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Importance of yam in the role of agrobiodiversity in Mayombe and Batéké Plateau ecozones in Democratic Republic of Congo

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The Mayombe and Batéké Plateau ecozones of the Democratic Republic of Congo (DRC) are experiencing differentiated deforestation and forest degradation, together with a trend toward homogenization of their agricultural diversity. These may undermine efforts to sustainably reverse household food, nutrition, and livelihood insecurity. In this context, this study seeks to assess the importance of yam in the role of agrobiodiversity among populations in the two contrasting ecozones. A sample of 351 households was surveyed. A dataset of about 202 testimonies from six focus groups and observations in 86 peasant agroforestry fields was also analyzed using descriptive statistics, correlation and regression, and calculations of different indices of crop importance. Overall, plant, animal, and fish species represent respectively 60.9%, 26.7% and 12.4% of genetic resources. About 50 of 72 species of these resources are found in both study areas. Regarding the overall use of species, the five top-ranked species that were utilized as food included *Manihot esculenta*, followed by *Arachis hypogaea*, *Zea mays*, *Dioscorea alata*, and *Musa acuminata*. Living in the Mayombe ecozone increases the household's preference for growing yams by up to 5.7 times. Population density was correlated with agricultural diversity. Villages with a high population density showed greater crop diversity than those with a low population density. In short, yam remains an important but under-represented crop, the contribution of which could be increased to secure sustainable livelihoods through biodiversity-rich peasant agroforestry systems.

Keywords Agrobiodiversity, Ethnobotany, Agroforestry, Yams, Sustainable livelihoods, Mayombe, Batéké Plateau, Democratic Republic of Congo

With only one year remaining, United Nations member states must redouble their efforts to achieve the goals of the UN Decade of Action for Nutrition (2016–2025)[1]. The question of how to feed the world of today and tomorrow with healthy food without contributing to environmental degradation is of growing concern[2,3]. Biodiversity for food and agriculture (BFA), because of its potential to contribute to sustainable and resilient food systems for healthy diets, appears to be an option to be further promoted[4,5]. BFA has been defined as the subset of biodiversity, which is the variety of life at genetic, species, ecosystem and landscape levels, that contributes in one way or another to agriculture and food production[5]. According to the FAO[5], around 80% of the calories in the human food supply are provided by terrestrial plants, 16% by terrestrial animals and 1% by aquatic animals and plants. BFA is vital to human food diets and household food security but also for sustainable development and essential ecosystem services.

In a global context that is characterized especially by an accelerating loss of agrobiodiversity and a trend towards the homogenization of agricultural production systems[6,7], the places that are occupied by certain traditional food crops in sub-Saharan Africa are changing. Numerous global challenges have emerged, such as climate change, deforestation, and the proliferation of plant diseases and crop pests, among others.

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Moreover, specific challenges are faced by countries in proposing and implementing coherent and appropriate policy responses to the decline in agrobiodiversity[8–10]. Although less thoroughly documented[11,12], the loss of agrobiodiversity has become one of the environmental impacts affecting yam-based (*Dioscorea* spp.) cropping systems in sub-Saharan Africa[13], the sustainable intensification of which is essential to feed the 10 billion or so people expected to inhabit the planet by 2050[14].

Yams are a pantropical crop and staple food for over 500 million people, particularly in West Africa[15]. They comprise over 600 species in the genus *Dioscorea*[16,17], and are of great importance for food, nutrition, income generation, pharmacopoeia, and religious rituals in different parts of the world[18–20]. Today, they have become a secondary food in certain regions of sub-Saharan Africa[13,21], whereas some forty years ago, along with taro (*Colocasia esculenta*) and sweet potato (*Ipomea batatas*), they were highly prized staple foods.

