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Diversity and ethnobotanical use-value of trees outside forests on the agricultural landscape of the Mongala Province, Democratic Republic of Congo

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Abstract Trees outside forests on agricultural land (TOF-AL) are essential for the livelihoods of rural communities in the Democratic Republic of Congo, yet their diversity, use, and management are poorly documented, particularly in Mongala province. This study aimed to characterize the diversity of TOF-AL species, quantify their ethnobotanical use values, and analyze the management strategies of local communities. We conducted ethnobotanical surveys and tree inventories in 900 agricultural plots across 45 villages in the three territories of Mongala province. The data were analyzed using diversity indices, the total ethnobotanical use value (TUV_s) index, and hierarchical clustering analysis to classify species based on their use values. We identified 136 TOF-AL species on agricultural land in Mongala, with a Shannon diversity index of 3.544. The results show that more than 62% of the total abundance is concentrated in ten most common species. The clustering analysis revealed three distinct clusters of 23 privileged species: Cluster 1 (high value for energy and construction), Cluster 2 (high value for commerce and crafts), and Cluster 3 (multifunctional species with high value for food, medicine, and commerce). The high abundance of Cluster 3 species and the rarity of Cluster 2 species indicate that use value directly influences the conservation status of the species. Our results show that the diversity and abundance of TOF-AL are the result of specific management choices guided by local ethnobotanical knowledge. Species that provide continuous and non-destructive benefits are actively conserved by farmers, while those with high commercial value are threatened by intense harvesting pressure. This study calls for the adoption of differentiated management strategies to ensure the sustainability of resources. It suggests targeted reforestation programs and economic incentives for threatened species (Cluster 2) and the strengthening of existing management practices for abundant species (Clusters 1 and 3), underscoring the importance of integrating traditional knowledge into agroforestry conservation.

Keywords Agroforestry · Conservation · Land management · Rural livelihoods · Sustainability · Traditional knowledge

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Introduction

The Democratic Republic of Congo (DRC), located in Central Africa, is a country with immense biodiversity (Ishara et al. 2022; Jocque et al. 2023), particularly tree species (Bienu et al. 2023). In this low-income country, trees, whether in forests or outside forests, are important in providing livelihood to local populations (Belcher et al. 2003; Park et al. 2019; Amuyou et al. 2021). They afford various products and services, such as construction timber, firewood, food, disease remedies, shade, and contribute to soil fertility (Tassew 2017; Yadav et al. 2017; Thapa et al. 2021; Pati et al. 2022; Kasekete et al. 2023). Beyond direct human utility, these trees are also crucial for carbon sequestration, as they play a significant role in mitigating climate change (Pandey 2002; Joshi and Singh 2020; Zomer et al. 2022).

Regarding the broad ecological and socioeconomic importance of trees in the DRC, it is necessary to understand human interactions with these vital resources. The multifaceted benefits provided by trees signifies their indispensable value (Peros et al. 2022), which naturally leads to the need to understand how human communities engage with them, manage them, and derive benefits from them. Such an examination finds its most comprehensive framework within the field of ethnobotany, which is an interdisciplinary field dedicated to understanding how various societies utilize, perceive, and manage indigenous flora, encompassing their medicinal, nutritional, material, and spiritual roles (Albuquerque et al. 2017). The foundation of ethnobotany is Traditional Plant Knowledge (TPK), which represents the accumulated wisdom, practices, and beliefs surrounding the use of plants within indigenous and traditional communities (Gupta and Wagh 2024).

Ethnobotany has significantly evolved beyond simple documentation of traditional knowledge to actively addressing pressing contemporary global issues, including biodiversity conservation, sustainable resource management, and intellectual property rights (Evans and Muir 2009; Ramirez-Santos et al. 2023). Nowadays, ethnobotany has emerged as a valuable tool in biodiversity conservation efforts, serving as a vital bridge between scientific knowledge and traditional practices (Uprety et al. 2012). By understanding how local communities use and manage plant resources, conservationists can develop more effective strategies that consider the unique cultural and ecological context of a region. This approach provides crucial insights into the complex interactions between humans and their environment, highlighting the cultural and spiritual significance of plants, which are often overlooked in conventional conservation approaches.

However, while deeply rooted in history, TPK is a dynamic system that adapts to evolving ecological conditions and societal changes (Duche-Pérez et al. 2024). Unfortunately, this adaptability also means that TPK is susceptible to erosion processes due to factors like urbanization, globalization, and shifts towards modern agricultural systems (Aswani et al. 2018). The increasing risk of losing traditional knowledge regarding the utility of plants underscores the urgency of current ethnobotanical efforts (Soelberg et al. 2016).

Given the global and regional importance of trees, the escalating threats to both floristic diversity and TPK, and the critical role of ethnobotanical studies in addressing these challenges, the specific context of Mongala Province becomes particularly urgent. Mongala province, the smallest of the 26 provinces of DRC, is characterized by a high deforestation rate, resulting in agricultural landscapes with reduced tree density (OSFAC 2020). This environmental degradation underscores the immediate need to understand the remaining tree resources, particularly "Trees Outside Forests on Agricultural Lands (TOF-AL)" (de Foresta 2017).

These remnant trees in fields and fallow lands are not only ecological remnants; they are vital components of anthropized agricultural landscapes, contributing significantly to both biological and cultural diversity. Their importance for local populations' livelihoods and climate change mitigation, as reported in other regions (Azenge and Meniko 2020), highlights their profound ethnobotanical significance. Unfortunately, there is a gap in knowledge related to their diversity and uses in this province. This lack of accurate information on their diversity, importance, and conservation status limits the development of sustainable management principles and practices. Without comprehensive data on these trees and their traditional uses, effective, evidence-based conservation and management strategies cannot be formulated. Thus, the present study constitutes a crucial step in filling this gap and enabling informed decision-making for long-term sustainability.

This study, therefore, aimed to assess the diversity and ethnobotanical use-value of TOF-AL within the agricultural landscapes of the Mongala Province and to identify patterns of use and management by local communities. Specifically, the objectives of this study were (1) to assess and compare the diversity of tree species between the three territories, and (2) to identify the use value of the TOF-AL by assessing TPK, and (3) to propose strategies for the sustainable management of these species. The findings of this study will enhance the understanding of TOF diversity, use-value, and conservation practices in the DRC. These results will contribute to promoting their conservation and sustainable management while preserving local communities' traditional knowledge and practices.

Materials and methods

Study area

The study was conducted in the Mongala Province (Fig. 1). Mongala is the smallest of the 26 provinces of DRC. Its area is estimated at 58,141 km^2. Mongala province is divided into three territories: Bongandanga, Bumba, and Lisala. All these territories are characterized by extensive forested areas (Ewango et al. 2019; Balandi et al. 2020). Administratively, each territory is subdivided into sectors or collectivities, encompassing many villages. The main vegetation types in this province are dense tropical rainforests and forests on hydromorphic soil. The soil and vegetation of Mongala are influenced by the Congo River, which crosses the province from West to East, forming two distinct physical entities. In the northern part (Bumba and Lisala), characterized by dense tropical rainforests, there are many agricultural complexes (about 22% of the area). The southern part is dominated by tropical rainforests associated with forests on hydromorphic soils along the hydrographic network (Enabel 2020). The predominant soil types of Mongala province are sandy, sandy clay, and lateritic. The soil *pH* is acidic (between 4 and 6). Its overall vegetation is the evergreen rainforest. However, several agricultural pressures have increased secondary forest areas, with a tendency towards savannah in some places (Enabel 2020). The population is primarily rural and mainly engaged in slash-and-burn agriculture for livelihood (Bosakabo 2024). Bumba is the smallest of the three territories but the most populated (Enabel 2020), where agricultural activities are particularly intense, leading to substantial deforestation (Balandi et al. 2020; OSFAC 2020). The Bongandanga territory has the lowest deforestation rate, primarily due to the lack of road infrastructure in the region. In Mongala province, local communities rely on forests for livelihood (OSFAC 2020).

The province of Mongala is characterized by a hot and humid tropical climate. With an annual average of 1680 mm, rainfall is abundant throughout the year, and only the month of January receives less than 60 mm of precipitation. Two peaks in rainfall are observed in April and August. The average temperature is 25.4 °C, with maximum temperatures reaching 32.6 °C and minimums dropping to 19.3 °C (World Bank 2025).

