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Research Article

Keywords: Traditional ecological knowledge, Plant-use knowledge, Ethnobotany, Sustainable Livelihoods Framework, Great Green Wall, Mali, Sahel, Ecological restoration

Posted Date: November 25th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11770607/v1

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Additional Declarations: No competing interests reported.

Linking plant-use knowledge with household livelihood assets and perceived environmental change in Mali: implications for restoration under the Great Green Wall for the Sahara and the Sahel Initiative.

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Abstract

Background

Reforestation and ecological restoration initiatives in Sub-Saharan Africa, including the Great Green Wall for the Sahara and Sahel Initiative (GGWSSI), aim to reverse land degradation while supporting rural livelihoods.

Understanding how household socio-economic characteristics relate to plant-use knowledge, a key component of Traditional Ecological Knowledge (TEK), is essential for designing effective restoration programs that integrate local knowledge systems with conservation goals

This study examines how livelihood assets, structured according to the Sustainable Livelihoods Framework, and perceived environmental change shape plant-use knowledge among Dogon, Sarakolé, and Maure communities in Mali.

We identify wild or semi-cultivated plant species of importance for local livelihoods and determine which socio-economic and ecological factors are most strongly associated with variation in plant-use knowledge.

Methods

Ethnobotanical and socio-economic surveys were conducted with 152 key informants from households across the Bandiagara (former Mopti) and Kayes regions.

Factor Analysis of Mixed Data (FAMD) characterised livelihood dimensions across five capitals (human, social, natural, physical, financial). A study-specific plant-use knowledge index (IndexCA),

integrating information on species, plant parts and reported uses, was constructed using Correspondence Analysis and modelled against socioeconomic and environmental predictors through regression analysis.

Results

Following the exclusion of cultivated taxa, 49 wild or semi-wild taxa were retained for ethnobotanical analysis. *Sclerocarya birrea (*A.Rich.) Hochst. (marula), showed the highest number of use reports (634) and cultural importance (4.3), followed by *Senegalia senegal* (L.) Britton (gum Arabic tree) and *Lannea microcarpa* Engl. & K.Krause (African grapes). The regression model accounted for a substantial proportion of the observed variation in IndexCA, this study's measure of plant-use knowledge ($R^2 = 0.767$; adjusted $R^2 = 0.691$).

Natural capital variables, perceived temperature trends, diversified plant-resource use, extraction of plant products, environmental governance, environmental awareness, and water availability, emerged as the strongest predictors. Ethnicity, household structure, and livestock-based livelihoods were also associated with variation in IndexCA.

Conclusions

These findings show that plant-use knowledge is embedded within broader social, ecological, and livelihood contexts. Integrating plant-use knowledge, community priorities, and other dimensions of biocultural diversity alongside ecological criteria may therefore strengthen the local relevance and social legitimacy of restoration initiatives such as the GGWSSI.

Keywords

Traditional ecological knowledge; Plant-use knowledge; Ethnobotany; Sustainable Livelihoods Framework; Great Green Wall; Mali; Sahel; Ecological restoration

Background

Ecological restoration and reforestation serve as critical mechanisms to mitigate environmental degradation, most notably within climate-stressed areas such as Sub-Saharan Africa (Di Sacco et al., 2021; Lazos-Chavero et al., 2016).

In addition to ecological benefits, they can support rural communities by integrating local needs, traditional environmental practices, and livelihood strategies based on wild and cultivated plants (McLain, 2001; Rinaudo et al., 2021).

Although many restoration projects in Sub-Saharan Africa have focused on biophysical and geographic indicators of environmental health, integrating household-level socio-economic information is also essential, as local characteristics can strongly influence the outcomes and sustainability of national and international conservation efforts (Sacande & Muir, 2022; Di Sacco et al., 2021; Duguma et al., 2018; Ceci et al., 2018a).

The Great Green Wall for the Sahara and the Sahel Initiative (GGWSSI), endorsed by the African Union in 2007, represents one of the largest landscape-scale restoration efforts in Africa, seeking to address land degradation, drought, and desertification while strengthening the resilience and livelihoods of communities across the Sahel. Its objectives extend beyond increasing vegetation cover and restoring degraded land to include improving food security, livelihoods, and the sustainable management of natural resources (Goffner et al., 2019; Gravesen & Funder, 2022).

Originally conceived as a continuous vegetation corridor stretching roughly 7,000 to 8,000 km and 15 km wide, it has evolved into a mosaic of land-use interventions, ranging from water harvesting and natural regeneration to agroforestry, designed to foster green, productive landscapes (Gravesen & Funder, 2022). The GGWSSI is implemented with support from several partner organisations, setting ambitious targets for 2030: restoring 100 million hectares of degraded land, sequestering 250 million tonnes of CO_2, and creating 10 million green jobs across participating countries (Gravesen & Funder, 2022; Earth.org, 2024). However, progress has been uneven: by 2023, approximately 18% (around 18 million hectares) of the restoration target was reported to have been achieved (Raman, 2023). Recent analyses based on the Inclusive Wealth Index (IWI), which integrates natural, human, and produced capital, suggests that while Great Green Wall (GGW) countries experienced a modest annual growth in natural capital (+0.1%) compared to a decline in non-GGW nations (–0.06%), overall wealth growth lagged due to opportunity costs and limited external funding (Coulibaly, 2025).

As part of this effort, the Royal Botanic Gardens, Kew (RBG Kew) through its global Millennium Seed Bank Partnership (MSBP) and in collaboration with national institutions and local communities, implemented the GGW Cross-border Pilot Project (2013-2020) in Burkina Faso, Mali and Niger under Access and Benefit-Sharing Agreements (Breman et al, 2021).

The project developed a replicable restoration model that combined plant science, local and traditional knowledge, and community engagement to generate environmental and socio-economic information relevant to larger-scale restoration efforts in the Sahara and the Sahel.

A participatory approach was used to identify native, useful plant species adapted to local environmental conditions and important for local livelihoods, and to support their seed conservation, restoration and sustainable use activities, while contributing to livelihood enhancement (Ceci et al., 2018b; Ceci et al., 2019). In Mali, implementation was led by the Institut d'Économie Rurale (IER), Programme de ressources forestières, in the Bandiagara (former Mopti) and Kayes regions.

At the national level, the GGWSSI is implemented within the National Plan for the Fight Against Desertification and coordinated by the National Agency of the GGW, established in 2019 under the Ministry of Environment (Mentz & Karambiri, 2022). Although the initiative covers eight regions and reaches approximately 4 million people, progress remains limited, with persistent pressures on forest recovery linked to household dependence on biomass energy, up to 64% of total household fuel use (Mentz & Karambiri, 2022; Raman, 2023; AP News, 2024).

Biocultural diversity links the biological, cultural, and linguistic dimension of socio-ecological systems (Maffi, 2005; Otamendi-Urroz et al., 2025). It provides a framework for understanding how endogenous drivers rooted in local livelihoods shape ecosystem restoration outcomes (Sena et al., 2022).

Central to biocultural diversity is Traditional Ecological Knowledge (TEK), also termed Indigenous and Local Knowledge (ILK): a collectively held, orally transmitted, and dynamically evolving knowledge system encompassing the practices, innovations, and worldviews through which communities interact with and steward their local ecosystems (CBD, 1992; FAO, 2009; IPBES, 2012; Tengö et al., 2017).

TEK is not only empirical but also integrates cosmologies, social values, and ethical frameworks that guide human-environment relationships (Gadgil et al., 1993; Whyte, 2013), and its integration into

biocultural restoration approaches can contribute to biodiversity conservation, food security, and cultural resilience (Delevaux et al., 2025; Nadasdy, 1999).

TEK informs how communities identify, classify, manage, and use plants for material, symbolic, and ecological purposes, making plant knowledge one of the most tangible and measurable expressions of biocultural diversity (Cotton, 1996; Martin, 2004). Because culturally and materially valued plant resources can motivate local conservation behaviours, plant-use knowledge may also provide an important entry point for linking community priorities with restoration and conservation objectives (Khosravi Mashizi & Escobedo, 2025; O'Neill et al., 2017). Consequently, understanding the social and cultural dimensions of restoration is essential for assessing not only ecological outcomes but also the capacity of local communities to participate in and sustain restoration processes.

Understanding how plant knowledge translates into livelihood outcomes and, in turn, into conservation and restoration potential, requires an analytical framework that captures the multiple assets on which rural communities depend. The Sustainable Livelihoods Framework (SLF) provides such a structure by distinguishing five key forms of livelihood capital: human (skills, knowledge, health), natural (resources and environmental conditions), financial (income, savings), physical (infrastructure, tools), and social (networks, institutions, relationships) (DFID, 1999; Elizondo et al., 2017).

This framework has been applied as an action-research infrastructure to implement community-based conservation initiatives across many countries, with practitioners developing tools to assess projects using criteria linked to the livelihood assets (Nasrnia & Ashktorab, 2021; Pandey et al., 2017; Wu et al., 2023).

By considering the five capitals, it enables a holistic analysis of the assets that shape community capacity, livelihood strategies, and access to resources. These interdependent forms of capital are particularly relevant for understanding how traditional knowledge of native plants and their uses is acquired, maintained, transmitted, and mobilised within the broader social, environmental, infrastructural, human, and economic context, with implications for biodiversity conservation and long-term community well-being (DFID, 1999; Berkes et al., 2000; Pretty & Smith, 2004).

Aims and scope

To achieve ambitious goals such as those set by the GGWSSI, it is important to understand the characteristics of local households that influence the conservation and utilisation of natural resources. Recognising the diverse uses of native plant species, from traditional medicine to food sources and building materials, is crucial.

At the same time, household-level socio-economic and ecological characteristics can complement conventional biophysical indicators (such as plant survival and growth, vegetation cover, number of seedlings and species planted, and carbon sequestered, etc.) by helping to explain the social and environmental drivers underlying restoration outcomes (Ceci et al., 2018a).

The aim of this study is to understand how socio-economic characteristics of households to plant-use knowledge, considered here as a component of TEK (Corroto et al., 2022; Ahoyo et al., 2024; Douandji et al., 2023) in the Sahel regions of Mali involved with the GGWSSI restoration initiative. Specifically, we aim to assess how livelihood assets are associated with plant-use knowledge and practices of the Dogon, Sarakolé, and Maure ethnic groups in Mali, and what plant species are the most important for local livelihoods.

We aim to address three key questions using ethnobotanical and socio-economic surveys, informed by the SLF methodology:

i) To what extent do natural, human, social, financial, and physical capital relate to plant-use knowledge and the use of native plants among the Dogon, Sarakolé, and Maure people in Mali?
ii) Which specific socio-economic and ecological factors are most strongly correlated with variation in plant-use knowledge?
iii) Which plant species hold the greatest significance for local livelihoods in this context?