With the population of the Democratic Republic of Congo (DRC) projected to increase to an estimated 215 million by 2050[18], the promotion of local agriculture should be combined with appropriate measures, including the use of local agrobiodiversity, to prevent food insecurity and malnutrition in the country. These measures apply particularly in the Mayombe ecozone[22,23], which is our main study area. Yam, the biodiversity of which is said to be under-utilized in the DRC, is one of the food crops with great potential for improving livelihoods, particularly for poor farming populations[24]. Its traditionally extensive cropping system is often associated with deforestation and soil degradation[14,25]. A better understanding of its importance in the use of agrobiodiversity would enable us to propose specific recommendations for its intensified use in agroforestry and its valorization. The hypothesis being tested is that yams are a crop component that is poorly represented in peasant agroforestry systems, and that this poor representation can be explained by the loss of traditional knowledge that is associated with biodiversity in the Mayombe and the Batéké Plateau ecozones. The aim of this study is to assess the importance of yam in the role of agrobiodiversity in Mayombe and Batéké Plateau ecozones. This study is part of a larger study on agroforestry systems for yam (*Dioscorea* spp.) production to improve food security and nutritional conditions in Mayombe and Batéké Plateau ecozones. The central research question is whether yam-based agroforestry systems can contribute to improving household food security and nutrition in the Mayombe and Batéké Plateau ecozones of the DRC.

Materials and methods

Study sites, design, and sampling

The study areas are the Mayombe and Batéké Plateau ecozones, which are two major biophysical and socio-cultural landscapes that are located respectively in the southwest and west of the DRC. In total, 10 villages were deliberately selected in these two ecozones, i.e., nine in the Mayombe and one in the Batéké Plateau ecozones, which provides insight into the diverse village dynamics present in the region. All villages in the Mayombe ecozone were known for their dependence upon natural resources given their proximity to the Luki Biosphere Reserve.

The study used a cross-sectional design and mixed approaches to data analysis (quantitative and qualitative). For the quantitative data, namely the ethnobotanical survey, the sample size was determined by using an average effect size of 0.5 and a critical threshold of 5%. These results are based on a test of comparison of means (with a power of 0.97) of two independent groups (the Mayombe ecozone vs. the Batéké Plateau ecozone). An attrition factor of 10% allowed us to retain a sample size of 351 households, using G*Power software[26,27]. With respect to the qualitative data, six focus-group discussions (FGDs) were held.

Quantitative data collection

Interviews were conducted with the heads of households using a questionnaire to collect data on the diversity of species that were used by the households and their types of use (food, handicrafts, energy, timber, pharmacology, other). In addition, inventories of all species that were found in 86 agroforestry fields located around ten villages in the two ecological zones were conducted to gather data on species that were cultivated and total surface field areas. An expert from the National Institute for Agronomic Study and Research (INERA) at Luki Biosphere Reserve oversaw this component. In each village, inventories were conducted in approximatively 10 peasant agroforestry fields[28]. A total of 86 peasant agroforestry fields were surveyed across the two areas. The variables that were recorded during these inventories were the number of species, the land surface area occupied by each species, and information on growth patterns[29,30], which were completed by exploiting existing readings[31–34]. Ten villages were selected for ethnobotanical surveys, focus groups, and the Accelerated Participatory Research Method (APRM)[35]. The surrounding villages of the Luki Biosphere Reserve that were used for the ethnobotanical survey data collection were: INERA Camp, Patu, Nlemba, Mangala, Manterne, Km 28 and Kinzau, together with the three enclaves of Kiobo, Tsumba Kituti and Kisavu.

Qualitative data collection

FGDs were held to collect data on the diversity of plant, animal, and fish species that were used by households, their contributions to livelihoods, and the perceptions regarding the ecological and socio-cultural values of agrobiodiversity. In total, six FGDs (three with men, three with women), each composed of 10–12 participants, were held in three villages in Mayombe and in one village that was located on the Batéké Plateau, using the snowball technique. This sampling technique is a special non-probabilistic method (nonrandom sampling) for developing a research sample where existing study subjects recruit future subjects from among their acquaintances, who may recruit further knowledgeable subjects in turn, and so on[36,37]. Participants were recruited on a voluntary basis. Data were collected until saturation, i.e., no further concepts were revealed[36,37].