Sampling and data collection

Data collection was conducted in two phases between January and May 2024. The first phase consisted of an inventory of TOF-AL in farmers' fields. The second phase was a survey of the ethnobotanical use values of the TOF species identified during the first phase.

Regarding the inventory of TOF-AL, a stratified multi-stage systematic sampling design was employed. This methodology was designed not only to ensure representative sampling, but also to consider the specific socio-agricultural context of the region (Diyarzola and Bernard 2024).

First, to capture the spatial variability in species diversity of TOF-AL, a stratified random sampling approach was used to select villages. In each territory, three major road axes have been selected, and each of these was stratified based on distance from the nearest major city (Bumba, Bongandanga, or Lisala). A village was randomly selected at every 25 km interval up to a maximum distance of 125 km. This resulted in the selection of 15 villages in each territory, giving a total of 45 villages across the province. This stratification minimized potential bias related to the rural–urban gradient, ensuring the sample was representative of the various land-use intensities found within each territory.

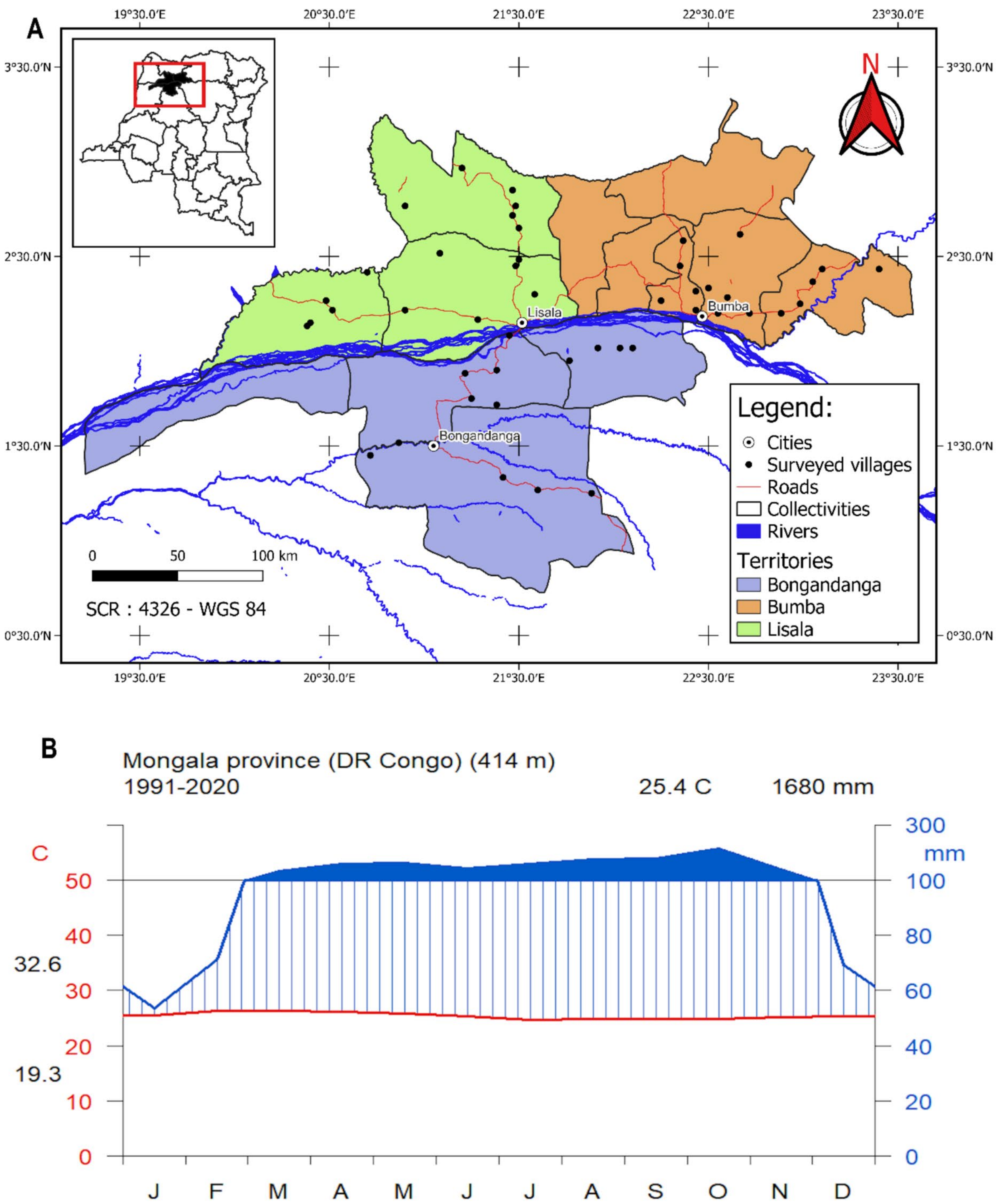

Fig. 1 Map (**A**) and climate diagram (**B**) of the study area

In the second stage, a single transect was established in each selected village. This transect was purposively selected as it corresponded to the most frequently used path by local households for accessing their agricultural fields over generations (Fig. 2). Along each of these transects, a systematic sampling method was then implemented to select the agricultural fields for inventory (Fig. 2). A number was assigned to each field encountered, and only those with an even number were chosen for the study, which ensured objectivity and minimized researcher selection bias. This process was continued until 20 fields containing TOF were inventoried per village, resulting in a total of 900 fields sampled across the province. Given that the sampling units were individual agricultural fields, the size of the inventory plots varied to accommodate the natural heterogeneity of these units. All trees encountered in the fields were identified by their local and scientific names. A counter-verification of the scientific names was subsequently carried out by comparing the local names with the list of forest species of the DRC (DIAF 2017).

After the inventory phase, a survey on the ethnobotanical use values of TOF-AL was conducted in the 45 villages. Given the lack of precise demographic data for villages in DRC, a preliminary survey was conducted to determine the sex ratio and population proportions in three predefined age groups (18–35 years, 35–50 years, and > 50 years). This information enabled the calculation of the number of individuals to be interviewed per sex and age group. In each village, 20 key informants were selected based on their duration of habitation in the village (at least 10 years) and their knowledge of the forest and trees in the village. These informants were identified through the guidance of village chiefs. Before the survey, a list of all species identified during the inventory phase was prepared. Each informant was asked to rate these species according to six categories of uses: medicine, food, construction, energy, crafts, and trade (Prance et al. 1987; Belem et al. 2008; Azenge and Meniko 2020). For each use category, the informants rated the species with a score ranging from 0 to 1.5. This rating considers the frequency of use of the species for the considered use category: a score of 0 corresponds to a species not used, 0.5 species occasionally used, 1 species used regularly, and 1.5 preferred species.

The total ethnobotanical use value for each species varies from 0 for a species not used for all categories to 9 for a species preferred in all categories (Belem

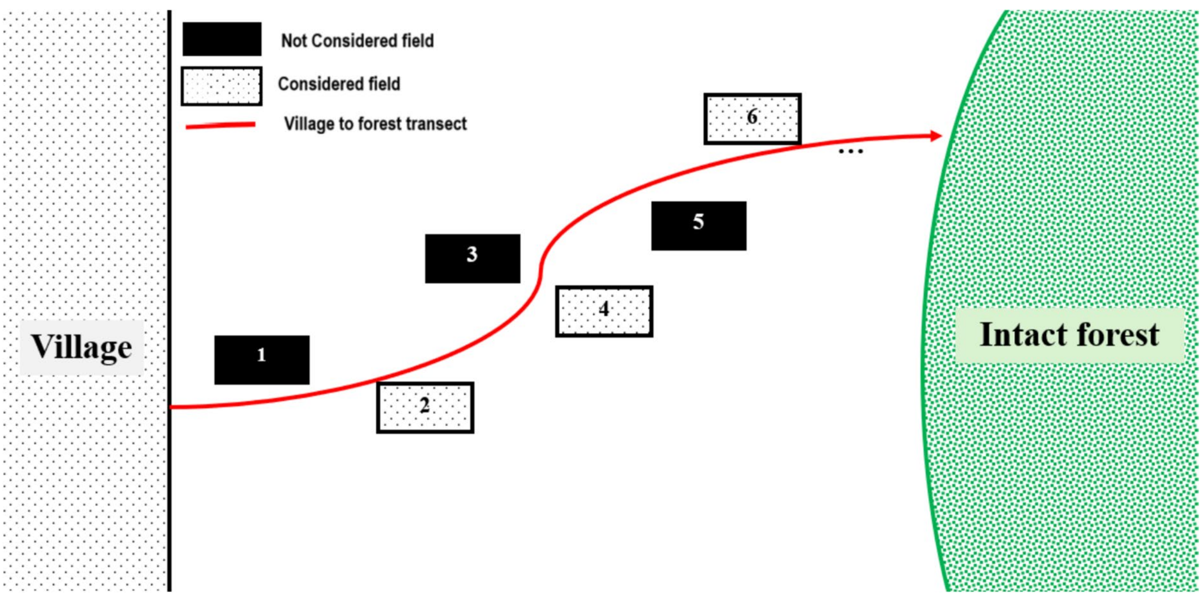

Fig. 2 Illustration of the Field Selection Protocol for Observations on Trees Outside Forests on Agricultural Lands in Mongala. The red line indicates the transect from the village to the nearest intact forest. Black rectangles denote fields without trees, which were excluded from the inventory. The white rectangles with dotted backgrounds represent the plots considered for the inventory

et al. 2008). Thus, each species was evaluated by 900 key informants for the six use categories. The use categories are determined according to the following elements (Prance et al. 1987):