By addressing these questions, we investigate the intricate dynamics between livelihoods, plant diversity, plant-use knowledge, and conservation strategies in the Sahel region in Mali, contributing to a more holistic understanding of sustainable development and to the objectives of the GGWSSI and similar large-scale restoration initiatives.

Materials and methods

Project intervention sites in Mali

In Mali, the GGW Cross-border Pilot Project of RBG Kew operated in four districts (Bankass, Bandiagara, Kayes, and Koro), located in the present-day Bandiagara and Kayes regions. At the time of data collection, Bankass, Bandiagara, and Koro belonged to Mopti Region. Local communities depend on natural resources to meet a wide range of livelihood needs and include farmers, agropastoralists, artisans, non-timber forest product processors, traditional healers, collectors of wild plant products, and other natural resource users.

This study focuses on data collected in the districts of Bankass, Bandiagara, and Koro (Bandiagara Region) and Kayes (Kayes Region) (Figure 1). The districts in the Bandiagara Region are characterised by a Sahelian climate and a landscape comprising three main geomorphological units: the Dogon Plateau, the Bandiagara Escarpment, and the sandy Séno Plain. The Dogon Plateau consists predominantly of elevated rocky terrain and is bordered by the Bandiagara Escarpment, which forms a steep transition towards the lower-lying Séno Plain. The Sahelian climate is characterised by high spatial and temporal variability in rainfall, with mean annual precipitation of approximately 500 mm.

The Bankass District extends across the Séno Plain, which stretches from the Dogon Plateau in Mali into Burkina Faso. Soils are predominantly sandy loam, becoming sandy clay in shallow areas, while rocky escarpments occur near the Dogon Plateau. During the hot dry season, the effects of high temperatures are exacerbated by sparse tree cover (Samaké et al., 2013).

The Bandiagara District is located on the Dogon Plateau, an area characterised by substantial climatic variability, with mean annual rainfall ranging from approximately 600 mm in the south to 200 mm in the north. Land cover is dominated by largely bare rocky terrain (Coulibaly et al., 2023).

The Koro District is situated in the Séno Plain, with sandy and sandy-clay soils in its southern part. The landscape is dominated by hills reaching elevations of up to 200 m. The climate is characterised by a long dry season and a short rainy season, with mean annual precipitation ranging from 500 to 600 mm. Vegetation consists predominantly of shrub savanna.

The Kayes District, located in the region of the same name, is bordered by the Bafoulabé District to the east, Senegal to the west, the Kéniéba District to the south, the Yélémané District to the north, and Mauritania further north. The landscape comprises plains, plateaus, and hills reaching elevations of 100–200 m. Soils are generally sandy or clay loam, with rocky areas occurring on plateaus and

hills. The climate is tropical dry, transitioning from Sudanian conditions in the south to Sahelian conditions in the north (Assemblée Malienne des Citoyens, 2009).

Ethnobotanical and socio-economic surveys for identifying useful plants and their importance in household economies

As part of the project's baseline assessments, an ethnobotanical and a socio-economic survey were administered to key informants, following a purposive, non-probability sampling. Respondents, whether affiliated with socio-professional organisations or small and medium agricultural enterprises, were selected according to their professional roles, including traditional healers, nursery operators, environmental protection officers, market gardeners, artisans, and processors of wild-harvested products.

In the Bankass District, respondents were selected from socio-professional organisations (associations and cooperatives) involved in natural resource management, environmental protection, and the processing and valorisation of non-timber forest products (e.g., fruits, nuts, aromatic plants, fodder). In all other districts, respondents were selected from farms designated by the respective Village Councils. Interviews were conducted between 2013 and 2017.

The aim of the ethnobotanical survey was to identify plant species used or demanded by households for land and vegetation cover restoration, based on their needs and current practices. Respondents were asked to list their ten most preferred species and to provide detailed information on their uses, the plant parts used for each purpose, and the perceived abundance of each species. A questionnaire was administered to collect ethnobotanical data, but it is not reproduced in full in the Supplementary Materials, as only five variables derived from it were retained in the final dataset and used in the present study: (i) each respondent's list of ten priority species; (ii) unequivocal species codes; (iii) documented uses of each species; (iv) the plant parts used for each purpose; and (v) the perceived abundance of all species mentioned.

For the socio-economic survey, a closed-ended questionnaire was adapted from previously validated studies (Ceci et al., 2018a; Sacande et al., 2021) and administered to the same individuals who participated in the ethnobotanical survey, with the aim of generating primary data on household livelihood characteristics. When an ethnobotanical respondent was unavailable at the time of the socio-economic interview, a knowledgeable adult member of the same household was invited to participate. In all cases, the questionnaire was completed by a single informant providing information specific to their household. Only one respondent per household was interviewed, thereby avoiding intra-household duplication.

The socio-economic questionnaire was structured into five sections corresponding to the different forms of livelihood capital. The initial questions collected socio-demographic information on the head of the household (Q1, Q2, Q3, and Q7); however, the household head was not necessarily the person responding to the questionnaire. The full questionnaire is provided in **Supplementary Table 1**. The surveys were conducted by technicians from IER, Eaux et Forêts, and the local NGO "SAHEL ECO", accompanied by guides and interpreters. The classification of the ten priority species was left to the discretion of the interviewee.

For the ethnobotanical survey, interviews were completed with 161 key informants. Of these, 152 individuals were successfully invited to participate in the socio-economic survey. The nine households that could not be recontacted were excluded from the final dataset and from all subsequent analyses to maintain internal consistency. The number and gender of respondents interviewed in each district, together with the corresponding survey periods, are reported in **Table 1**.

Table 1: Number of respondents per district and corresponding survey periods. The number of men (M) and women (W) interviewed is shown in parentheses.

Region	**District**	**Ethnobotanical survey**		**Socio-economic survey**	
		# interviewees	**Period**	**# interviewees**	**Period**
Bandiagara	Bankass	12 (11 M, 1 W)	05/2013	12 (11 M, 1 W)	05/2017
Bandiagara	Koro	49 (34 M, 15 W)	05/2015	40 (33 M, 7 W)	03/2016
Bandiagara	Bandiagara	30 (26 M, 4 W)	05/2015	30 (27 M, 3 W)	03/2016
Kayes	Kayes	70 (51 M, 19 W)	04/2016	70 (67 M, 3 W)	04/2016
Total		161 (122 M, 39 W)		152 (138 M, 14 W)	

Given the non-probabilistic sampling strategy, targeting practitioners recognised for their substantive and context-specific knowledge of the topics under investigation, the resulting sample distribution was uneven across regions. Specifically, 82 respondents were from the Bandiagara Region and 70 from the Kayes Region, leading to disparities in ethnic representation: 53.9% Dogon (all from Bandiagara), 32.9% Sarakolé, and 13.2% Maure. A pronounced imbalance was also evident in the gender distribution of household heads, 99.3% of whom were male (only 1 female was the household head). These sampling characteristics were therefore considered when interpreting comparisons among regions, ethnic groups, and household characteristics. The results of this study should not be interpreted as statistically representative of the wider population. The geographical distribution of the survey sites, including the precise location of each village surveyed, is presented in **Figure 1**.

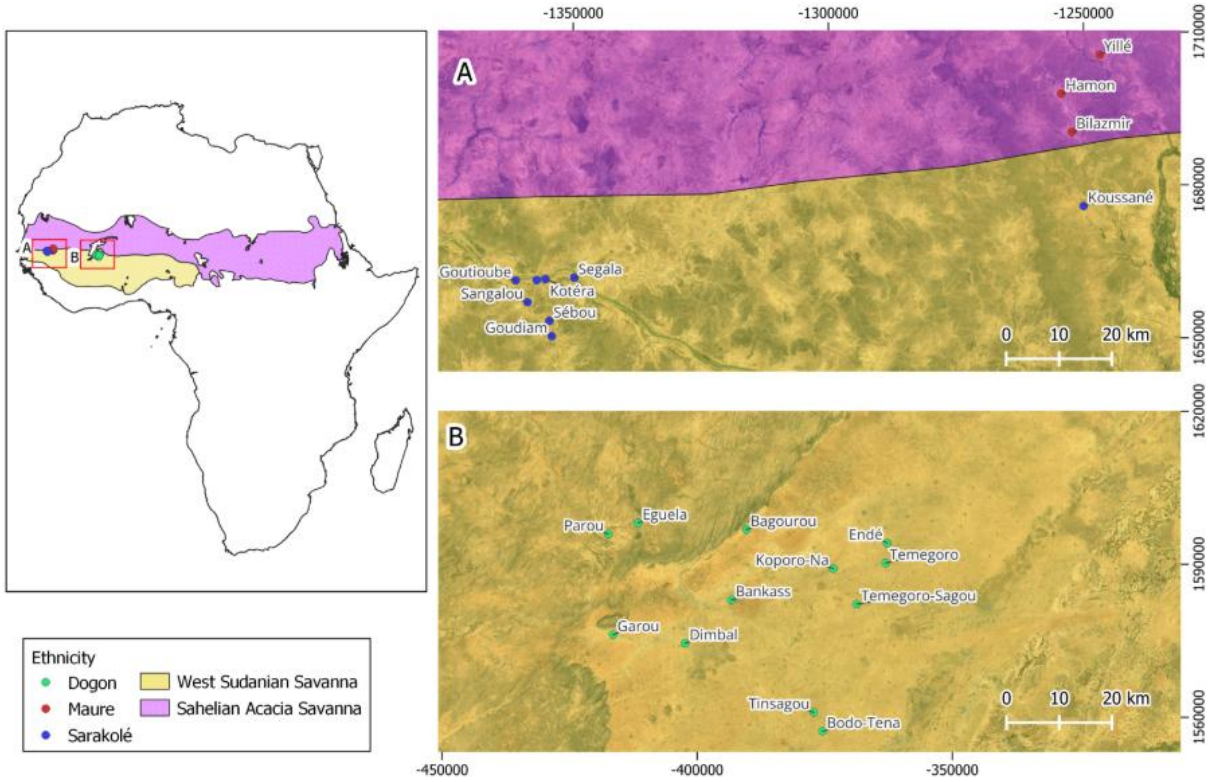


Figure 1: Location of surveyed villages overlaid with ecoregion boundaries and associated ethnic groups.

For Figure 1, spatial boundaries and ecoregion polygons for Mali were derived in QGIS from the Africa Ecoregions shapefile provided by RCMRD Open Data, focusing on the West Sudanian savanna and Sahelian Acacia savanna ecoregions (https://opendata.rcmrd.org/datasets/africa-ecoregions/about).