The agrobiodiversity assessment guide that was used was adapted from the International Biodiversity protocol designed for Mali[38]. For each FGD, the objective of the exercise was explained, and verbal consent was obtained from each participant. During FGDs, an inventory of Genetic Resources (GRs) was conducted using the quadrat method, which considered two levels of agrobiodiversity assessment: production systems and the market[38]. The GRs included annual and perennial plant species and cultivated and forest products (including trees, terrestrial and aquatic wildlife) that were utilized by participants. Quadrat inventories are an effective method of assessing biodiversity, by systematically providing a complete picture of the agrobiodiversity under study. These were used for the agrobiodiversity assessment and aimed to identify and quantify all useful plant, animal, and aquatic species that were utilized by rural households and communities, together with information on markets attended and general socioeconomic household characteristics of households. This information was used to characterize three dimensions of agrobiodiversity in terms of the elements and relationships involved and the exogenous factors that influence their status and dynamics[38]: (1) diversity within the production system, including on the farm and common lands; (2) dietary diversity; and (3) market diversity. Information regarding the perception of socio-cultural values of agrobiodiversity was also gathered. Socio-cultural values of agrobiodiversity can be seen as the importance that people, as individuals or as a group, give to this diversity on the basis of their preferences or social norms[39]. Building upon de Groot et al.[40] and Scholte et al.[39], the ecological values of agrobiodiversity are described in terms of provisioning, regulating and supporting ecosystem services[41]. Based on studies of Priyanka et al.[42] two modalities have been defined to classify the land devoted to the exploitation of GRs: ≤ 2 ha for small scale farms and > 2 ha for large scale farms. The *many households* and *few households* modalities proposed by Bellon et al.[38] were used during the FGDs to facilitate and simplify the definition of the number of households using GRs. To collect data on agricultural products that were used throughout the year, a participatory calendar was developed with FGD participants[41]. Agricultural activities in support of livelihoods, and periodic problems that were linked to agrobiodiversity management were also documented. A game using pebbles was also used to quantify the proportions of foodstuffs, which were used for different purposes (foods, handicrafts, pharmacology, energy, other) and that had been consumed or sold in the past 18 months. This "accounting" ensured that the periodicity of production activities and potential challenges directly or indirectly associated with them could be identified.

Data analysis

Focus group data analysis

A dataset of around 202 testimonials from six focus groups was analyzed to assess agrobiodiversity at both the production system and market levels. These testimonies involving four villages comprised 129 from Mayombe and 73 from the Batéké Plateau. Thirty-two testimonials came from Kimufu village, 64 from Mangala, 33 from Tsumba-kituti, and 73 from Mbakana. The testimonials referred to zoological, phytogenetic, and fisheries resources that are exploited by households in these two study areas. The data that were analyzed on agrobiodiversity in farmers' fields and the ethnobotanical surveys were processed according to the variables of interest that were set at the time of data collection, namely, the types of species that were exploited (i.e., perennials, trees grown in agroforestry plots, wild food species, domestic and wild animals, fish and other aquatic resources), together with the area that was allocated to the exploitation of GRs, the perceived number of households exploiting the different GRs, perceptions on the ecological value of GRs and perceptions on the socio-cultural values of GRs. To answer the question of whether yam production significantly differed between the Mayombe and Batéké Plateau ecozones, Student's two-sample *t*-test was performed for each variable on sampling (with replacement) carried out on the initial sample to enlarge it and obtain more robust results (Bootstrap). A logistic regression model was further run to determine the odds ratio of growing yams in either study area. The response variable in the model is Y = {1 if the household grows yams and 0 otherwise}.

The seasonality that was observed for each crop enabled us to understand how women and men perceive changes in their agricultural production activities. Farming activities and problems that are linked to agrobiodiversity management were reported. Data from the ethnobotanical surveys were analyzed using response frequencies to determine cultural scores.