Food: fruits, seeds, and latex, which people consume;
Construction material: wood used in post-and-beam construction, canoes, bridges, and leaves used for roofing thatch;
Crafts (technology): This is a very broad category that includes lashing material, glue, pottery temper, dye, soap, pipe stems, and chairs that people make with trees;
Medicine: leaves, fruits, bark or roots used for sinusitis, congestion, diarrhea, headache, vomiting, fever, unwanted pregnancy, bleeding wounds, snakebite, cradle-cap, canker sores, insect repellent, etc.;
Trade: everything from trees that people sell (fruit, wood, leaves, root, bark);
Energy: trees that are used for wood energy and charcoal production.

Data processing and analysis

We calculated Shannon's diversity index (H) with data collected from the inventory phase. Depending on the value of H obtained, we classified the diversity of a site as low (H < 1), medium (1 < H < 3) or high (H > 3) (Shannon and Weaver 1949). Since the Shannon index is based on species richness (number of species present in an ecosystem) and evenness (distribution of individuals between different species), we associated it with the Pielou equitability evenness (J), which varies between 0 and 1 (J = 1: equitability is maximum; J = 0: equitability is minimum) (Bandeira et al. 2013). By combining these two indices, we distinguished the effects of species richness from evenness on overall diversity. These two indices were calculated using Past 4.03 software for each village in each territory. Analysis of variance was carried out to compare diversity and equitability between the three territories of the Mongala province. These analyses were conducted in R software 4.5.1 using the *ggbeetwenstats* function of the *ggstatsplot* package (Patil 2021). The pairwise comparison test was performed with the Student's t-test to analyze differences in evenness and diversity between territories.

To determine the most abundant species, the relative abundance of each species was calculated by the following formula:

$$AB_r = \frac{n}{N} * 100 \tag{1}$$

where AB_r is the relative abundance in percentage, n is the number of individuals of a species, and N is the number of individuals of all species. The ethnobotanical use value was calculated by the following formula (Belem et al. 2008):

$$TUV_s = \frac{\sum UV_{s,i}}{N} \tag{2}$$

where: TUV_s is the total ethnobotanical use value of species s, $UV_{s,i}$ is the ethnobotanical use value of species s considered according to informant i, and N is the total number of informants who evaluated species **s**. The total ethnobotanical use value of each species is obtained by summing the ethnobotanical value of the species in each use category. A species is considered "preferred by local communities" when the sum of its scores in all use categories is greater than or equal to 3 (Belem et al. 2008). A Hierarchical Clustering on Principal Components (HCPC) was performed using the *FactoMineR* package of the R software 4.5.1 (Lê et al. 2008) to group the preferred species according to their predominant uses for local people.

For the top 5 most abundant species, use scores were transformed into binary (0: the species is not used in this category, and 1: the species is used, regardless of the frequency of use). Using these transformed data, three ethnobotany indices were calculated using *ethnobotanyR* packages in R 4.4.2 software (Whitney 2022): the Relative Frequency of Citation index (RFC_s), Fidelity Level per species (FL_s), and Use Report per species (UR_s) (Friedman et al. 1986; Prance et al. 1987; Tardío and Pardo-de-Santayana 2008). The Relative Frequency of Citation index is calculated by the following formula:

$$RFC_s = \frac{FC_s}{N} = \frac{\sum_{i=i_1}^{iN} UR_i}{N} \tag{3}$$

where: FC_s is the frequency of citation for each species (s), UR_i are the use reports for all informants (i), and N is the total number of informants interviewed in the survey (Tardío and Pardo-de-Santayana 2008). The Fidelity Level per species is calculated by:

$$FL_s = \frac{N_s * 100}{FC_s} \quad (4)$$

where: N_S is the number of informants that use a particular plant for a specific purpose, and FC_S: is the frequency of citation for the species (Friedman et al. 1986). The Use Report per species was calculated by:

$$UR_s = \sum_{u=u_1}^{uNC} \sum_{i=i_1}^{iN} UR_{ui} \quad (5)$$

where: UR_s is the total uses for the species by all informants (from i1 to iN) within each use category for that species (s). It is a count of the number of informants who mention each use category NC for the species and the sum of all uses in each use category (from ui1 to uNC) (Prance et al. 1987; Whitney 2022).

To determine the effects of gender and age on ethnobotanical knowledge, a linear mixed-effects model (LMM) was used. This approach was chosen to account for the non-independence of observations, as each respondent provided data for multiple tree species, thereby treating the respondent as a random effect. The model included gender (male, female) and age group (18–35, 35–50, > 50) as fixed effects, along with their interaction. The total ethnobotanical use-value (TUV_s) score, representing the ethnobotanical knowledge of each species and their utility for respondents, served as the response variable. All statistical analyses were performed using R software 4.5.1, with the *lme4* and *lmerTest* packages, and significance was set at a *p*-value of < 0.05.

Results

The abundance and diversity of TOF-AL in Mongala province

In total, 136 species of TOF-AL were identified, distributed across 103 genera and 37 families (see Supplementary Materials). The ten most abundant species are: *Petersianthus macrocarpus* (P.Beauv.) Liben (16.68%), *Pycnanthus angolensis* (Welw.) Warb. (11.88%), *Ricinodendron heudelotii* (Baill.) Heckel (11.59%), *Erythrophleum suaveolens* (Guill. & Perr.) Brenan (8.51%), *Piptadeniastrum africanum* (Hook.f.) Brenan (5.46%), *Pterocarpus soyauxii* Taub. (2.32%), *Margaritaria discoidea* (Baill.) G.L.Webster (1.70%), *Nauclea diderrichii* (De Wild. & T.Durand) Merr. (1.58%), *Albizia ferruginea* (Guill. & Perr.) Benth. (1.48%), and *Amphimas pterocarpoides* Harms (1.29%). The top ten species accounted for 62.49% of the total abundance of all 136 species inventoried on agricultural land in the Mongala province. The five most abundant species represent over 50% of the total abundance of all species. These are also the most widespread species across the 900 fields surveyed. *P. macrocarpus* is present in 67.22% of the observed fields, *P. angolensis* in 52.33%, *R. heudelotii* in 47.44%, *E. suaveolens* in 50.89%, and *P. africanum* in 29.11% (see Supplementary Materials).

Among the 37 families in which the 136 species are distributed, the ten most abundant families on agricultural land in the province are: Fabaceae (26.47%), Lecythidaceae (16.68%), Myristicaceae (12.91%), Euphorbiaceae (12.69%), Meliaceae (4.53%), Phyllanthaceae (2.91%), Apocynaceae (2.50%), Irvingiaceae (2.18%), Sapotaceae (2.09%), and Rubiaceae (1.88%). These families represent 84.84% of the abundance of TOF-AL in the study area.

The highest species richness is observed in the Bongandanga territory (120 species), followed by the Lisala territory (114 species), and the Bumba territory (81 species). The lowest number of individuals is also recorded in Bumba (1879 trees) compared to 2999 in Bongandanga and 2977 in Lisala. Overall, there is a high diversity of TOF-AL species in Mongala province. The Shannon diversity index is 3.544 in the province and varies from one territory to another. It is 3.48 in Bongandanga, 3.22 in Lisala, and 2.26 in Bumba. Pielou's evenness indices are 0.72 at the provincial level, 0.83 in the Bongandanga territory, 0.82 in the Lisala territory, and 0.76 in the Bumba territory (Fig. 3). These evenness indices indicate that, whether at the provincial or territorial level, most species are relatively abundant and homogeneously distributed.