Survey data was initially recorded on paper questionnaires and subsequently entered into an Excel worksheet. To construct the study dataset, data on the five livelihood capitals associated with each unique identifier were aligned with the corresponding variables derived from the ethnobotanical survey. For each respondent, multiple rows were created in the spreadsheet to document each plant part used for every reported purpose across all species mentioned. In the analytical framework, the livelihood variables were treated as explanatory variables, whereas the ethnobotanical variables were considered as response variables to characterise plant-use knowledge and practices.

Data analysis

All statistical analyses were carried out using R version 4.2.3 (2023-03-15) "Shortstop Beagle" (R Foundation for Statistical Computing, Vienna, Austria). The code and data supporting the findings of this study are openly available at https://github.com/MaraevaGianella/GGW_Mali (https://doi.org/10.5281/zenodo.19853517) under MIT License (code) and CC BY 4.0 (data). The mapping between anonymised participant IDs and original field identifiers is not publicly available to protect participant confidentiality.

Prior to statistical analysis, to simplify and enhance the interpretability of certain nested variables within the socio-economic section of the dataset, we grouped specific questions into broader

subcategories. For questions where respondents provided binary answers (e.g., 1 for "yes", and 0 for "no"), indicating the presence or absence of a particular attribute or behaviour, we aggregated the responses into categories based on the total count of positive responses. For example, in a question set that asked whether respondents employed a series of techniques or strategies (with multiple binary options), individual responses were grouped into broader categories according to the number of techniques or strategies applied (e.g.: 1-2 techniques, 3-4 techniques, etc.). By summarising the data in this way, we preserved key variations while making the dataset more manageable for analysis.

Factor Analysis of Mixed Data

To summarise the information within the livelihood dataset, separate Factor Analyses of Mixed Data (FAMD) were conducted for each capital (human, social, natural, physical, and financial) of the livelihood assets, in order to extract the most relevant information from each thematic block. We excluded constants (single-level factors), and descriptive variables (i.e., IDs, years of the interviews), and species-specific questions (see questions and sub-questions Q54 and Q55 in **Supplementary Table 1**). The first five dimensions were retained. Ethnicity, religion and region were used as qualitative supplementary variables. Variable selection relied on two complementary diagnostics: (i) contribution, to capture which variables most strongly *build* the factorial dimensions, and (ii) Cos^2, to quantify the *quality of representation* of each variable on the factorial map. We first retained variables for which contribution exceeded the average expected contribution (100/p) on at least one of the first five dimensions. Among these candidates, we ranked variables by their maximum Cos^2 across the same dimensions.

Taxonomic reconciliation and ethnobotanical indices

For the ethnobotanical data, we performed taxonomic reconciliation of the list of total species mentioned using Plants of the World Online (POWO, https://powo.science.kew.org/), specifically referencing the World Checklist of Vascular Plants, to ensure that all plant taxa were identified and aligned with the most current botanical nomenclature.

Following taxonomic validation, we identified the taxa cultivated at the time of the interviews based on on-site identification by expert co-authors familiar with the local flora. Cultivated taxa were subsequently removed from the ethnobotanical analyses so that these analyses focused on wild or semi-wild taxa and the knowledge associated with their use.

We computed several ethnobotanical indices to assess the significance of each species within the dataset, using the *ethnobotanyR* package (Whitney, 2022) for all calculations except for the Plant Part Value Index. The indices calculated for each species are presented in **Table 2**.

Table 2. Indices calculated for each species.

Metric	Description	Citation
Use Report (UR)	The number of individual reports of use within the dataset.	Prance et al., 1987
URsum	The sum of all use reports (UR) across all species in the dataset.	Prance et al., 1987
Cultural Importance Index (CI)	Indicates the significance of each species within the	Tardio and Pardo-de-Santayana, 2008

	cultural context of the study area.	
Frequency of Citation (FC)	Represents how often a species was mentioned by informants during interviews.	Prance et al., 1987
Number of Uses (NU)	Quantifies the different uses reported for each species.	Prance et al., 1987
Relative Frequency of Citation (RFC)	Provides insight into the proportion of citations each species received relative to the total citations.	Tardio and Pardo-de-Santayana, 2008
Relative Importance Index (RI)	Summarises the overall significance of each species based on the frequency and diversity of its reported uses.	Tardio and Pardo-de-Santayana, 2008
Use Value (UV)	Reflects the overall utility of each species as reported by informants.	Tardio and Pardo-de-Santayana, 2008
Cultural Value (CVe)	Assesses the cultural, practical, and economic importance of species.	Reyes-Garcia et al., 2006
Fidelity Level (FL)	Indicates the percentage of informants who use a particular plant for the same purpose relative to all reported uses of that plant.	Friedman et al., 1986

The Plant Part Value Index (PPV) (Chaachouay et al., 2019) was calculated as the ratio of the total reported uses for each plant part to the total number of reported uses for a given plant. Higher PPV values therefore indicate a greater relative contribution of a particular plant part to the reported uses of that species.

Plant-use knowledge index

To quantify individual knowledge of plant use, we developed a proxy index integrating three dimensions of the ethnobotanical information reported by each respondent: the number of plant species mentioned by each respondent, plant part used, and associated uses.

Because respondents were not presented with a fixed list of species and were permitted to name a maximum of ten species, the survey did not constitute a complete free-listing exercise, and the resulting index should therefore be interpreted as a study-specific proxy for selected dimensions of plant-use knowledge, and not as a comprehensive measure of Traditional Ecological Knowledge.

We computed an index for plant-use knowledge using Correspondence Analysis (CA), a multivariate technique suitable for exploring relationships among categorical variables. CA was applied to a matrix summarising, for each respondent, the number of species, plant parts, and uses reported. The resulting components capture the main gradients of variation in plant-use knowledge across individuals.

The index was calculated as a weighted combination of the CA component scores, using the proportion of variance explained by each axis as weights. Although multiple dimensions were

produced, the first two axes accounted for the majority of the explained variability and were therefore used to construct the final index.

The IndexCA provides a synthetic, study-specific measure of reported plant-use knowledge. It is not based on a predefined or validated scale, and it accounts for limitations in the data collection process.

The resulting index provided a single value per individual, which was later used in modelling against the socio-economic variables. The relationships between IndexCA and livelihood variables were explored using stepwise regression, starting with a null model (no predictors), and then bidirectional (both-direction) stepwise selection to iteratively add or remove socio-economic variables based on the change in Akaike Information Criterion (AIC) they produced.

This procedure allowed identifying the most important predictors while minimising overfitting. After selecting the significant predictors, we built a final model that included only the selected variables. The most significant predictors were identified by sorting by |t| value and their effect size was estimated based on |β| values exceeding Median |β| (Cohen, 1988).

Use of AI

AI-based language models (Claude, Anthropic; ChatGPT, OpenAI) were used to assist with grammar and clarity editing, statistical verification, bibliography search and checking, and code debugging during manuscript preparation. All AI-assisted content was reviewed and verified by the authors, who take full responsibility for the accuracy and integrity of the final manuscript.

Results

Summary of the dataset

Table 3 summarises the demographic information and education level of the household heads of the 152 respondents, together with households' ethnicity and religious affiliation.

Table 3. Socio-demographic characteristics of respondents' household (HH) heads.

Category	Sub-category	Number	Percentage
HH head age class	20 to 35 years	13	8.6%
	36 to 50 years	38	25.0%
	51 to 65 years	65	42.8%
	Above 65 years	36	23.7%
HH head gender	Male	151	99.3%
	Female	1	0.7%
HH head education	Never been to school	114	75.0%
	Koranic school	11	7.2%
	Primary not completed	15	9.9%

	Secondary not completed	2	1.3%
	Primary completed	5	3.3%
	Secondary completed	3	2.0%
	University degree	1	0.7%
	Professional technical school	1	0.7%
Ethnicity	Dogon	82	53.9%
	Maure	20	13.2%
	Sarakolé	50	32.9%
Religion	Muslim	151	99.3%
	Christian	1	0.7%

Factor Analysis of Mixed Data

FAMD was applied to each of the five capitals (human, social, natural, physical, and financial) to identify the variables with the greatest explanatory contribution to the dataset. The first five dimensions were retained for each capital based on eigenvalues and cumulative variance explained. Variables exceeding the mean expected contribution (100/p) were retained for interpretation, and dimensions were labelled based on the magnitude of variable coordinates, with cos^2 values to assess representation quality.

Table 4 summarises the eigenvalues and cumulative variance explained by the dimensions retained.

Supplementary Table 2 provides the FAMD dimensions interpretation. For each dimension, variables are ranked by contribution (%) and interpreted according to variable coordinates sorted in descending order of magnitude.

Biplots for the five capitals, illustrating the relationships between the key socio-economic variables and the clusters formed by the different ethnic groups, are shown in **Supplementary Figure 1**.

The resulting dimensions revealed capital-specific gradients: human capital combined adaptive livelihood practices with food stress and coping responses; social capital reflected community participation and reciprocal support networks; natural capital captured land degradation, deforestation, and changes in vegetation and water availability; physical capital described variation in housing and access to infrastructure; and financial capital reflected livelihood diversification, credit access, and market integration.

Table 4. Summary of FAMD results by capital. The table presents the eigenvalues and cumulative variance explained by the first five dimensions, along with the number of included variables and dimension label.