Determining cultural scores

The index of cultural importance (CI) was designated on one hand, as the cultural value that is attributed to the plant. On the other hand, the value that was attached to plant parts/organs by local populations[29,43] was calculated. A CI index and a parts or organ use score (SP) were calculated to quantify the cultural importance of the species that were surveyed. The two scores are usually found to be quite similar and can be used interchangeably[30]. However, an adjusted use score (CIA) was constructed, incorporating a correction that was based on the different parts being used of a given species. The adjusted score was obtained by multiplying the two indices. The higher the score, the more the species is used in the community. The use of multiplication is justified by a concern for conserving the properties of the two sub-indices. Using multiplication as an operator also resolves the problem of asymmetry between the two indices. Species with a very low or zero score for one of the two indices will also have a very low or zero score for the adjusted index.

$$CIA_i = CI_i \times SP_i \tag{1}$$

$$CI = \sum_{u=u_1}^{u_{nc}} \sum_{I=1}^{I_N} \frac{UR_{ui}}{N} \tag{2}$$

$$SP_i = \frac{1}{s_i} \sum_{i}^{s_i} sum\,of\,the\,number\,of\,parts\,used \tag{3}$$

where *CIAi* is the adjusted score of the index of cultural importance for species *i*, *nc* is the number of use categories, *N* is the total number of information, *si* is the number of times the species *i* has been cited.

Plant species classification using the k-Prototype method
Once the scores had been calculated, the plants were classified according to their characteristics using the *k*-Prototype algorithm. The k-Prototype method is a clustering approach that partitions data and is designed to efficiently handle mixed data clustering. It represents a significant improvement over the k-Means and k-Mode clustering algorithms[39]. Zhexue Huang introduced this method in 1998 to overcome the limitations of its predecessors[44]. Unlike k-Means, which is suitable for numerical data, and k-Mode, which is designed for categorical data, the k-Prototype algorithm assigns centroids for both numerical and categorical variables. It uses a dissimilarity (distance) measure that is adapted to each type of variable. In our study, we utilized the Euclidean distance for numerical variables and the Simple Correspondence distance for categorical variables.

$$d\left(x,y\right)=d_{euclid}\left(x,y\right)+d_{corespondancesimple}\left(x,y\right) \tag{4}$$

During the clustering process, it is necessary to specify the number of groups (k) at the beginning. The variability principle was used to determine the optimal number of clusters. This involved classifying the data for different values of k and evaluating the inter-group variability. The number of groups at which the inter-group variability no longer decrease significantly was chosen.

To measure intergroup variability, we used inertia, which is the sum of the squared distances between each data point and the centroid of its group. The objective was to choose k in a way that minimizes inertia while avoiding an excessive number of groups.

Characterization of peasant agroforestry fields in Mayombe
To characterize the agroforestry systems, another dataset consisting of a representative sample of 86 peasant agroforestry fields was analyzed. The floristic specific diversity was evaluated using the Shannon index[45], together with richness, i.e., the number of species[46].

Univariate descriptive analyses were performed followed by bivariate statistics to establish the strength and direction of relationships between crop diversity and population density in the villages where the peasant agroforestry fields were surveyed. For this purpose, Kendall's rank correlations were performed (Tau-b = 1, strong positive relationship; perfectly concordant; Tau-b = 0, no agreement; Tau-b = − 1, strong negative relationship; perfectly discordant).

The purpose of the Kruskal–Wallis test was to examine the correlation between density and diversity. The density variable was categorized into three classes: low, medium, and high. The 'low' class includes peasant agroforestry fields in villages with a density less than or equal to the first quartile of density. The 'medium' class includes peasant agroforestry fields in villages with a density above the first quartile and less than or equal to the third quartile. The 'high' class covers densities above the third quartile. This test is based on the main assumption that diversity is the same for all density levels.

A linear regression was fitted to quantify the strength of the relationship between population density and specific floristic diversity in the peasant agroforestry fields. To reduce large differences in scale between the two variables and improve the fit that we had postulated, an exponential relationship between the two variables was used considering the natural logarithm of density without the constant (Y-intercept). The model equation is as follows:

$$diversity_i=\alpha\times Ln(density_i)+\epsilon_i \tag{5}$$

where the residuals are $\epsilon_i\sim\mathfrak{N}\left(0{,}1\right) andiid$. After estimating the model by ordinary least-squares (OLS), the fitted value likelihood was obtained for:

$$\widehat{diversity}_i=\widehat{\alpha}\times Ln(density_i) \tag{6}$$

By differentiating the equation (6) we obtain:

$$\Delta\widehat{diversity}_i=\widehat{\alpha}\times\frac{\Delta density_i}{density_i} \tag{7}$$

Rates of change or the percentage increase in density were obtained. A 1% increase in density results in an increase of $\frac{\widehat{\alpha}}{100}$ in diversity and when density doubles, diversity increases by $\widehat{\alpha}$.