Figure 3 shows that Shannon's diversity and Pielou's evenness indices vary significantly between the three territories.

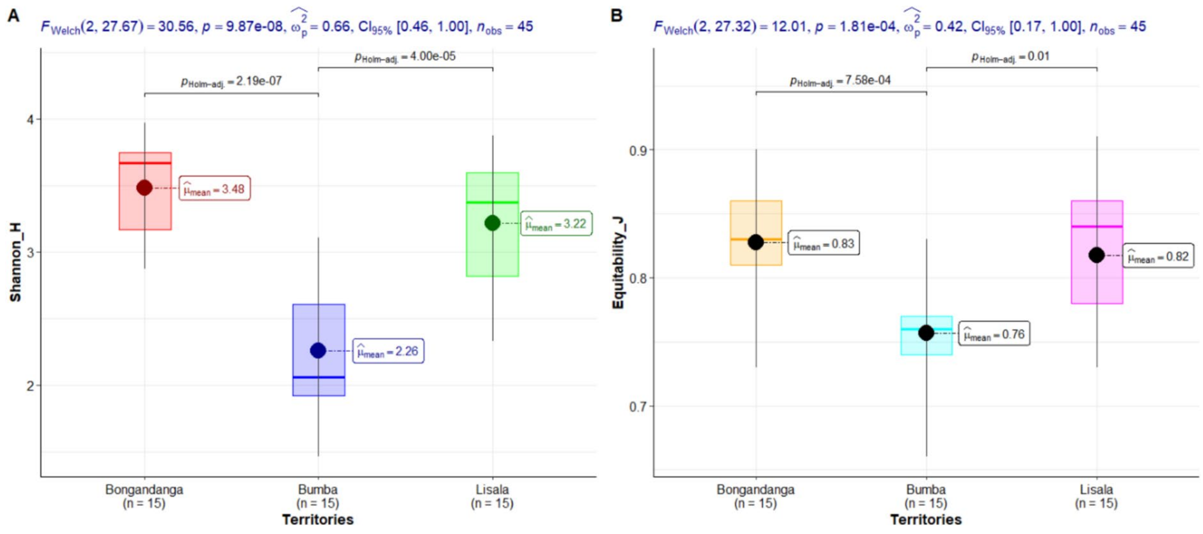

Fig. 3 Variation of the TOF diversity and evenness indices between the three territories of Mongala province (**A**: Shannon diversity index, and **B**: Pielou evenness index)

The TOF diversity is higher in the territories of Bongandanga (3.48), Lisala (3.22), and medium diversity (2.26) in the Bumba territory (Fig. 3A). The difference in diversity is significant between Bumba and Bongandanga ($p < 0.001$) and between Bumba and Lisala ($p < 0.001$), while Bongandanga and Lisala are not significantly different. Figure 3B shows that the distribution of TOF-AL abundance between species is less homogeneous in the Bumba territory than in the Lisala and Bongandanga territories ($p < 0.001$).

Figure 4 shows that the abundances of trees of these first five species vary significantly between territories and species.

The territories of Bongandanga and Lisala have significantly higher abundances than the territory of Bumba ($\chi^2 = 411.36$; $p < 0.001$). In the Bongandanga and Lisala territories, the top 5 species accounted for similar tree abundance (Fig. 4). However, in the Bumba territory the top five tree species accounted for > 70% of the abundance, while the other 131 species accounted < 30%. This indicates tree species evenness is poor in Bumba compared to the other territories. Moreover, conservation of tree species seems more important in this territory than the other territories. The chi-square test indicates that tree abundances significantly differ between species in this territory ($p = 0.00$). In the Lisala territory, the top 5 most abundant species account for about 49% of tree abundances, which are significantly different between species ($p = 0.00$). The most abundant species are *P. macrocarpus* (15%), followed by *R. heudelotii* and *P. angolensis* (11%), then *E. suaveolens* (8%), and finally, *P. africanum* (4%). In the territory of Bumba, these first five species represent more than 70% of the abundance of trees of all species. The most abundant species is still *P. macrocarpus* (23%), followed by *R. heudelotii* (17%), then *P. angolensis* (15%), *E. suaveolens* (10%), and *P. africanum* (7%). The Chi-square test indicates that, as in Bongandanga and Lisala, in the territory of Bumba, the abundance of trees on agricultural land varies significantly according to the species ($p < 0.001$).

Ethnobotanical significance of trees outside forests on agricultural lands in Mongala Province

As shown in Table 1, *P. macrocarpus, E. suaveolens,* and *R. heudelotii* are used by all 900 key informants ($RFC_s = 1$). The other two species, *P. africanum* and *P. angolensis,* are used by 98% and 97% of key informants, respectively ($RFC_s = 0.98$ and 0.97). Among these five most abundant species, Table 1 shows that *P. macrocarpus* is the one that received the highest use report (3907), followed by *E. suaveolens* (3636), *R. heudelotii* (3279), *P. angolensis* (2576) and *P. africanum* (1972).

However, the use reports of these five most abundant species vary depending on the use categories

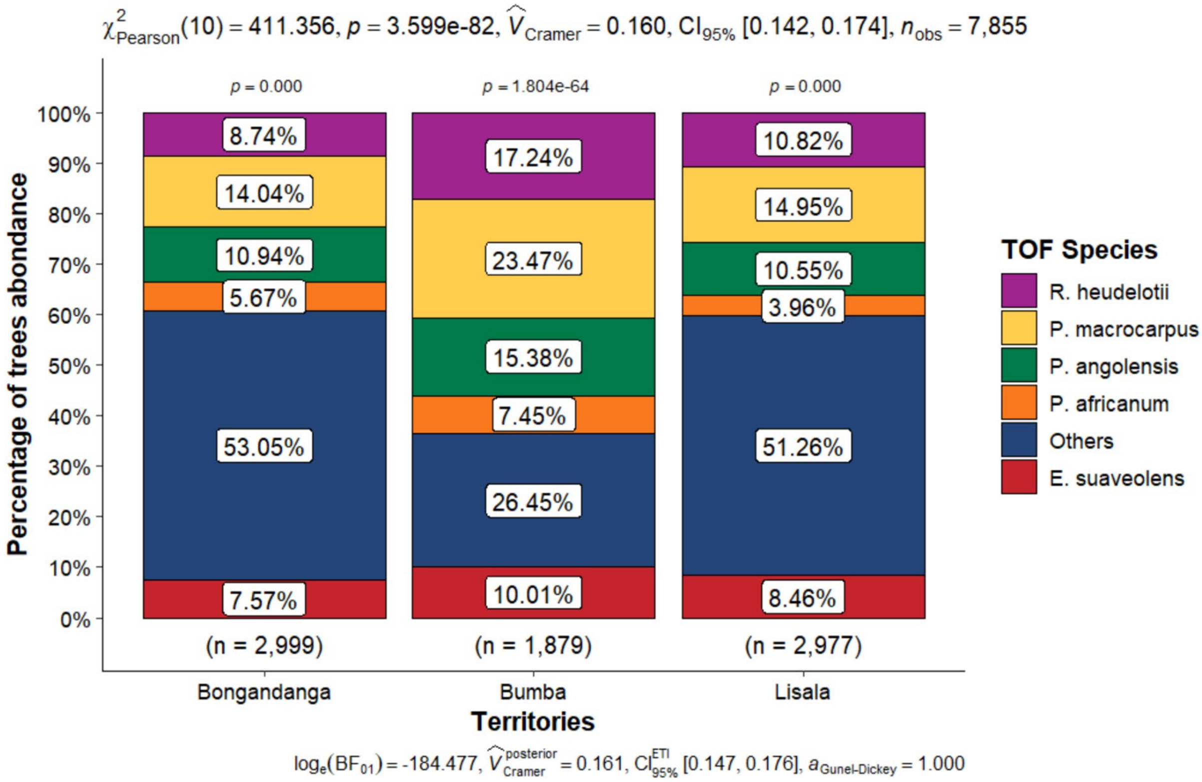

Fig. 4 Species abundance distribution of the most common trees on agricultural lands in three territories of Mongala province

Table 1 Relative frequency of citation, use reports and fidelity level of the most abundant TOF species in Mongala province (RFC_s: relative frequency of citation; UR_s: use reports; FL_s: Fidelity Levels)

Species	RFC_s	UR_s	FL_s					
			Trade	Construction	Food	Energy	Medicine	Crafts
Erythrophleum suaveolens	1.00	3636	100	40.2	99.9	38.6	99.4	25.9
Petersianthus macrocarpus	1.00	3907	95.9	56.4	99.7	30.8	100	51.3
Piptadeniastrum africanum	0.98	1972	24.3	29.4	18.0	98.3	26.4	26.4
Pycnanthus angolensis	0.97	2576	4.6	48.2	47.0	94.7	54.0	48.0
Ricinodendron heudelotii	1.00	3279	48.8	45.4	99.8	43.8	80.4	46.1

and territories. Of the 900 key informants who assessed the use-value of the TOF species in the three territories, 100% use *E. suaveolens* for trade, 99.9% for food, and 99.4% for medicine. For other uses, *E. suaveolens* is used by less than 40% of informants.