Capital	Dimension	Eigenvalue	Cumulative Variance %	N of variables	Label
Human	Dim. 1	5.76	9.60	8	Adaptive Human Capacity and Livelihood Response Gradient
	Dim. 2	3.67	15.72	7	Food Stress Exposure and Nutritional Stability Gradient
	Dim. 3	3.12	20.91	8	School Attendance and Adaptive Capacity Gradient

	Dim. 4	2.70	25.41	6	Household Education and Knowledge Transmission Gradient
	Dim. 5	2.56	29.68	12	Household Food Stress and Subsistence Practices Gradient
Social	Dim. 1	2.54	15.90	4	Community Participation and Reciprocal Support Gradient
	Dim. 2	1.97	28.24	4	Reciprocal Labour Exchange and Group Involvement Gradient
	Dim. 3	1.86	39.86	3	Women's Leadership and Support Network Gradient
	Dim. 4	1.37	48.42	3	Place Attachment and Community Integration Gradient
	Dim. 5	1.28	56.42	3	Community Engagement and Place Attachment Gradient t
Natural	Dim. 1	5.77	8.48	9	Natural Resource Pressure and Governance Gradient
	Dim. 2	4.71	15.41	7	Perceived Climate Change and Risk Response Gradient
	Dim. 3	4.11	21.46	9	Environmental Stress, Land Access and Plant Resource Gradient
	Dim. 4	2.96	25.81	9	Resource Availability and Landscape Change Gradient
	Dim. 5	2.67	29.74	10	Ecosystem Pressure and Plant Resource Use Gradient
Physical	Dim. 1	2.34	13.02	5	Household Housing and Local Service Infrastructure Gradient
	Dim. 2	1.93	23.76	5	Productive Assets and Market Access Infrastructure Gradient
	Dim. 3	1.71	33.27	4	Household Living Conditions and Local Infrastructure Gradient
	Dim. 4	1.70	42.72	5	Housing Conditions and Market Accessibility Gradient
	Dim. 5	1.29	49.88	4	Productive Assets and Local Processing Infrastructure Gradient
Financial	Dim. 1	3.61	13.35	6	Financial Inclusion and Forest-Related Income Gradient
	Dim. 2	2.08	21.04	5	Livelihood Diversification and Market Integration Gradient
	Dim. 3	1.62	27.03	5	Livelihood Performance and Income Stability Gradient
	Dim. 4	1.48	32.50	3	Credit Access and Livelihood Market Constraints Gradient
	Dim. 5	1.39	37.65	5	Livelihood Structure and Cash-Crop Economy Gradient

Ethnobotanical indices and IndexCA

An overview of the ethnobotanical data revealed that 81 plant taxa were reported by the respondents. **Supplementary Table 3** presents a summary of the plant taxonomy along with their taxonomic status, accepted names, authorship, origin, and cultivation status. Following taxonomic reconciliation, 32 cultivated taxa were excluded, resulting in 49 wild or semi-cultivated taxa used for the ethnobotanical analyses. Five of the 152 respondents were also excluded from these analyses because their reported knowledge pertained solely to cultivated taxa.

Only one respondent listed all ten species, the maximum number permitted by the questionnaire, while 5 respondents mentioned only a single species. The mean number of species cited per respondent was 4.01, with a median of 4. In total, respondents provided 590 species citations.

The three most cited species, among the non-cultivated taxa, were *Sclerocarya birrea* (A.Rich.) (marula) Hochst., *Lannea microcarpa* Engl. & K.Krause (African grapes), and *Senegalia senegal* (L.) Britton (formerly *Acacia senegal* (L.) Willd; gum arabic tree). They are utilised for human food, animal feed, human health purposes, timber and lumber production, artisanal craftsmanship, and beekeeping (Lykke et al., 2004; Wezel & Haigis, 2002). The plant parts used encompass fruits, leaves, bark, roots, trunk, sap, and flowers. Of all species, the most important genera include *Vachellia* Wight & Arn. (Fabaceae Lindl.), *Ficus* Tourn. ex L. (Moraceae Gaudich.), and *Combretum* Loefl. (Combretaceae R.Br.). Fabaceae is the most common family of plants (30.6%) from the study, followed by Combretaceae (12.2%), and Malvaceae (8.2%). **Figure 2** shows the Frequency of Citation (FC) for each of the retained plant species cited by the respondents, and **Supplementary Table 4** displays the percentage of the respective plant families and their number and percentage of citation.

Table 5 summarises the ethnobotanical indices calculated for each species. *Sclerocarya birrea* had the highest number of use reports (UR = 634), and the greatest cultural significance (CI = 4.313) (Tardio & Pardo-de-Santayana, 2008; Sop et al., 2012), followed by *S. senegal* with 234 use reports and a CI of 1.592. These species are primarily used for animal food, human health, and various artisanal products. Other species, like *L. microcarpa* (UR = 224, CI = 1.524) and *Mitragyna inermis* (Willd.) Kuntze (false abura) (UR = 132, CI = 0.898) also showed substantial cultural importance.

The most cited uses across species include human food, human health, and wood products (timber and lumber). For instance, *Bombax costatum* Pellegr. & Vuillet (red-flowered silk cotton tree) and *Ficus platyphylla* Delile (broadleaf fig) were frequently cited for their contributions to human nutrition and health, whereas *Vitex doniana* Sweet (black plum) and *Ziziphus mucronata* Willd. (buffalo thorn) were primarily recognised for their medicinal properties.

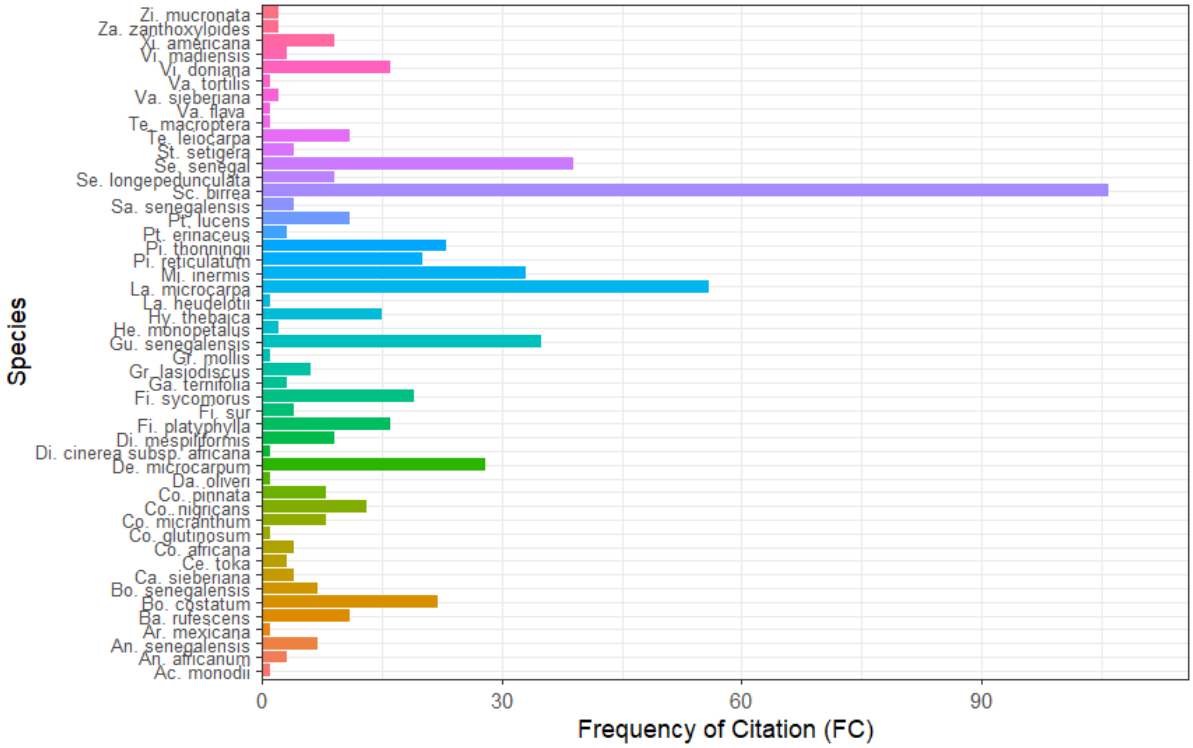


Figure 2. Frequency of Citation (FC) for each plant species cited by the respondents. FC represents the number of informants who mentioned a given species for any use. Higher FC values indicate greater recognition and potential cultural importance of species within the study area.

Table 5. Ethnobotanical indices by species, and information on taxonomic family, endemism, and IUCN Red List status. UR = Use Report, CI = Cultural Importance, FC = Frequency of Citation, NU = Number of Uses, RFC = Relative Frequency of Citation, RI = Relative Importance, UV = Use Value, CVe = Cultural Value, FL = Fidelity Level. Endemic: Y = Yes (endemic species), N = No | IUCN: LC = Least Concern, EN = Endangered, VU = Vulnerable, - = Not Assessed | FL = Fidelity Level (%) — percentage of informants citing the species for its primary use. Primary use indicates the use category with the highest Fidelity Level (FL) score for each species; where two or more categories share the same highest FL value, all are listed as co-primary uses. Primary Use categories: HumanHealth = medicinal/health uses; HumanFood = food for humans; AnimalFood = fodder/feed for animals; AnimalHealth = veterinary uses; Wood = timber/construction; Dyeing = dye production. Colour scale applied to UR, RI, UV, CVe and FL columns: white = lowest value, deep red = highest value.

Taxon	Author	UR	CI	FC	NU	RFC	RI	UV	CVe	Family	Endemic	IUCN	Primary Use	FL (%)
Acridocarpus monodii	Arènes & P.Jaeger ex Birnbaum & J.Florence	**3**	0.020	1	1	0.020	**0.104**	**0.020**	0.000	Malpighiaceae	**Y**	**EN**	HumanHealth	**100**
Anonychium africanum	(Guill. & Perr.) C.E.Hughes & G.P.Lewis	**18**	0.122	3	5	0.082	**0.514**	**0.122**	0.004	Fabaceae	N	LC	HumanHealth	**50**
Annona senegalensis	Pers.	**33**	0.224	7	3	0.184	**0.332**	**0.224**	**0.009**	Annonaceae	N	LC	HumanHealth	**77.78**
Argemone mexicana	L.	**3**	0.020	1	1	0.020	**0.104**	**0.020**	0.000	Papaveraceae	N	-	HumanHealth	**100**
Bauhinia rufescens	Lam.	**44**	0.299	11	1	0.299	**0.152**	**0.299**	0.006	Fabaceae	N	LC	HumanHealth	**100**
Bombax costatum	Pellegr. & Vuillet	**105**	0.714	22	3	0.714	**0.424**	**0.714**	**0.109**	Malvaceae	N	LC	HumanHealth	**59.05**
Boscia senegalensis	Lam.	**28**	0.190	7	3	0.184	**0.332**	**0.190**	**0.007**	Capparaceae	N	LC	HumanHealth	**77.78**
Cassia sieberiana	DC.	**28**	0.190	4	3	0.136	**0.324**	**0.190**	0.006	Fabaceae	N	LC	AnimalHealth, Human Health	**60**
Celtis toka	(Forssk.) Hepper & J.R.I.Wood	**9**	0.061	3	3	0.027	**0.305**	**0.061**	0.000	Cannabaceae	N	LC	HumanHealth, AnimalFood, Shade	**75**
Commiphora africana	(A.Rich.) Engl.	**18**	0.122	4	3	0.095	**0.317**	**0.122**	0.002	Burseraceae	N	LC	HumanHealth	**78.57**
Combretum glutinosum	Perr. ex DC.	**5**	0.034	1	3	0.027	**0.305**	**0.034**	0.000	Combretaceae	N	LC	HumanHealth	**75**