Results
Summary of qualitative variables from quadrat surveys
Several variables are documented as part of the present study. Table 1 below shows the opinions of the various households, expressed as a percentage in relation to some of the variables of interest documented during the focus group sessions. Household allocations to Genetic Resources appear to differ between the two locations. Collectively, the percentages of households exploiting the 10 types of Genetic Resources do not differ between the Batéké Plateau and Mayombe (Wilcoxon signed-rank test: $p = 0.646$).

Based on data from six focus groups in the two ecozones, 72 species are identified as GRs 49 of which are common to both Mayombe and the Batéké Plateau (See Supplementary Materials 1). Of these species, 60.89% are identified as plant genetic resources (PGRs). Fish resources (FRs) and zoogenetic resources (ZGRs) account for 12.38% and 26.73%, respectively. Annual (37.98%) and perennial (18.60%) PGRs, together with domesticated

	Batéké Plateau	Mayombe	All
Area allocated to the exploitation of GRs			
Large area (> 2 ha)	16.44%	33.33%	27.23%
Small area (≤ 2 ha)	83.56%	66.67%	72.77%
Perceived number of households using GRs			
Many households	19.18%	14.73%	16.34%
Few households	80.82%	85.27%	83.66%
Perceptions on the ecological value of GRs			
With ecological value	27.40%	17.05%	20.79%
Without ecological value	72.60%	82.95%	79.21%
Perceptions on the socio-cultural value of GRs			
With socio-cultural value	17.81%	17.83%	17.82%
Without socio-cultural value	82.19%	82.17%	82.18%
Types of GRs			
Annual	37.98%	27.40%	34.16%
Perennial	18.60%	6.85%	14.36%
Pets	16.28%	28.77%	20.79%
Cultivated trees	9.30%	6.85%	8.42%
Cultivated shrubs	0.78%	0.00%	0.50%
Fish	8.53%	17.81%	11.88%
Wild animals	2.33%	12.33%	5.94%
Other wild food resources	3.10%	0.00%	1.98%
Other food and non-food resources	2.33%	0.00%	1.49%
Other aquatic resources	0.78%	0.00%	0.50%

Table 1. Proportion (%) of households allocating areas to Genetic Resources (GRs), types of GRs harvested, and perceptions about ecological and socio-cultural values of GRs in Mayombe and Batéké Plateau.

animal (16.28%) species, characterize the Mayombe ecological region. On the Batéké Plateau, the most common GRs are domestic animals (28.77%) and annual plant species (27.40%).

The different GRs are exploited over different areas within the two ecological zones. On the Batéké Plateau, nearly 84% of households claim to exploit GRs on small areas, compared with around 67% in the Mayombe. In the latter ecozone, one-third of all households (33.33%) claim to farm GRs on relatively large areas.

In the two study areas, 83.66%of GRs are being exploited by few households over large areas; in contrast, many households would exploit around 16.34% of GRs on small areas. Twice as many PGRs are cultivated on large areas in Mayombe than on the Batéké Plateau.

For the majority of those who were interviewed, the resources that have been cited have no ecological value. Indeed, on the Batéké Plateau, 72.60% of respondents perceive the resources that they are farming as having no ecological value. This proportion is higher in Mayombe, where more than eight out of ten people consider that the resources they exploit have no ecological value. When it comes to the socio-cultural value of harvested resources, the trend remains the same. In both ecozones, more than eight out of ten people believe that the resources they exploit have no socio-cultural value, i.e., 82.19% on the Batéké Plateau and 82.17% in Mayombe.