Of the 136 species inventoried, 23 are preferred by local populations because of their use values. Table 2 presents the list of these 23 species with their total ethnobotanical use value. The complete list of all 136 species and their TUV_s is provided in Supplementary Materials.

Table 1 shows that *P. africanum* is mainly used as a source of energy (98.3% of informants), and less than 30% use it for other uses. About 94% of informants use *P. angolensis* as a source of energy and 54% as medicine. Less than 50% of the respondents use it for construction, food, and local technologies. Very few informants associate a commercial interest with it (4.6%). The species *P. macrocarpus* is used by all

Table 2 Preferred species of trees outside forests on agricultural lands in Mongala province (TUV_s: total ethnobotanical use value)

Species	Medicine	Food	Construction	Energy	Crafts	Trade	TUV_s	Rank
R. heudelotii	1.3	1.4	0.5	0.4	1.0	1.2	5.9	1
E. suaveolens	1.2	1.4	0.5	0.6	0.4	1.2	5.3	2
P. macrocarpus	1.3	1.4	0.5	0.1	0.3	1.3	5.0	3
E. utile	0.3	1.4	0.6	0.1	0.9	1.4	4.8	4
E. cylindricum	0.3	1.4	0.4	0.3	0.8	1.3	4.5	5
E. candollei	0.2	1.3	0.5	0.2	0.9	1.3	4.5	5
E. angolense	0.2	1.3	0.4	0.2	0.9	1.4	4.3	6
C. acuminata	1.4	1.1	0.0	0.3	0.0	1.4	4.2	7
G. kola	1.3	0.9	0.3	0.0	0.0	1.5	4.0	8
C. schweinfurthii	0.8	1.1	0.6	0.8	0.2	0.3	3.8	9
A. bipendensis	0.5	0.5	0.7	0.8	0.6	0.5	3.7	10
A. adianthifolia	0.3	0.4	0.5	1.3	0.6	0.4	3.6	11
P. africanum	0.4	0.4	0.5	1.3	0.4	0.4	3.5	12
N. diderrichii	0.1	0.0	0.0	0.8	1.2	1.3	3.4	13
K. gabonensis	0.4	0.0	0.5	1.3	0.4	0.7	3.3	14
A. ferruginea	0.6	0.4	0.6	1.2	0.3	0.1	3.2	15
A. mannii	0.7	1.3	0.6	0.0	0.0	0.5	3.1	16
A. boonei	0.4	0.1	0.6	0.6	0.7	0.7	3.1	16
A. ferrugineus	0.8	0.1	0.9	1.0	0.2	0.1	3.0	17
S. kamerunensis	0.0	0.0	0.3	0.0	1.4	1.2	3.0	17
P. angolensis	0.6	0.6	0.7	0.7	0.4	0.0	3.0	17
A. laurentii	0.5	0.0	0.5	1.0	1.0	0.0	3.0	17
C. botryoides	0.5	0.0	0.7	0.6	0.9	0.3	3.0	17

informants for medicine; 99.7% use it for food, 95.9% associate a commercial interest with it, and 51.3% report using it for local technologies. It is, therefore, the species with the most recognized uses in the province of Mongala. Finally, *R. heudelotii* is used by 99.8% of informants as a plant with edible interest, and 80% use it as a medicinal value.

Clustering of TOF-AL species in Mongala Province

The Hierarchical Clustering on Principal Components allowed the grouping of these 23 preferred species into three main clusters (Fig. 5). The first cluster includes 11 species: *A. pterocarpoides*, *A. ferruginea*, *Albizia adianthifolia* (Schumach.) W.F.Wight (1914), *Afzelia bipindensis* Harms (1901), *Alstonia boonei* De Wild. (1914), *Albizia laurentii* De Wild. (1905), *Canarium schweinfurthii* Engl. (1899), *Coelocaryon botryoides* Vermoesen (1919), *Klainedoxa gabonensis* Pierre ex Engl. (1897), *P. africanum*, and *P. angolensis*. This cluster is formed by the species with higher use-values for energy and construction, while lower use value for food and trade (Table 3). The second cluster includes *Entandrophragma angolense* (Welw.) C.DC. (1878), *Entandrophragma cylindricum* (Sprague) Sprague (1910), *Entandrophragma candollei* Harms (1896), *Entandrophragma utile* (Dawe & Sprague) Sprague (1910), *N. diderrichii*, and *Staudtia kamerunensis* Warb. (1897). These six species have the higher ethnobotanical use-values for crafts and trade, while low use values for energy and medicine (Table 3). Thus, this group comprises species highly valued for local technologies and trade, though they are less utilized for energy and traditional medicine.

Anonidium mannii (Oliv.) Engl. & Diels (1907), *Cola acuminata* (P.Beauv.) Schott & Endl. (1832), *E. suaveolens*, *Garcinia kola* Heckel (1883), *P. macrocarpus*, and *R. heudelotii* form the third cluster. These are species highly valued for medicine, food, and trade (Table 3). In this cluster are the three most distributed trees outside forest species in Mongala province: *P. macrocarpus, R. heudelotii,* and *E. suaveolens*.

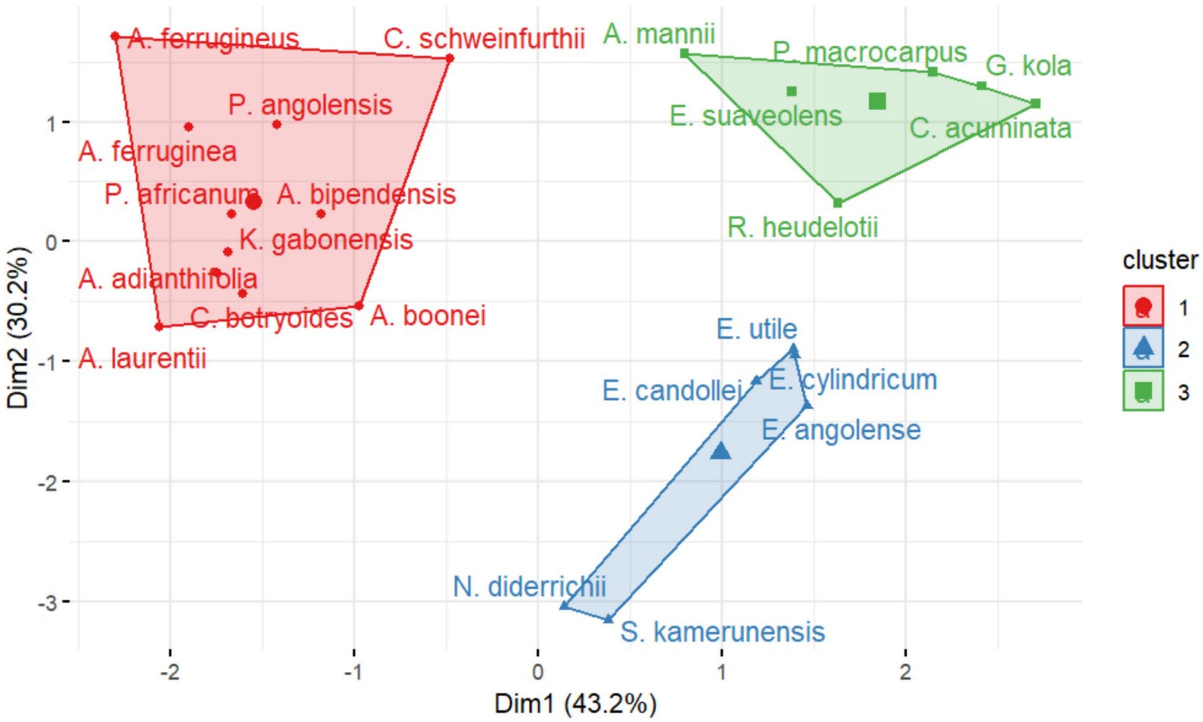

Fig. 5 Clustering of trees outside forests species by uses in the province of Mongala