Combretum micranthum	G.Don	**22**	0.150	8	2	0.150	**0.226**	**0.150**	0.003	Combretaceae	N	LC	HumanHealth	**81.82**
Combretum nigricans	Lepr. ex Guill. & Perr.	**38**	0.259	13	2	0.259	**0.245**	**0.259**	**0.010**	Combretaceae	N	LC	HumanHealth	**65.79**
Cordyla pinnata	(A.Rich.) Milne-Redh.	**48**	0.327	8	4	0.218	**0.438**	**0.327**	**0.020**	Fabaceae	N	LC	HumanHealth, AnimalFood	**50**
Daniellia oliveri	(Rolfe) Hutch. & Dalziel	**4**	0.027	1	1	0.027	**0.105**	**0.027**	0.000	Fabaceae	N	LC	HumanHealth	**100**
Detarium microcarpum	Guill. & Perr.	**112**	0.762	28	3	0.762	**0.432**	**0.762**	**0.124**	Fabaceae	N	LC	HumanHealth	**50**
Dichrostachys cinerea subsp. africana	Brenan & Brummitt	**3**	0.020	1	1	0.020	**0.104**	**0.020**	0.000	Fabaceae	N	LC	HumanHealth	**100**
Diospyros mespiliformis	Hochst. ex A.DC.	**45**	0.306	9	4	0.306	**0.453**	**0.306**	**0.027**	Ebenaceae	N	LC	HumanHealth	**40**
Ficus platyphylla	Delile	**66**	0.449	16	3	0.333	**0.358**	**0.449**	**0.032**	Moraceae	N	LC	HumanHealth, Animal Food	**65.31**
Ficus sur	Forssk.	**16**	0.109	4	2	0.088	**0.215**	**0.109**	0.001	Moraceae	N	LC	HumanHealth, Animal Food	**61.54**
Ficus sycomorus	L.	**91**	0.619	19	2	0.490	**0.285**	**0.619**	**0.043**	Moraceae	N	LC	HumanHealth	**77.78**
Gardenia ternifolia	Schumach. & Thonn.	**7**	0.048	3	1	0.048	**0.108**	**0.048**	0.000	Rubiaceae	N	LC	HumanHealth	**100**
Grewia lasiodiscus	K.Schum.	**22**	0.150	6	3	0.143	**0.325**	**0.150**	0.005	Malvaceae	N	LC	HumanHealth	**76.19**
Grewia mollis	Juss.	**4**	0.027	1	2	0.027	**0.205**	**0.027**	0.000	Malvaceae	N	LC	HumanHealth	**100**

Guiera senegalensis	J.F.Gmel.	**116**	0.789	35	2	0.714	**0.324**	**0.789**	**0.081**	Combretaceae	N	LC	HumanHealth	**99.05**
Hexalobus monopetalus	(A.Rich.) Engl. & Diels	**8**	0.054	2	2	0.054	**0.209**	**0.054**	0.000	Annonaceae	N	LC	HumanHealth	**75**
Hyphaene thebaica	(L.) Mart.	**45**	0.306	15	3	0.306	**0.353**	**0.306**	**0.020**	Arecaceae	N	LC	HumanFood, AnimalFood, Wood	33.33
Landolphia heudelotii	A.DC.	2	0.014	1	1	0.014	0.102	0.014	0.000	Apocynaceae	N	-	AnimalFood	**100**
Lannea microcarpa	Engl. & K.Krause	**224**	1.524	56	2	1.524	**0.465**	**1.524**	**0.332**	Anacardiaceae	N	LC	HumanHealth	**75**
Mitragyna inermis	(Willd.) Kuntze	**132**	0.898	33	2	0.898	**0.356**	**0.898**	**0.115**	Rubiaceae	N	LC	HumanHealth	**75**
Piliostigma reticulatum	(DC.) Hochst.	**83**	0.565	20	3	0.429	**0.374**	**0.565**	**0.052**	Fabaceae	N	-	HumanHealth	**63.49**
Piliostigma thonningii	(Schumach.) Milne-Redh.	**94**	0.639	23	3	0.483	**0.384**	**0.639**	**0.066**	Fabaceae	N	-	Dyeing, Human Health	**64.79**
Pterocarpus erinaceus	Poir.	**15**	0.102	3	3	0.082	**0.314**	**0.102**	0.002	Fabaceae	N	**EN**	HumanHealth	**75**
Pterocarpus lucens	Lepr. ex Guill. & Perr.	**23**	0.156	11	3	0.156	**0.327**	**0.156**	0.005	Fabaceae	N	LC	Wood, Animal Food	**47.83**
Saba senegalensis	(A.DC.) Pichon	**16**	0.109	4	3	0.082	**0.314**	**0.109**	0.002	Apocynaceae	N	LC	HumanHealth	**66.67**
Sclerocarya birrea	(A.Rich.) Hochst.	**634**	4.313	106	3	2.878	**0.800**	**4.313**	**2.659**	Anacardiaceae	N	LC	HumanHealth	**74.94**
Securidaca longepedunculata	Fresen.	**25**	0.170	9	1	0.170	**0.130**	**0.170**	0.002	Polygalaceae	N	LC	HumanHealth	**100**

Senegalia senegal	(L.) Britton	**234**	1.592	39	5	1.592	**0.777**	**1.592**	**0.905**	Fabaceae	N	LC	HumanHealth	33.33
Sterculia setigera	Delile	**15**	0.102	4	2	0.102	**0.218**	**0.102**	0.001	Malvaceae	N	LC	HumanHealth	**80**
Terminalia leiocarpa	(DC.) Baill.	**54**	0.367	11	5	0.224	**0.539**	**0.367**	**0.029**	Combretaceae	N	LC	HumanHealth	**66.67**
Terminalia macroptera	Guill. & Perr.	**5**	0.034	1	3	0.027	**0.305**	**0.034**	0.000	Combretaceae	N	LC	HumanHealth	**75**
Vachellia flava	(Forssk.) Kyal. & Boatwr.	1	0.007	1	1	0.007	0.101	0.007	0.000	Fabaceae	N	-	AnimalFood	**100**
Vachellia sieberiana	(DC.) Kyal. & Boatwr.	**6**	0.041	2	1	0.041	**0.107**	**0.041**	0.000	Fabaceae	N	LC	HumanHealth	**100**
Vachellia tortilis	(Forssk.) Galasso & Banfi	**5**	0.034	1	3	0.027	**0.305**	**0.034**	0.000	Fabaceae	N	LC	HumanHealth, Animal Food	**50**
Vitex doniana	Sweet	**73**	0.497	16	3	0.435	**0.376**	**0.497**	**0.046**	Lamiaceae	N	LC	HumanHealth	**75**
Vitex madiensis	Oliv.	**9**	0.061	3	1	0.061	**0.111**	**0.061**	0.000	Lamiaceae	N	LC	HumanHealth	**100**
Ximenia americana	L.	**36**	0.245	9	2	0.245	**0.243**	**0.245**	**0.009**	Olacaceae	N	LC	HumanHealth	**75**
Zanthoxylum zanthoxyloides	(Lam.) Zepern. & Timler	**6**	0.041	2	1	0.041	**0.107**	**0.041**	0.000	Rutaceae	N	LC	HumanHealth	**100**
Ziziphus mucronata	Willd.	**8**	0.054	2	2	0.041	**0.207**	**0.054**	0.000	Rhamnaceae	N	LC	HumanHealth	**100**

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The analysis of plant uses provided key insights into the Fidelity Levels (FL) associated with different species and their primary applications, as presented in **Table 5**. Several species exhibited particularly high fidelity, underscoring their importance to local communities. Eleven taxa showed 100% fidelity for their primary use in human health. Likewise, *Vachellia flava* (Forssk.) Kyal. & Boatwr. (former *Acacia flava* (Forssk.) Schweinf.; salam) and *Vachellia sieberiana* (DC.) Kyal. & Boatwr. (former *Acacia sieberiana* DC.; paperbark acacia) displayed complete fidelity to their roles as sources of animal food and contributors to human health, respectively. In contrast, the dataset also highlighted multipurpose species with low fidelity levels, reflecting their broad range of applications within the communities. For instance, *Anonychium africanum* (Guill. & Perr.) C.E. Hughes & G.P. Lewis (African mesquite) is used for human food, fertiliser, wood, and artisanal crafts, yet its highest fidelity value reaches only 50% for human health.

Plant Part Value

The analysis of the Plant Part Value Index (PPV) revealed varying degrees of reliance on different plant parts. The most frequently utilised part across all taxa included leaves, fruits, and bark, as illustrated in **Figure 3**.

For example, *Acridocarpus monodii* (Arènes & P. Jaeger ex Birnbaum & J. Florence), the only endemic species recorded, with a 100% FL for human health, is used for multiple plant parts, including bark, leaves, and roots, each with a PPV of approximately 33%. Some species show a much narrower pattern of use: *Vachellia flava* is valued exclusively for its leaves (PPV = 100%), while *Celtis toka* (Forssk.) Hepper & J.R.I. Wood is used primarily for its leaves, with only minor reliance on its roots.

By contrast, *Senegalia senegal* (L.) Britton had the greatest diversity of plant parts reported, with six different parts utilised (bark, flowers, leaves, roots, sap, and trunk).