GRs for household self-consumption

Generally, for a given household living in one of the two ecozones, the proportion of resources that are allocated to self-consumption ranges from a minimum of 0% to a maximum of 100%. Some resources are devoted entirely to self-consumption. On average, a household allocates almost 27% of the species that it farms to self-consumption. With a median of 10%, half of all households dedicate less than 10% of their harvested species to self-consumption. Households are, therefore, largely sellers. However, it should be noted that self-consumption behavior varies greatly from one household to the next (standard deviation; SD = ± 32.93%). The average portion that is dedicated to self-consumption appears to be higher in Mayombe than on the Batéké Plateau (29.14% vs. 22.25%). Moreover, this superiority is confirmed by the values of the 3rd quartile and the median. Indeed, half of all households in Mayombe devote at least 20% of their harvested species to self-consumption, compared with less than 10% on the Batéké Plateau.

The marketing of GRs, an essential survival issue

In general, for a given household in one of the two ecozones, the proportion of resources that are allocated to marketing ranges from a minimum of 0% to a maximum of 100%. This means that some resources are allocated entirely to the marketplace. On average, a household allocates almost 65% of the resources that it produces to sale in local markets. With a median of 80%, half of all households allocate more than 80% of their exploited resources to sales. Households are, therefore, largely sellers, as highlighted in the previous section. From a specific point of view, the average portion that is dedicated to sales seems to be lower in Mayombe than on the Batéké

Plateau (58.45% vs. 76.38%). This is more logical given that self-consumption and sales play complementary roles. Moreover, the median confirms this superiority. In Mayombe, half of all households sell at least 76% of their harvested species, while on Batéké Plateau, half of all households sell more than 90% of their harvested species.

Plant families and growth forms inventoried in Mayombe

Observations that were made in the agroforestry fields of Mayombe (Table 2) show 72 species, more than half of which are trees. These species belong to 37 families, with the family **Fabaceae** being the largest in terms of number (eight species). **Moraceae** were second (seven species). The two other best-represented families are the **Anacardiaceae** and **Euphorbiaceae**, with four species each. The **Bombacaceae**, **Dioscoreaceae**, **Malvaceae**, **Musaceae,** and **Solanaceae** are each represented by three species. The remaining families are less well represented, i.e., **Amaranthaceae**, **Apocynaceae**, **Asteraceae**, **Verbenaceae,** and **Zingiberaceae**, among others.

GR utilization scores

The overall use of food and non-food species is captured in calculations of indices such as CI, SP and CIA scores. Table 3 shows that before adjusting CI scores, the top 10-ranked culturally important species at the household level in Mayombe and the Batéké Plateau are food species. *Manihot esculenta* is the highest ranked on the list, followed by *Arachis hypogaea*, *Zea mays*, *Dioscorea alata,* and *Musa acuminata* (Table 3: Rank 1). Using the adjusted scores, however, *Manihot esculenta*, which is the top on the list of culturally important food species, fell to 14th place (Table 3: Rank 2). *Arachis hypogaea* loses its position as the second most culturally important food species, falling to 38th place on the list of 72 species.

Table 4 presents an overview of the species groups obtained using the k-Prototype algorithm for mixed data types (categorical and numerical). The table is divided into two parts. The first part shows the scores calculated for each of the six species groups. The second part describes the characteristics and frequencies of the species in each group.

In the first group, the species that were under consideration have a mean adjusted score of < 0.0055, and all of them are used for wood energy, e.g., *Albizia ferruginea, Anthocleista vogelii* Planch., *Pentaclethra macrophylla* Benth., *Hymenocardia acida* Tul., and *Millettia versicolor* Welw. ex Bak. The second group includes species with a mean adjusted score < 0.0514. These species have a low food use. About 36% of these species are used for pharmaceutical purposes and most are used for timber, e.g., *Ceiba pentandra*, *Celtis mildbraedii* Engl., *Entandrophragma angolense*, *Milicia excelsa*, *Nauclea diderrichii* (De Wild.) Merr., and *Terminalia superba*. Species that are used for handicrafts account for about 18% of this group. These include, for example, *Lannea welwitschii*, *Musanga cecropioides* R. Br., *Ricinodendron heudelotii*, and *Alstonia boonei*. In group 3, the average score is below 0.0698. Food use remains low. All species in this group are used for pharmaceutical purposes, e.g., *Cola bruneelii* De Wild., *Carica papaya*, *Alchornea cordifolia, Pycnanthus angolensis*, *Celtis mildbraedii*, and *Millettia versicolor*. The last three groups have the highest use scores. In group 4, the species that are listed have been cited for food use in approximately one in three cases. Finally, the last group contains species with an adjusted score of over 0.41 and a CI score in the range of 0.6 to 0.9. This group is strongly dominated by species for food use, with nearly 77% of declarations.