Table 3 Description of trees outside forests on agricultural land clustering by uses in the Mongala province

Cluster	Uses	v.test	Mean in category	Overall mean	Sd in category	Overall sd	p-value
1	Energy	3.824	0.964	0.591	0.267	0.437	0.000
	Crafts	2.737	0.618	0.496	0.119	0.201	0.006
	Food	−3.094	0.327	0.717	0.322	0.566	0.002
	Trade	−4.162	0.318	0.804	0.241	0.525	0.000
2	Technology	3.084	1.017	0.587	0.211	0.388	0.002
	Trade	2.721	1.317	0.804	0.069	0.525	0.007
	Energy	−2.069	0.267	0.591	0.256	0.437	0.039
	Medicine	−2.906	0.183	0.613	0.107	0.412	0.004
3	Medicine	3.969	1.2	0.613	0.231	0.412	0.000
	Food	2.621	1.25	0.717	0.189	0.566	0.009
	Trade	2.013	1.183	0.804	0.324	0.525	0.044
	Crafts	−2.179	0.283	0.587	0.358	0.388	0.029
	Energy	−2.281	0.233	0.591	0.221	0.437	0.023

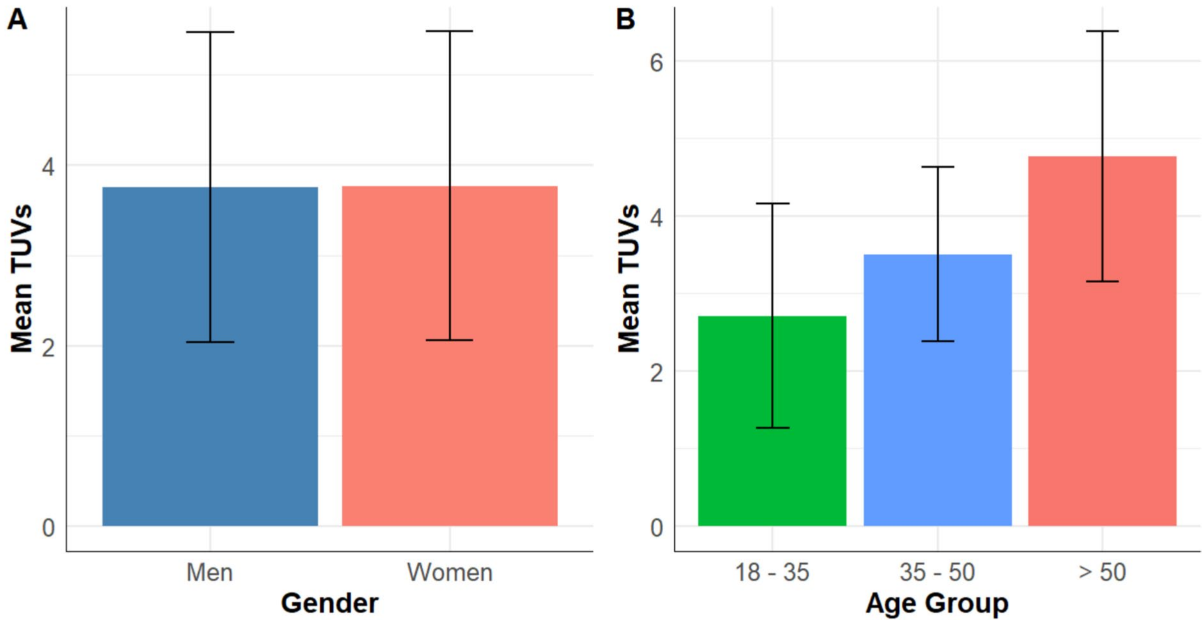

Fig. 6 Variations of the total ethnobotanical use-value (TUVs) of TOF-AL species by respondent gender and age group

However, the species that form the third cluster are not appreciated by local populations for crafts and energy (Table 3).

Influence of gender and age on ethnobotanical knowledge

Figure 6 reveals a clear trend in the distribution of ethnobotanical knowledge within the studied community, highlighting a divergence between the effects of gender and age. While gender does not appear to be a significant differentiating factor (Fig. 6A), age emerges as a crucial predictor of ethnobotanical knowledge (Fig. 6B). The similarity in mean TUV_s scores between men and women, along with the substantial overlap of their standard deviation bars, suggests that knowledge of plants and their uses is broadly shared and not confined to traditional gender roles.

In contrast, the positive and progressive relationship between age and the TUV_s of plants is attractive. Figure 6B shows that older respondents possess a considerably richer body of knowledge than their younger counterparts, with a notable increase in TUV scores from the 18–35 age group to the over-50 age group.

The results of the LMM are summarized in Table 4. While initial visual analysis suggests that gender is not a significant differentiating factor (Fig. 6), the LMM provides a more robust and detailed understanding (Table 4). The analysis confirms that both age and gender are significant

Table 4 Effects of respondent gender and age on the total ethnobotanical use-value (TUV_s)

Fixed effect	Estimate	Standard error	Degrees of freedom	t-value	*p*-value
(Intercept)	4.783	0.009	122,405	530.754	< 0.001
Gender (Male)	0.034	0.013	122,405	2.709	0.007
Age (18–35)	− 1.991	0.013	122,405	− 148.315	< 0.001
Age (35–50)	− 1.222	0.015	122,405	− 79.203	< 0.001
Gender (Male): Age (18–35)	− 0.121	0.019	122,405	− 6.336	< 0.001
Gender (Male): Age (35–50)	− 0.084	0.021	122,405	− 3.913	< 0.001

predictors of ethnobotanical knowledge, with a notable interaction effect between them.

The model indicates a strong and highly significant effect of age, with younger age groups possessing substantially lower TUV_s scores compared to the reference group of women over 50. Furthermore, the LMM shows a significant main effect of gender, with males demonstrating a slightly higher overall TUV_s score than females.

Most importantly, the analysis highlights a significant interaction between gender and age, suggesting that the effect of age on knowledge is not uniform across genders. The negative interaction coefficients indicate that the knowledge gap between age groups is more pronounced for men than for women. This implies that while both genders experience an increase in ethnobotanical knowledge with age, the rate of knowledge acquisition or retention among men is steeper than among women. This finding supports that, in Mongala province, traditional knowledge is not only age-dependent but also has a nuanced relationship with gender, where specific knowledge transmission pathways or social roles may contribute to gender-specific learning curves.

Discussion

This study provides a comprehensive analysis of the abundance, diversity, and distribution of TOF-AL in the Mongala province, DRC. Our findings reveal a high species richness and diversity within this traditional agroforestry system, underscoring its significant role in preserving botanical diversity and providing a wide range of ecosystem services for local communities.

We identified 136 species, distributed across 103 genera and 37 families, confirming the high floristic diversity of TOF-AL in the study area. The prevalence of certain families, particularly Fabaceae (26.47%) and Myristicaceae (12.91%), is consistent with findings from other ethnobotanical and ecological studies in Central Africa (Ndavaro et al. 2024; Besisa et al. 2025). This dominance is not only a statistical observation; it carries significant socio-economic importance. For instance, the high abundance of Fabaceae, the most represented family in this study, aligns with research in the Lubero Mountain Massif, DRC, where Fabaceae is also the most frequently cited family due to its high use value (Ndavaro et al. 2024). Species within this family, such as *Pterocarpus soyauxii* and *Albizia ferruginea*, are known for their timber, medicinal, energy, and nutritional uses.