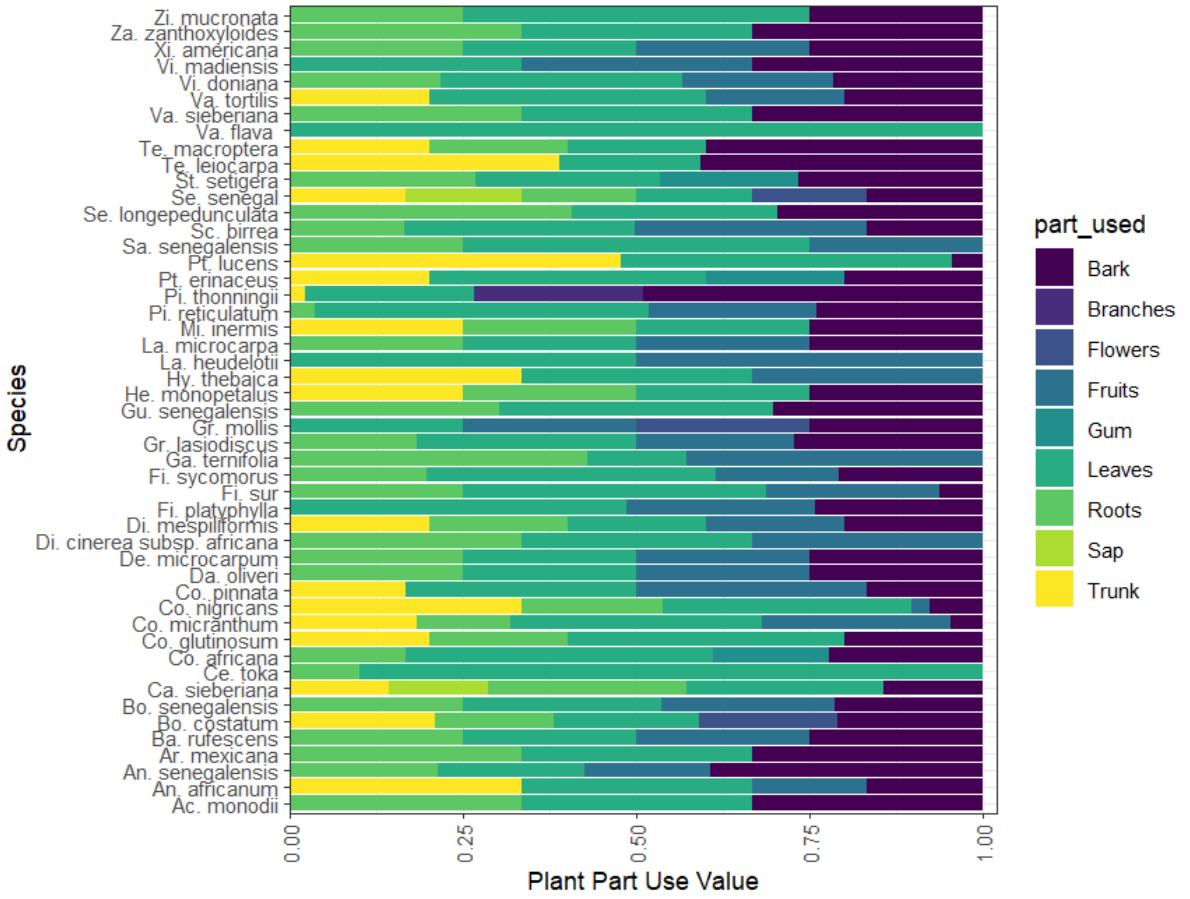


Figure 3. Stacked bar plot showing the distribution of Plant Part Values (PPV) across species used by households. Each bar represents the proportional use of different plant parts (e.g., bark, leaves, fruits) for each species. Detailed PPV values for all species are provided in **Supplementary Table 5**.

Plant-use knowledge index

The IndexCA values among participants ranged from -0.337 to 0.414, indicating variability in plant-use knowledge levels within the sample. The mean IndexCA was -0.003 (± 0.141), with a median of 0.010. This indicates a generally low to moderate plant-use knowledge level across the sample, with a slight skew in distribution toward lower values. The mean and median being close to zero indicate that plant-use knowledge is, on average, evenly distributed without large outliers among respondents.

Regression analysis of plant-use knowledge (indexCA)

To examine the influence of livelihood assets on plant-use knowledge, we modelled IndexCA against socio-economic and environmental predictors using stepwise regression. Starting from a null model, bidirectional stepwise selection based on the Akaike Information Criterion (AIC) converged on a final model comprising ethnic background and 20 socio-economic and environmental predictors (see **Supplementary Table 6** for full model estimates). The model intercept is estimated at 0.832 ($p < 0.001$), representing the expected value of IndexCA in the absence of other predictors.

The final model achieved an AIC of −297.11, an R^2 of 0.767 (explaining 76.7% of the variance in IndexCA), an adjusted R^2 of 0.691, and a residual standard error of 0.0786, indicating strong explanatory power once model complexity is taken into account.

The predictors with significant effects on the IndexCA outcome are presented in **Supplementary Table 7**. Predictors were sorted by |t| value and their effect size are estimated based on |β| values exceeding Median |β| (Cohen, 1988). Subsequent discussion only considers predictors with high effect on the dependent variable, presented in **Table 6**.

Table 6. Subset of predictors from the final regression model, high effect only (full results in Supplementary Table 6). Variable meaning, key coefficient, standard error, significance levels, |t| and |β| value, and effect size of the predictors retained in the final regression model, sorted by decreasing |t| value. Effect size is classified as High when |β| exceeds the median |β| (= 0.214; Cohen, 1988). Variable codes correspond to questionnaire items in Supplementary Table 1.

Variable	Variable meaning	Estimate	Std. Error	t value	Pr(>|t|)	|t|	|β|	Effect size / relevance
EthniesMaure	Household belongs to the Maure ethnic group	-0.268	0.038	-7.101	1.29E-10	7.101	0.268	High effect
Q38No	Household reports that average temperatures have not increased in the last 10 years	-0.446	0.084	-5.294	6.17E-07	5.294	0.446	High effect
Q38Yes	Household reports that average temperatures have increased in the last 10 years	-0.326	0.070	-4.681	8.20E-06	4.681	0.326	High effect
Q57Some	Household uses some plant parts	0.305	0.069	4.413	2.39E-05	4.413	0.305	High effect
Q56Several	Household uses several plant/tree products (fuelwood, timber, charcoal, etc.)	-0.282	0.068	-4.126	7.21E-05	4.126	0.282	High effect
Q56Some	Household uses some plant/tree products	-0.281	0.073	-3.832	0.000	3.832	0.281	High effect
Q57Several	Household uses several plant parts (leaves, bark, trunk, roots, etc.)	0.254	0.069	3.679	0.000	3.679	0.254	High effect
Q51Several	Household identifies several causes of deforestation	0.229	0.067	3.431	0.001	3.431	0.229	High effect
Q59No	Women and youth do not participate in risk/disaster management	0.242	0.073	3.302	0.001	3.302	0.242	High effect
Q37Yes	Natural water points have dried up in the last 5 years	-0.216	0.072	-3.012	0.003	3.012	0.216	High effect

Q03Married	Household head is married	-0.258	0.088	-2.943	0.004	2.943	0.258	High effect
Q72Cattle	Household's main livelihood is livestock	-0.214	0.101	-2.109	0.037	2.109	0.214	High effect

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Nine of the most significant predictors are associated with natural capital, and one each with ethnic group, human capital and financial capital.

Two of the strongest predictors in the model are related to perceived climate change: Average temperatures have increased in the last ten years (Q38, natural capital). The coefficients associated with this variable are negative, indicating that households reporting stable or rising temperatures tend to be associated with lower values of IndexCA, relative to the reference category.

Important predictors also relate to the use of plant and forest resources: Parts of plants/trees used by the household for uses other than food (Q57, natural capital). The positive coefficients associated with both "some" and "several" plant parts used, indicate that patterns of resource extraction are strongly associated with IndexCA. This variable captures the interaction between livelihoods and natural resource use. Other key predictors relate to different patterns of resource use: Products extracted by the household from plants/trees besides food (Q56, natural capital). The negative coefficients linked to both "several" and "some" products extracted, show a negative effect on the IndexCA outcome.

Ethnic background emerged as a strong predictor of IndexCA. Specifically, membership in the Maure ethnic group was associated with a decrease of 0.268 units in IndexCA ($p < 0.01$), while belonging to the Sarakolé ethnic group was associated with a decrease of 0.081 units ($p < 0.05$), relative to the reference category (Dogon).

Marital status of the household (Q03, human capital) revealed to have a negative correlation with the IndexCA when the head is married, highlighting the importance of household structure.

Another important predictor relates to risk and disaster management: Women and youth in the household take an active part in risk and disaster management (Q59, natural capital). This variable is at the interface between natural resources and community participation. The coefficients are positive, suggesting that communities where women and youth are not involved in risk management tend to be associated with higher values of IndexCA.

Causes of deforestation (Q51, natural capital) emerges as one of the predictors with a relatively large coefficient magnitude in the regression model. Households identifying "several" causes of deforestation show a positive correlation with IndexCA. Another important predictor relates to water resources: Natural water points have dried up in the last five years (Q37, natural capital). The negative coefficients indicate that areas where water points have dried up are associated with lower values of the dependent variable.

Finally, livelihood strategies also play a role, as pointed out by: First source of livelihoods of the household (Q72, financial capital). When livestock is the first source, the variable coefficient is negative, indicating that households relying primarily on livestock tend to be associated with lower value of IndexCA.

Main Findings

This study investigated the socio-economic and environmental drivers shaping household plant-use knowledge in two regions of Mali within the context of the GGW. By integrating ethnobotanical indices, FAMD, and regression modelling, the research examined how the five livelihood capitals (human, social, natural, financial, and physical) relate to variations in plant-use knowledge. The most relevant plant species for local restoration and livelihoods were also identified.

Sample Characteristics

The sample comprised 152 respondents, 99.3% of data pertained to male heads of households, and predominantly Muslim (99.3%). The sample showed low education levels, with 75% of the respondents having never attended school, and with only two individuals having received university education. The ethnic distribution was uneven, with 53.9% of the respondents belonging to the Dogon ethnic group (Bandiagara region), 32.9% to the Sarakolé ethnic group (Kayes), and 13.2% to the Maure ethnic group (Kayes). This was because, despite the effort to keep a balance between the respondents across the two regions, the surveyed districts of the Bandiagara Region are inhabited predominantly by Dogon people, while different ethnic groups live in the Kayes District.

FAMD Results

FAMD analysis on the five capitals of the livelihood assets (human, social, natural, physical and financial) was used to characterise the population and understand the context around plant-use knowledge and knowledge transmission. It highlights a multidimensional configuration of household livelihood conditions in the study area. Human capital dimensions primarily combine adaptive livelihood practices, such as climate adaptation strategies, agricultural knowledge, and technical training, with experiences of food stress and coping responses, suggesting that adaptive capacity is often mobilised in response to livelihood pressures. Other dimensions emphasise the role of schooling and intergenerational knowledge transmission in shaping household capabilities.

Within the social capital domain, the main gradients reflect community participation, reciprocal labour exchange, and women's involvement in collective organisations and decision-making processes, pointing to the importance of locally embedded networks of cooperation and mutual support.

Natural capital dimensions capture several interacting environmental dynamics, including land degradation, deforestation pressures, changes in vegetation and water availability, and land-use pressures. These gradients indicate that households experience environmental change through multiple ecological processes affecting the condition and accessibility of natural resources.

The physical and financial capital dimensions further describe variation in household infrastructure, productive assets, and livelihood organisation. While physical capital mainly reflects differences in housing conditions, equipment, and access to local services, financial capital highlights variation in livelihood diversification, access to credit, and integration into local markets and agricultural value chains.

Overall, the FAMD results suggest that household livelihoods are structured by interacting social, environmental, infrastructural, and economic conditions that shape the broader context within which plant knowledge and use are embedded.

Ethnobotanical Insights

The most cited species were *Sclerocarya birrea*, *Senegalia senegal*, and *Lannea microcarpa*. *Senegalia senegal* had the greatest diversity of plant parts reported and resulted second in terms of use reports and cultural significance, following *Sclerocarya birrea*. The only endemic species recorded was *Acridocarpus monodii* Arènes & P. Jaeger ex Birnbaum & J. Florence, with a 100% FL for human health, which is used for multiple plant parts, including bark, leaves, and roots, each with a PPV of approximately 33%. Generally, the most reported uses across the species list were food for people, medicine, and timber.