Yams as a component poorly represented in peasant agroforestry fields

A hypothesis that the proportion of yam-growing households in both regions was less than 3% was subjected to the Student's *t*-test. In view of the results of the Student's *t*-test, at the critical threshold of 5%, there is sufficient evidence to affirm that yam cultivation is carried out in a very low proportion (< 3%) in both ecozones. A logistic regression was performed to investigate the factors that explain why yam is under cultivation or what factors increase the likelihood of a household growing the crop. This model shows that ecozone, the number of households cultivating yams, and household perception of its ecological value are the factors with the greatest impact on the probability of a household cultivating yams. The fact that a household belongs to the Mayombe ecozone and perceives yams as having no socio-cultural value has a positive impact on its probability of growing yams. However, the fact that the species is cultivated by a few households negatively affects the probability of the species being yam.

The results in Table 5 show that if a household is in the Mayombe ecozone it increases its chances of growing yams by up to 5.72 times. Yam is perceived as being grown by many households rather than a small group. Finally, species that are considered to have no socio-cultural value are 3.34 times more likely to be yams than species that are considered to have socio-cultural value.

Specific diversity in peasant agroforestry fields around the Luki biosphere reserve in Mayombe

A total of 86 peasant agroforestry fields have been inventoried. Their surface areas range in size from a minimum of less than one ha to a maximum of one hectare (ha). However, the average size of a unit is around 0.19 ha, with a SD of around 0.2 ha. Furthermore, one unit in two is less than 0.12 hectares in size.

In terms of population density, the villages under consideration have densities ranging from a minimum of 10 inhabitants per km^2 to a maximum of 416.67 inhabitants per km^2. The average density is around 55.24 inhabitants per km^2. However, this distribution is highly disparate, with a standard deviation of 138.44 inhabitants per km^2. Three villages out of four have a density of less than 5.00 inhabitants per km^2, and one village out of two has a density of less than 1.89 inhabitants per km^2.

To capture the species diversity of the different peasant agroforestry fields, the Shannon index was calculated. One field in four has an index below 0.28, and one field in two has an index below 0.44. This indicates a low level of diversity within the units considered. In addition, some peasant agroforestry fields are highly diversified, with

