, which partially agrees with the current study. Similarly, Coulibaly et al. (2021) in Gana exhibited higher diversity indices of the cropland in Bawku and Pusiga sites, although it was observed low in Binduri and Garu sites compared with the rangeland. However, Lawal et al. (2020) reported the least species richness of indigenous fodder trees in the farmland compared with the farm fallow, homestead, and cattle route.

The mean species richness and diversity indices of area closure unveiled significant difference ($p < 0.05$) compared with other land use (grazing land, homestead, and farmland) in all agroecological zones explained the level of protection while the lower in grazing lands explained the level of exploitation by human being and livestock. Area closure received protection from human and animal impact and hence revealed higher species richness and diversity indices. Area closure was used for forage production during the critical dry season with a cut and carry system; otherwise, it was a reserved area for most of the year and hence maintained its higher diversity. In agreement with the current study, Guyassa et al. (2014) revealed forest land exhibited higher species richness of fodder trees and shrubs compared with cropland and home garden in Tigray region. Likewise, Coulibaly et al. (2021) displayed that the forest reserve exhibited the highest diversity indices compared with the cropland and rangeland in all study sites. Area closure has no human and animal interference unlike the other land uses, which limits the impact of anthropogenic and livestock factors that induce the degradation of fodder trees and shrubs (Birhane et al., 2007). On the other hand, the grazing lands have been entertained freely by human beings and livestock which were the factors for the degradation of the biodiversity, describing the reason for low species richness and diversity indices. Grace and Tamara (2014) noted that anthropogenic factors induce 18.3% reduction in species richness. They also described that land-use change and species invasions had a prevalent impact on species richness causing 24.8% and 23.7% decline, respectively. Some plots and land uses, namely HGL and HHS, have revealed zero Shannon–Weiner diversity indices, which implies that the ILFTS counted belong to the same species (Figure 1). Farmers in the highland prefer trees having high economic importance such as Eucalyptus species and Acacia decurrens in farming systems, which might be the reason for low diversity indices and species richness of ILFTS. Meaza and Demssie (2015) described that farmers' willingness to grow trees depends on their perceived advantages of trees.

Species richness and diversity indices of LGL in the current study revealed a significant difference ($p < 0.05$) with HGL, though it observed higher numerical value with MGL and explained the extensive grazing area of the lowland inhabited by diverse ILFTS species relative to the fellow land uses in respective agro-ecologies leverage to sustain better the impact of anthropogenic and animal factors that induce degradation. The species of ILFTS that inhabited the lowland, midland, and highland in the study area were 16, 11, and five, respectively; hence, the higher species diversity of the lowlands might favour the LGL better to sustain the degradation pressure compared with the fellow land uses. Coulibaly et al. (2021) reported higher diversity indices of rangeland in Binduri and Garu sites, although it was observed least in Bawku and Pusiga compared with cropland in Gana.

5 Conclusion and Recommendation

ILFTS have been an integral component of the farming system which complements the land uses and enhances their function. About 21 ILFTS species which deliver multiple benefits have been integrated into various land uses such as homesteads, farmlands, area closures, and grazing lands identified across all agroecological zones. ILFTS were among the preferred agroforestry trees making use of abandoned
areas, sloppy areas, and marginal areas in land uses and hence improving the efficient utilisation of the limited land resource. ILFTS improved productivity via enhancing the ecosystem functioning and growing season and allowing efficient resource utilisation; however, its diversity and species richness varied with land use and agroecological zone. Farmers’ indigenous knowledge and previous experience determined the species richness and diversity of ILFTS in farmlands and homesteads; however, the level of exploitation or protection was the reason for variation in area closure and grazing lands. Therefore, understanding farmers’ indigenous knowledge and previous experience and designing policy measures that avoid inappropriate exploitation are necessary for the management and maintenance of ILFTS diversity across the land use in agroecological zones of the Gamo landscape.

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CONFLICT OF INTEREST
The authors declare no conflict of interest.

ETHICS STATEMENT
The authors confirm that the ethical policies of the journal, as noted on the journal’s author guidelines page, have been adhered to. However, the research did not involve animals but questionnaire survey, and field observation and measurement. Hence data collection was performed after a verbal agreement was made with the agricultural and locality administrative offices and target farmers of the research.

AUTHOR CONTRIBUTIONS
G.A. conceptualised the idea of the study, curated the data, performed formal analysis and investigation, designed methodology, administered the project, and wrote the original draft. Y.K. acquired funding, performed supervision, and reviewed and edited the manuscript. D.A. performed supervision. T.D. performed formal analysis.

DATA AVAILABILITY STATEMENT
The data associated with this research are available at https://zenodo.org (https://doi.org/10.5281/zenodo.5594872) and can be accessed under the condition (License) of Creative Commons Attribution 4.0 International.

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