Regression Findings (IndexCA Predictors)

The regression model had the following performance values: R^2 = 76.7%, Adjusted R^2 = 69%, AIC = −297.11. These indicate strong predictive capability.

The predictors with the largest effect sizes, above the median |β| (|β| > median |β| = 0.2139), indicate that natural capital plays a central role in shaping the IndexCA outcome. Several of the strongest predictors relate to perceived environmental change and patterns of plant resource use. Perceptions of temperature trends over the past decade (Q38) are strongly associated with the outcome variable, suggesting that climatic conditions and variability may influence how households interact with local vegetation resources. Resource-use practices also appear particularly important. The use of multiple plant parts for non-food purposes (Q57) shows a positive relationship with IndexCA, indicating that diversified use of plant parts may reflect stronger plant-use knowledge and closer engagement with local ecosystems. By contrast, households extracting a greater diversity of non-food plant or forest products (Q56) tend to show lower IndexCA values, suggesting that reliance on a broader range of extracted products, such as fuelwood, timber, or construction material, may correspond to greater ecological pressure or a more generalist pattern of resource use. Lack of active involvement of household women and youth in natural risk and disaster management (Q59) is positively correlated with IndexCA, an unexpected direction discussed below. Environmental awareness also appears relevant, as households identifying multiple causes of deforestation (Q51) tend to show higher IndexCA values, whereas the drying up of natural water points (Q37) is negatively associated with the outcome variable, highlighting water scarcity as a key environmental stress.

Beyond environmental factors, ethnicity also helps explain variation in plant-use knowledge, with Maure households showing lower IndexCA values compared with the reference group. Socio-economic variables play a smaller but significant role. Human capital, represented by household structure (Q03), and financial capital, reflected in livestock-based livelihoods (Q72), both show negative associations with IndexCA. Livestock-based livelihoods may involve fewer interactions with diverse plant resources, leading to lower levels of plant-use knowledge.

Discussion

The regression analysis provides a robust explanation of the variables associated with plant-use knowledge among rural households in Mali. The final model shows strong predictive capability, indicating that the selected predictors explain a large share of the variation in the IndexCA indicator. The predictors with the largest standardised effect sizes highlight the dominant role of natural capital variables, particularly those related to environmental perceptions and plant-resource use practices. These findings confirm that ethnobotanical knowledge in Sahelian landscapes is strongly shaped by ecological conditions and everyday interaction with vegetation resources. At the same time, cultural background and livelihood strategies contribute to explaining how this knowledge varies across households. This interpretation is consistent with broader research showing that TEK develops through long-term interactions between people and ecosystems and remains embedded within local livelihood systems (Berkes, 2012; Reyes-García et al., 2013; Reyes-García et al., 2014; Turner et al., 2000; Ladio & Lozada, 2004).

Environmental change and natural capital

Among the strongest predictors in the model, the variable capturing perceptions of temperature trends over the past decade (Q38) shows a negative association with IndexCA for both perceived

stable and warming temperature conditions. This indicates that households perceiving either stable temperature regimes or increasing temperatures tend to exhibit lower levels of plant-use knowledge compared with the reference category. This suggests that perceived temperature stability or warming may reflect environmental stress or deteriorating ecological conditions in the local landscape. In dryland ecosystems such as the Sahel, both perceived climatic stability and warming trends may correspond to ecological conditions that reduce opportunities for interaction with diverse vegetation resources. Rising temperatures are widely associated with declining vegetation productivity, increased evapotranspiration, and reduced regeneration of woody species, which can limit the diversity and availability of useful plants. These processes may reduce the ecological contexts within which plant-use knowledge is developed and maintained.

At the same time, perceptions of stable temperature conditions may reflect environments where vegetation dynamics are already constrained by long-term aridity and limited ecological variability. In such contexts, plant communities may be dominated by a relatively small number of drought-tolerant species, potentially limiting the diversity of plant uses and the breadth of plant-use knowledge maintained within households. Similar dynamics have been documented in Sahelian landscapes, where climatic warming and recurrent drought contribute to vegetation degradation and declining access to useful plant species (Lykke et al., 2004; Sop et al., 2012). Reduced plant diversity and ecosystem productivity can weaken the practical relevance of plant-use knowledge, particularly when households rely on a narrower set of species or shift toward alternative livelihood strategies.

These results therefore suggest an association between household perceptions of environmental change and reported plant-use knowledge, but the mechanisms underlying this relationship require further investigation. Similar interactions linking environmental change and the erosion of plant-use knowledge have been documented in other socio-ecological systems experiencing rapid environmental transformation (Reyes-García et al., 2014). In Sahelian rural contexts, climate variability may also affect livelihood strategies and natural resource management practices, reshaping how households interact with natural assets (Ceci et al., 2021).

Plant-resource use practices

Beyond climatic perceptions, the regression results highlight the importance of plant-resource use practices. The positive association between Q57 (use of multiple plant parts for non-food purposes) and IndexCA indicates that households engaging in diversified plant use tend to possess stronger plant-use knowledge. Diversified practices involving plant resources may reflect plant-use knowledge and resource reliance, shaping positive environmental outcomes. The use of different plant parts, such as bark, leaves, roots, fibers, or resins, requires detailed understanding of species characteristics, harvesting practices, and ecological conditions, reflecting close engagement with local ecosystems. Ethnobotanical research consistently shows that multifunctional plant uses are associated with richer bodies of plant-use knowledge because they involve deeper ecological familiarity and broader interaction with plant resources available in the surrounding environment (Reyes-García et al., 2014; Asfaw et al., 2023).

In contrast, the negative association observed for Q56 (extraction of a greater diversity of non-food plant or forest products, such as fuelwood, timber, or construction material) suggests that households drawing on a wider range of extracted products tend to display lower levels of plant-use knowledge. This may reflect a more generalist, subsistence-driven pattern of resource use under higher ecological or economic pressure, rather than the more specialised, knowledge-intensive engagement with specific plant resources captured by IndexCA.

The results therefore highlight an important distinction between the diversity of plant parts reported for different uses and resource extraction, which may correspond to ecological pressure and reduced vegetation diversity.

Participation of women and youth in environmental management

Another noteworthy result concerns Q59, which captures the lack of active involvement of women and youth in natural risk and disaster management. The positive association between this variable and IndexCA is unexpected and not straightforward to interpret. One possible explanation is that households devoting female and younger members' time to participation in such management groups have less time available for activities that generate and transmit plant-use knowledge; alternatively, the association may reflect unmeasured differences between households, for example, in labour allocation, wealth, or other governance arrangements, that were not captured in this study. Rather than pointing to a specific causal mechanism, this result highlights the need for further research examining participation directly among women and younger household members, and how different forms of environmental governance relate to knowledge acquisition and transmission (Agarwal, 2009; Berkes, 2009; Howard, 2003).

Environmental awareness and water availability

Environmental awareness also appears to influence plant-use knowledge. Households identifying multiple causes of deforestation (Q51) tend to exhibit higher IndexCA values, suggesting that awareness of environmental degradation is linked to stronger ecological knowledge. This variable reflects local perceptions of land-use change and environmental pressures (Friedman et al., 1986; Folke, 2004). Its significance in the model indicates that awareness of multiple deforestation drivers and local knowledge are important in shaping socio-ecological dynamics. Conversely, the drying up of natural water points (Q37) shows a negative association with the outcome variable, highlighting water scarcity as a major environmental stress affecting plant-resource availability and, by consequence, plant-use knowledge and IndexCA (Berkes et al., 2000). In dryland ecosystems, water availability strongly influences vegetation dynamics and plant diversity, and declining water resources may therefore reduce opportunities for interaction with useful plant species. This variable highlights how experienced environmental change interacts with accumulation of plant-use knowledge.

Taken together, these findings emphasise the central role of natural capital in shaping plant-use knowledge. Variables related to climatic and environmental perceptions, plant-resource use practices, environmental governance and ecological awareness all show strong relationships with IndexCA. Similar relationships between vegetation diversity and ethnobotanical knowledge have been documented in other Sahelian contexts. Studies in Burkina Faso, for example, show that communities living in areas with greater woody plant diversity tend to maintain broader knowledge of useful species used for food, medicine, and fodder (Lykke et al., 2004; Sop et al., 2012).

Interpretation through the Sustainable Livelihoods Framework

The observed patterns can also be interpreted through the Sustainable Livelihoods Framework. Within this framework, plant-use knowledge appears closely linked to households' access to natural capital and to the ways in which this capital is incorporated into livelihood strategies. Households that depend directly on natural vegetation resources tend to maintain stronger ecological knowledge systems because such knowledge supports subsistence practices, risk management strategies, and food security (Berkes, 2012; Asfaw et al., 2023). However, this general pattern was

not observed for the risk management dimension in this study. Individual or household-level engagement with natural resources for risk-buffering may differ from the formal participation in structured risk and disaster management practices (Q59), for which an unexpected negative association with plant-use knowledge was observed. This suggests that individual/household-level practices and formal community risk-management structures may relate to plant-use knowledge differently, thereby needing further investigation. Wild plant resources often provide important safety nets during periods of environmental stress or food scarcity (Asfaw et al., 2023). At the same time, rural households facing climatic variability frequently adjust their livelihood strategies in response to environmental risks, which may influence how natural resources are used and how ecological knowledge is mobilised in local adaptation processes (Ceci et al., 2021).

Ethnicity and cultural context

Beyond environmental variables, ethnicity also contributes to explaining variation in plant-use knowledge. In the regression model, households belonging to the Maure ethnic group in particular show lower IndexCA values compared with the reference group. However, this association should be interpreted with caution: in this sample, ethnicity and geography are closely confounded, as all Dogon respondents are located in the Bandiagara Region, while Sarakolé and Maure respondents are located in the Kayes Region. Ethnicity and regional/livelihood context therefore cannot be cleanly separated in the present analysis, and the observed differences may reflect geographic and livelihood-related factors as much as, or instead of, cultural or ethnic ones. With this caveat in mind, ethnic variation in ethnobotanical knowledge has been widely documented elsewhere and often reflects differences in livelihood specialisation, cultural practices, and historical relationships with local landscapes (Turner et al., 2000; Reyes-García et al., 2006; Reyes-García et al., 2014; Maffi & Woodley, 2010; Ghimire et al., 2004). In Sahelian contexts, such differences may reflect historical adaptations to environmental variability and socio-economic change affecting rural communities.