Similarly, the high abundance of the family Myristicaceae is largely driven by the dominance of *Pycnanthus angolensis* (11.88%). This species is widely used for timber, medicine, and food (as non-timber forest products or NTFPs), making it a valuable component of local livelihoods (Caspa et al. 2020; Mobunda et al. 2025). The fact that these top-ranking families and species are not only abundant but also highly valued by local communities, as documented in other studies, suggests that farmers deliberately retain or manage them within their agricultural landscapes. This practice enhances agricultural productivity and resilience while also contributing to household income and food security (Smith Dumont et al. 2014; Kayusi et al. 2025). The study also identified *Amphimas pterocarpoides*, which has been cited as a woody species with a very high fidelity level for use as firewood in Sankuru province, DRC, further highlighting its economic value (Mobunda et al. 2025).

The overall high diversity of TOF-AL in Mongala province, as indicated by a Shannon diversity index of 3.544, suggests that agricultural landscapes in this region are not biodiversity deserts but rather play a crucial role in conservation. The average Shannon index in this study is comparable to or even higher than some findings for complex agroforestry systems in West and Central Africa (Smith Dumont et al. 2014; Batsi et al. 2020).

However, the significant variation between territories (Bongandanga at 3.48, Lisala at 3.22, and Bumba at 2.26) reveals distinct management practices and conservation statuses. The lower diversity and species evenness (Pielou's index) in the Bumba territory are particularly notable. With the five most abundant species accounting for over 70% of the total tree abundance in Bumba, the landscape here is less homogeneous compared to Bongandanga and Lisala. This finding aligns with observations that human-intensive activities like agriculture and logging can lead to a decline in species diversity and a dominance of a few resilient or highly valued species (Besisa et al. 2025). The fact that *P. macrocarpus* and *R. heudelotii* are particularly dominant in Bumba suggests that they are highly favored by farmers for their specific uses, perhaps as fast-growing timber or for other economic benefits. This highlights a critical need for targeted conservation efforts in this territory to maintain a more balanced species distribution and prevent further loss of biodiversity.

The high diversity and abundance of TOF-AL in Mongala province indicate that these systems serve as vital reservoirs of biodiversity outside of protected forest areas (Boffa et al. 2005). This is particularly important in a country like the DRC, where agricultural expansion is a major driver of forest degradation (Tanzito et al. 2020). The integration of trees into agricultural lands mitigates this pressure by providing essential ecosystem services, such as soil fertility improvement, carbon sequestration, and habitat creation for soil macrofauna (Kataka et al. 2023, 2024). The presence of diverse tree species, especially indigenous ones, can improve soil health and resilience to environmental stressors, contributing to sustainable land management (Kataka et al. 2023; Kayusi et al. 2025).

The findings also have implications for landscape-level conservation strategies. The significant differences in diversity between territories, particularly the low evenness in Bumba, signal that a one-size-fits-all approach to agroforestry is not appropriate. For territories with lower diversity and evenness, such as Bumba, conservation initiatives should focus on promoting the planting of a wider variety of indigenous species to enhance ecological resilience and diversify the benefits to local communities. Supporting community-based natural resource management and providing incentives for retaining and planting a broader range of tree species could be effective strategies (GEF, 2021). This approach not only aids in the conservation of species but also ensures a wider array of social and economic benefits, from food and medicine to timber and cultural resources, supporting long-term rural livelihoods in the region.

Our results emphasize the significant ethnobotanical value of TOF-AL within the agricultural landscapes of Mongala province. The high relative frequency of citation and use reports for several species underscores their integral role in local communities' livelihoods and well-being. Five species, *P. macrocarpus, E. suaveolens, R. heudelotii, P. angolensis,* and *P. africanum*, emerged as particularly important, exhibiting high RFCs (ranging from 0.97 to 1.00) and substantial UR_s. This dominance suggests a deep traditional knowledge and reliance on these species, as suggested in several studies (Parrotta et al. 2016; Mechaala et al. 2022; Sime et al. 2024). The high RFC values indicate that these species are widely recognized and frequently mentioned by the key informants, signifying their cultural importance (Phillips and Gentry 1993; Tardío and Pardo-de-Santayana 2008; Lougbegnon et al. 2011).

P. macrocarpus stood out with the highest UR, indicating its diverse applications and frequent use across various categories. This aligns with its high-fidelity level (FL) for medicine, food, and trade purposes. Its versatility is further emphasized by its presence in almost all use categories assessed, highlighting its multifunctional role in local communities (Idaguko and Adeniyi 2023). Similarly, *E. suaveolens* demonstrated high importance, particularly for trade, food, and medicinal uses. The concentration of its use in these specific categories suggests specialized knowledge and management practices associated with this species (Dongmo et al. 2001). These results align with those found by Katayi et al. (2023) in the Biosphere Reserve of Yangambi in DRC, where *E. suaveolens* and *P. macrocarpus* were considered very important species for the riverside populations of the reserve. In the province of Mongala, poverty could explain the different roles attributed to these species in the population's daily life (Enabel 2020). This population, reliant on natural resources for its survival, has likely developed and passed down specialized knowledge about the use of these species across generations. This specialized local knowledge on TOF species uses can contribute to the conservation of floristic biodiversity in this context of increasing deforestation.

The URs' variation across different use categories and territories highlights the differentiated understanding and utilization of TOF-AL species. This variation likely reflects differences in local cultural preferences and resource availability (Welcome and Van Wyk 2020; Rimlinger et al. 2021). For example, while *P. africanum* and *P. angolensis* are widely recognized (high RFCs), their URs and FLs suggest more specialized uses, primarily as energy sources. This specialization for particular uses underscores the importance of considering several indices (RFC, UR, FL) to understand the full spectrum of ethnobotanical significance of a given species (Hoffman and Gallaher 2007).

This study also identified 23 preferred species based on their total ethnobotanical use value. The ranking of these species (Table 2) provides valuable insights into local priorities and preferences, as the preferences of these 23 species are based on different uses, with each species or group of species being favored for one or more distinct uses. These results suggest that for a comprehensive measure of a species' overall value, it is important to use the VUETs, which integrate various use categories (Hoffman and Gallaher 2007). This integrated approach is particularly crucial in tropical regions, such as in DRC, where complex relationships exist between people and plant resources. *R. heudelotii, E. suaveolens,* and *P. macrocarpus* topped the list, confirming their importance as demonstrated by Azenge and Meniko (2020) and Katayi et al. (2023) in the Tshopo province in DRC.

The low representation of species such as *Entandrophragma cylindricum*, *E. candollei*, *E. angolense*, and *E. utile* on agricultural lands is a matter of particular concern. These species, commonly known as "Bois rouge" or "Liboyo", are part of the family Meliaceae and are among the most sought-after timber species in the Congo Basin (Kasongo et al. 2019; Caspa et al. 2020). Their ecological characteristics, including slow growth rates and a need for specific forest conditions for regeneration, make them highly susceptible to over-exploitation (Kasongo et al. 2019). The pressure to harvest these trees for commercial purposes, even in non-forest settings, is immense. This high demand, coupled with their long-life cycle, explains why they are not being retained or successfully integrated into fast-turnover agricultural systems.

Similarly, species like *G. kola* (bitter cola) and *C. acuminata* (cola nut) are prized for their nuts, which are non-timber forest products (NTFPs) of great economic and cultural value (Caspa et al. 2020; Mobunda et al. 2025). While these species are typically found in forest environments, their presence on farmlands is a testament to their high use value to local communities. However, the heavy exploitation of these species, often through destructive harvesting practices like bark-stripping or over-collection of seeds, may inhibit their regeneration and lead to a decline in their populations. Studies from the Congo Basin have consistently shown that species with high economic value, whether for timber or NTFPs, face the highest levels of anthropogenic pressure and are often rare or absent in human-dominated landscapes (Besisa et al. 2025). The low abundance of these species in the agricultural landscapes of Mongala province is therefore a direct reflection of this human pressure.

The findings from Mongala are not an isolated case but rather reflect a regional trend of a disconnect between a species' high ethnobotanical value and its low abundance in agroforestry systems. A study on traditional knowledge in the Lubero Mountain Massif in the DRC found that while local communities have extensive knowledge of high-value woody plants, these species are often scarce in areas of high human activity (Ndavaro et al. 2024). This phenomenon is also documented in other parts of Central and West Africa, where valuable species like *G. kola* and *E. utile* are found in higher densities in protected or primary forests compared to fallows or village lands (Caspa et al. 2020). This highlights a critical challenge: the very value that makes these trees important to communities also makes them vulnerable. The short-term economic gains from harvesting often outweigh the long-term benefits of retention, especially in the absence of robust management and tenure systems.