Household structure and livelihood strategies

Socio-economic variables also contribute to explaining plant-use knowledge, although their effects are smaller than those associated with environmental predictors. Household structure (Q03, human capital) shows a negative association with IndexCA, suggesting that it may influence livelihood strategies that increase environmental pressure, decreasing, in turn, plant-use knowledge. Household composition is likely to shape participation in subsistence activities and opportunities for knowledge transmission in the community. Previous studies have also shown that socio-economic differentiation within rural communities influences how ethnobotanical knowledge is distributed among households (Dovie et al., 2008).

Similarly, the negative association between IndexCA and livestock-based livelihoods (Q72, financial capital) suggests that households primarily engaged in livestock production tend to exhibit lower levels of plant-use knowledge. This may reflect the ecological pressure and environmental impacts associated with grazing and land-use shift. Livestock-oriented livelihoods may involve fewer interactions with diverse plant resources compared with farming or agroforestry systems where households routinely collect wild foods, medicinal plants, and other plant products (Cámara-Leret et al., 2014). Comparable patterns have been reported in other Sahelian studies showing that farmers engaged in crop cultivation or agroforestry maintain broader knowledge of useful plant species than households oriented primarily toward livestock-based livelihoods (Sop et al., 2012).

Implications for restoration and the Great Green Wall

Overall, the regression results indicate that plant-use knowledge is associated most strongly with variables describing environmental conditions, perceptions, and plant-resource practices, while cultural background and livelihood strategies influence how this knowledge varies across households.

These findings support the broader view showing that TEK develops through long-term interactions between people and ecosystems and remains embedded within local livelihood systems (Berkes, 2012; Reyes-García et al., 2014; Turner et al., 2000), of which the plant-use knowledge measured here represents one component.

These findings have important implications for landscape restoration initiatives such as the GGWSSI. Restoration programs in the Sahel often prioritise ecological indicators such as vegetation cover or carbon sequestration to assess progress. These indicators are essential, but they do not capture the full social and biocultural dimensions of restoration.

However, the results of this study suggest that local ecological knowledge, particularly knowledge linked to plant uses and environmental change, represents a valuable resource for sustainable landscape management. Communities possessing strong plant-use knowledge may be better positioned to identify locally adapted species, monitor ecological changes, and manage restored ecosystems in ways that support both biodiversity conservation and livelihood resilience (Berkes, 2012; Reyes-García et al., 2014; Sacande & Berrahmouni, 2016). Locally important species such as *Sclerocarya birrea*, *Senegalia senegal*, and *Lannea microcarpa*, identified as prominent within the plant-use system documented here, may warrant consideration in restoration planning where their ecological suitability, conservation status, provenance, and community priorities are also demonstrated.

Integrating TEK into restoration planning can therefore improve the social relevance and long-term sustainability of environmental interventions. Increasingly, restoration scholars emphasise the importance of biocultural approaches that recognise the co-evolution of ecosystems and human societies (Otamendi-Urroz et al., 2025; Sena et al., 2022).

Sectoral policies and restoration programmes could therefore aim at i) including plant-use knowledge, as a component of TEK within relevant environmental programs, ii) strengthening its role through appropriate formal and informal educational mechanisms, iii) monitoring biocultural diversity alongside ecological restoration outcomes, and iv) encourage community participatory approaches and inclusive governance structures in environmental governance that creates meaningful opportunities for women, youth, and marginalised groups to contribute to environmental decision-making.

Limitations and future research

Despite the strong explanatory power of the model, some limitations should be acknowledged. First, plant-use knowledge was measured using IndexCA, a study-specific proxy index developed for the structure of the ethnobotanical questionnaire; it captures selected dimensions of plant-use knowledge (species, plant parts, and uses reported) and should not be interpreted as a comprehensive measure of TEK, which encompasses broader cosmological, social, and ethical dimensions not captured by this instrument.

Second, the sampling strategy deliberately targeted individuals recognised for their knowledge of plant use and natural resource management. Although this approach was appropriate for obtaining

detailed ethnobotanical information, the resulting sample is not statistically representative of the wider population (Berlin, 1992).

Third, the sample was strongly imbalanced by gender and ethnicity. Household heads were overwhelmingly male, while ethnic groups were unevenly represented and partly structured geographically. These characteristics limit interpretation of gender- and ethnicity-related associations and make it difficult to distinguish cultural effects from geographical and livelihood differences.

Finally, this study employed a cross-sectional design, capturing plant-use knowledge and livelihood characteristics at a single point in time. As such, the associations identified between livelihood capitals, perceived environmental change, and plant-use knowledge should be interpreted as correlational rather than causal, and the direction of these relationships cannot be established from the present data. For example, it is equally plausible that limited plant-use knowledge shapes households' livelihood strategies as it is that livelihood strategies shape the acquisition and retention of such knowledge.

Future research could employ probabilistic and stratified sampling approaches to ensure a more balanced representation of ethnic groups and genders, while also examining how plant knowledge varies across age groups, occupations, locations, and livelihood strategies.

Greater involvement of women and younger respondents would be particularly valuable for examining knowledge transmission across generations and genders.

Longitudinal studies could also help clarify how plant-use knowledge changes in response to environmental change and development interventions, such as reforestation and agroforestry programmes, livelihood diversification or market-access initiatives, and water-management or drought-resilience projects.

Such research could provide valuable insights into how biocultural knowledge systems contribute to the resilience of dryland landscapes. Combining ethnobotanical data with direct ecological measurements, for example, vegetation composition, useful-species abundance, water availability, and land-use change, would help distinguish perceived environmental change from measured ecological conditions and provide stronger evidence for the mechanisms underlying the associations identified here.

Conclusions

The results of this study demonstrate that plant-use knowledge among rural households in Mali is strongly associated with natural capital variables, particularly environmental perceptions and patterns of plant-resource use.

Perceived temperature trends, diversified use of plant parts, extraction of plant products, environmental governance, awareness of deforestation drivers, and water scarcity were among the variables most strongly associated with the IndexCA. Socio-cultural background and livelihood strategies also contributed to variation in plant-use knowledge, with ethnicity, household structure, and livestock-based livelihood showing significant associations with the outcome. These findings indicate that plant-use knowledge is unevenly distributed within and between communities and is embedded in broader social, ecological, and livelihood contexts.

These findings highlight the close relationship among ethnobotanical knowledge, environmental conditions and change, socio-cultural background, and livelihood strategies in Sahelian landscapes.

Recognising plant-use knowledge as one component of broader TEK can therefore help design effective restoration and rural development strategies that seek to integrate ecological and social objectives. Policies aimed at restoring degraded landscapes should not focus solely on ecological indicators but also consider the social and economic conditions that sustain local knowledge systems. Supporting community participation, documenting traditional knowledge, and integrating culturally important species into restoration strategies may strengthen both biodiversity conservation and rural livelihoods.

Programs such as the GGWSSI may benefit from integrating biocultural diversity, community knowledge of plant resources, and local perceptions of environmental change into restoration planning. Such an approach can enhance the ecological relevance and social legitimacy of restoration initiatives while helping to maintain the knowledge systems that underpin sustainable use of dryland plant resources.

List of abbreviations

AIC: Akaike Information Criterion; CA: Correspondence Analysis; CBD: Convention on Biological Diversity; CI: Cultural Importance Index; CVe: Cultural Value; DFID: Department for International Development; FAMD: Factor Analysis of Mixed Data; FAO: Food and Agriculture Organization; FC: Frequency of Citation; FL: Fidelity Level; GGW: Great Green Wall; GGWSSI: Great Green Wall for the Sahara and Sahel Initiative; HH: Household Head; IER: Institut d'Économie Rurale; ILK: Indigenous and Local Knowledge; IndexCA: study-specific composite plant-use knowledge index derived from Correspondence Analysis; IPBES: Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services; NU: Number of Uses; PPV: Plant Part Value; RBG Kew: Royal Botanic Gardens, Kew; RFC: Relative Frequency of Citation; RI: Relative Importance Index; SLF: Sustainable Livelihoods Framework; TEK: Traditional Ecological Knowledge; UR: Use Report; UV: Use Value

Declarations

Ethics approval and consent to participate

This study was conducted under the oversight of the Ethics Committee established by the Ministry of Higher Education and Scientific Research of Mali. The Committee is chaired by a president appointed upon the recommendation of the Director General of the National Centre for Scientific and Technological Research (CNRST). It is responsible for reviewing the ethical aspects of research protocols submitted by Malian and foreign researchers, in accordance with the Declaration of Helsinki and other applicable ethical provisions governing research involving humans, animals, agriculture, the environment, and mining, as well as relevant Malian legislation (Decision No. 2026-001633/MESRS-SG).

Consent from local communities was obtained through district councils and municipal authorities, whose representatives facilitated the implementation of field surveys. Following the completion of the surveys, feedback meetings were organised at municipal offices to present and discuss the findings with local stakeholders.

Consent for publication

Not applicable

Availability of data and materials

The R analysis code and the anonymised datasets supporting the findings of this study are openly available in the GGW_Mali repository on GitHub: https://github.com/MaraevaGianella/GGW_Mali and archived on Zenodo at https://doi.org/10.5281/zenodo.19853517 (version v1.0.1). The repository includes the raw and recoded survey matrices, code tables, and the full analysis script (data recoding, ethnobotanical indices, Factor Analysis of Mixed Data, and regression modelling). Participant identifiers in all shared files are anonymised; the mapping between original field identifiers and anonymised codes is held privately by the authors and is not included in the repository. Code is released under an MIT licence; data are released under a Creative Commons Attribution 4.0 International (CC BY 4.0) licence.

Competing interests

The authors declare that they have no competing interests.

Funding

This work was supported by the Royal Botanic Gardens, Kew, through the Great Green Wall Cross-border Pilot Project in Burkina Faso, Mali and Niger.

Authors' contributions

P.C., S.S. and T.U. conceived and designed the study. S.I.S., S.S., and B.A.K. led data collection in Mali. M.G. and I.P. performed the statistical analysis and drafted the manuscript. F.A. and G.P.B. contributed to the manuscript draft and revision. T.U. supervised the project. All authors read, revised, and approved the final manuscript.

Acknowledgments

The authors acknowledge the Millennium Seed Bank Partnership of the Royal Botanic Gardens, Kew (RBG Kew), for hosting and facilitating the Great Green Wall Cross-border Pilot Project, and the Institut d'Économie Rurale (IER, Mali) for providing technical and logistical support. Sincere thanks are extended to the Forest Resources Programme team at the Regional Agricultural Research Centre (CRRA) in Sikasso, Mali, the local Forestry Service, and the Bankass District Council, particularly Mr Kaleb Tessougué, for their contributions to the implementation of field surveys and other project activities. The authors are deeply grateful to the farmers from the districts of Bankass, Bandiagara, Koro, and Kayes for their participation in the ethnobotanical and socioeconomic surveys. The authors also thank Dr Benedetta Gori for her input and support on the ethnobotanical aspects of the research.

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