The Hierarchical Clustering on Principal Components results reveal three distinct clusters based on local communities' perceived utility of these 23 preferred tree species in Mongala province. These findings provide important information about how local communities interact with forest resources in the province and show how various species support people's livelihoods.

Species with high use values for energy and construction characterize the first cluster, regrouping 11 species. This aligns with the dependence of the population of Mongala on wood energy and the common observations in many rural communities where wood remains a primary source of energy and building material (Kebede et al. 2015; Aabeyir et al. 2016; Bamwesigye et al. 2020). In this cluster, the dominance of species like *A. pterocarpoides, Albizia spp.*, and *C. schweinfurthii* underscores their importance for firewood and charcoal production in this province. However, this cluster's low use values for food and commercial purposes suggest a potential focus on utilitarian rather than economic or nutritional value. This specialization could indicate a reliance on readily available and abundant species for basic needs, potentially overlooking other species with greater economic or nutritional potential, such as *E. suaveolens* and *P. macrocarpus* (Azenge and Meniko 2020; Katayi et al. 2023). The statistically significant differences ($p < 0.01$) between the cluster means and the overall means for these use categories further support this observation.

The second cluster comprises species with high use values for craft applications and trade, including *Entandrophragma* spp*., Nauclea diderrichii,* and *Staudtia stipitata*. This group's preference for craft uses likely encompasses a range of applications, such as toolmaking, canoe construction, and furniture production, reflecting specialized knowledge and craftsmanship within the community (Kasongo et al. 2019; Lhoest et al. 2020). The high commercial value of these species suggests their importance for income generation, potentially through timber trade or the sale of processed products (Zhang et al. 2020). The lower use values for energy and medicinal value in this cluster suggest a different set of priorities, potentially reflecting the availability of alternative species for these purposes or a lower reliance on these species for traditional medicine. The significance of Entandrophragma species for timber is well-documented (Yakusu et al. 2019; Harris et al. 2021), further supporting the observed clustering.

The third cluster stands out for its high use values for medicine, food, and trade. Species like *A. mannii, G. kola,* and *R. heudelotii* are valued for their medicinal properties, nutritional value, and market potential. This cluster highlights certain species' multifunctional nature, contributing to health and economic well-being. The presence of the three most widely distributed species in the province (*P. macrocarpus, R. heudelotii,* and *E. suaveolens*) within this cluster emphasises their socioeconomic importance. The high medicinal value of these species is consistent with ethnobotanical literature (Azenge & Meniko 2020; Dongmo et al. 2022; Enogieru & Momodu 2021; Katayi et al. 2023), highlighting their continued relevance in local healthcare systems. This is particularly important in the Mongala province, where access to modern health care is difficult, especially for poor rural populations (UNICEF 2021).

The positive and progressive relationship between age and ethnobotanical knowledge observed in this study aligns with a broad body of research demonstrating that TPK increases with age (Sharma et al. 2019). The older respondents in this study possess a significantly richer body of TPK than their younger counterparts, a phenomenon often attributed to the "temporal advantage" of lived experience (Sharma et al. 2019). The decline in TPK among younger age groups is a widely reported trend, often linked to modernization, formal education, and a shift away from agrarian livelihoods (Mothupi and Shackleton 2025). The schooling system, for instance, can undermine traditional knowledge transmission and disrupt acquisition, as school curricula often lack indigenous knowledge content (Mothupi and Shackleton 2025). This study's findings corroborate the hypothesis that a longer lifespan and greater cultural experience contribute to the accumulation of ethnobotanical knowledge, with younger generations having reduced exposure to the natural environment and traditional knowledge systems (Ndavaro et al. 2024; Mothupi and Shackleton 2025).

The LMM results, which show a significant main effect of gender, highlight the importance of documenting "gender-distinct ethnobotanical knowledge" to achieve a more nuanced and holistic understanding of local ecological knowledge (Luizza et al. 2013). While a simple comparison of mean scores may not reveal a significant difference, the LMM demonstrates that gender is a crucial variable (Sharma et al. 2019). This finding is particularly important because, in many cultures, the transmission of knowledge and the roles associated with it can be gender-specific (da Costa et al. 2021). Studies have shown that women are more inclined to share information with each other than men, facilitating a horizontal transfer of knowledge (da Costa et al. 2021). This social dynamic can lead to women's networks being more connected and cohesive, with women often acting as "key-individuals" in structuring the community's plant knowledge (da Costa et al. 2021). The study revealing a greater centrality in women's networks in a Spanish community supports the notion that gender shapes the social-ecological networks through which ethnobotanical knowledge is distributed and transmitted (da Costa et al. 2021).

The most critical finding of this study is the significant interaction between gender and age, which suggests that the effect of age on knowledge is not uniform across genders. The negative interaction coefficients indicate that the knowledge gap between age groups is more pronounced for men than for women. This implies that while both genders acquire more ethnobotanical knowledge with age, the rate of knowledge acquisition or retention among men is steeper than among women. This result provides a compelling insight into the specific knowledge transmission pathways and social roles within the Mongala community that may contribute to gender-specific learning curves. This finding underscores that traditional knowledge is not only age-dependent but also has a nuanced relationship with gender, reflecting complex social dynamics that influence how knowledge is learned, shared, and retained.

Conclusion

Our study revealed a rich diversity of 136 species of trees outside forests on agricultural land (TOF-AL) in Mongala province, with a high Shannon diversity index (3.544). Our results show that, at the province level, more than 62% of the total abundance is concentrated in the ten most common species. Using a hierarchical classification approach, we identified three distinct clusters of 23 priority species, each characterized by a unique set of ethnobotanical use values. Cluster 1 includes species with high value for energy and construction, Cluster 2 groups species highly preferred after for commerce and crafts, and Cluster 3 contains the most abundant, multifunctional species valued for food, medicine, and commerce.

The findings of this study provide new insight into the complex dynamics between local communities and tree resources in their agricultural landscape. They show that the composition and abundance of TOF-AL are not a matter of chance, but a direct reflection of specific management choices dictated by perceived use value. The high abundance and wide distribution of Cluster 3 species confirm that farmers are inclined to actively conserve trees that provide continuous and non-destructive benefits. Conversely, the scarcity of Cluster 2 species highlights the impact of commercial pressure and unsustainable harvesting, demonstrating that their low presence is not due to a lack of interest, but to their vulnerability. These results underscore the crucial role of traditional knowledge in biodiversity conservation, showing that the economic and cultural valuation of a species can be a driver of its conservation or, conversely, of its overexploitation.

While this study provides a solid foundation, it has certain limitations. The methodology, based on key informant statements, although rigorous, may not capture the full extent of informal management practices or less widespread knowledge. Furthermore, as the scope of this research is limited to Mongala province (DRC), it is necessary to extend it to other regions of Central Africa to evaluate the generalizability of these dynamics.

Considering our findings, several needs for future research emerge. It is imperative to conduct complementary studies on the phytosociology of these species, their reproductive biology, and their vulnerability to climate change to ensure their sustainability. It would also be relevant to explore the socioeconomic aspects in greater detail by analyzing the impact of markets and value chains on the conservation practices of Cluster 1 and 2 species. Future research should also evaluate the effectiveness of differentiated conservation strategies, such as targeted reforestation programs and economic incentives for threatened species.

In fine, the floral diversity of Mongala's agricultural landscape is not simply the result of ecological processes, but a manifestation of management practices rooted in local ethnobotanical knowledge. The conservation of these valuable resources can only succeed by recognizing and strengthening this fundamental link. Our results call for a paradigm shift, from simple tolerance of trees in agricultural lands to their active, managed integration. By adapting management strategies to the use value of each species, we can not only protect biodiversity but also ensure the food security and livelihoods of local communities. This study thus serves as an appeal for a conservation approach that draws on traditional knowledge to forge a sustainable future.

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Authors contribution J.P.A conceptualized the study, designed the methodology, coordinated all research data collection and analysis interpretation, and drafted the manuscript.

P.W.C. and J.K.N. provided crucial academic supervision throughout the study, offering substantial intellectual inputs and critical revisions to the manuscript. I.S.W. assisted in the data analysis, the discussion of results, and manuscript drafting. All authors critically reviewed and approved the final version of the manuscript submitted for publication.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Conflict of interest The authors declare no conflict of interest.

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