Families	Species	Vernacular names (Kiyombe)	Growth forms
Amaranthaceae	*Amaranthus viridis* L.	Biteku-teku	aH
Anacardiaceae	*Spondias mombin* L. *Mangifera indica* L. *Lannea welwitschii* (Hiern) Engl *Pseudospondias microcarpa* (A. Rich.) Engl	Mingiengi Manga Nkambi Nzuza	T T T T
Annonaceae	*Annona muricata* L.	(Soursop, guanábana)	S
Apocynaceae	*Alstonia boonei* De Wild	Tsonguti	T
Araceae	*Colocasia antiquorum* (= *C. esculenta*) *Colocasia esculenta* (L.) Schott	Makoko Makoko	vH vH
Arecaceae	*Elaeis guineensis* Jacq	Diba	T
Asteraceae	*Vernonia amygdalina* Delile	Mandudi ndudi	S
Bombacaceae	*Adansonia digitata* L. *Bombax buonopozense* P. Beauv *Ceiba pentandra* (L.) Gaertn	Nkondo Longo mfuma Mfuma	T T T
Bromeliaceae	*Ananas comosus* (L.) Merr	Mafubu	aH
Burseraceae	*Dacryodes edulis* (G.Don) H.J. Lam *Canarium schweinfurthii* Engl	Nsafu Mbidi kala	T T
Cannabaceae	*Cannabis sativa* L.	Diamba	aH
Caricaceae	*Carica papaya* L.	Malolo	T
Clusiaceae	*Allanblackia floribunda* Oliv	Nionzo	T
Combretaceae	*Terminalia catappa* L. *Terminalia superba* Engl. & Diels	Lidame Limba	T T
Convovulaceae	*Ipomea batatas* L.	Biyangidi	vH
Dioscoreaceae	*Dioscorea alata* L. *Dioscorea* sp. *Dioscorea cayenensis* Lam	Mbala nguvu Mbunzu Mboma	L L L
Euphorbiaceae	*Manihot esculenta* Crantz *Ricinodendron heudelotii* (Baill.) Heckel *Alchornea cordifolia* (Schum & Thonn) Müll.Arg *Macaranga* sp.	Madioko Nsanga nsanga Mambuzi mbuzi Nsiasia	sS T S S
Fabacaeae	*Acacia auriculiformis* A. Cunn. ex Benth *Albizia adiantfolia* (Schumach.) W.F.Wight *Albizia gummifera* (J.F.Gmel.) C.A.Sm *Albizia ferruginea* (Guill. & Perr.) Benth *Arachis hypogaea* L. *Hylodendron gabunense* Taub. (1894) *Phaseolus vulgaris* L. *Vigna unguiculata* (L.) Walp	Acacia Kasa Jada Kasa Jada Kasa Jada Nguba Phangu Madezo Bizangi	T T T T aH T aH aH
Irvingiaceae	*Irvingia gabonensis* (Aubry-Lecomte ex O'Rorke) Baill	Ntesi	T
Lauraceae	*Persea americana* Mill	Mvoka	T
Lecythidaceae	*Petersianthus macrocarpus* (P. Beauv.) Liden	Minzu	T
Malvaceae	*Hibiscus acetosella* Welw. ex Hiern *Abelmoschus esculentus* (L.) Moench *Urena lobata* L.	Ngai-ngai (Okra) Ngombo	aH aH vH
Meliaceae	*Blighia welwitschii* (Hiern) Radlk *Entandrophragma angolense* (Welw.) Panshin	Nguba khote Mvovo	T T
Moraceae	*Milicia excelsa* (Welv.) C.C. Berg *Ficus mucuso* Welw. ex Ficalho *Ficus* sp. *Myrianthus arboreus* P.Beauv *Antiaris toxicaria* (Pers.) Lesch *Artocarpus incisa* L. *Trilepisium madagascariense* DC	Nkambala Kimbidi Diwakasa Mbuba Tsangu Phava Nsekeni	T T T T T T T
Musaceae	*Musa acuminata* Colla *Musa x paradisiaca* L. *Musa sapientum* L.	Bitabi Makemba Bitika	vH vH vH
Myristiceae	*Pycnanthus angolensis* (Welw.) Warb	Nlomba	A
Myrtaceae	*Psidium guajava* L.	Mpela	S
Oxalidaceae	*Averrhoa carambola* L.	Paka paka	S
Poacaeae	*Oryza sativa* L. *Saccharum officinarum* L. *Zea mays* L.	Losi (Sugar cane) Mansangu	aH aH aH
Rubiaceae	*Coffea* sp.	Kafi	S
Rutaceae	*Citrus* sp.	Mwamu	S
Sapindaceae	*Blighia welwitschii* (Hiern) Radlk	(Tsana, Akee apple)	T
Solanaceae	*Lycopersicon esculentum* Mill *Nicotiana tabacum* L. *Solanum melongena* var. *esculentum* L.	(Tomato) Tsunga (Aubergine, eggplant)	aH S aH
Sterculiaceae•	*Sterculia tragacantha* Lindl	Nkole nkole	T
Continued			

Families	Species	Vernacular names (Kiyombe)	Growth forms
Ulmaceae	*Trema orientalis* (L.) Blume	Nsengi Nsengi	T
Verbenaceae	*Gmelina arborea* Roxb. ex Sm	(White teak, gamhar)	T
Zingiberaceae	*Zingiber officinale* L.	Tangawisi	vH

Table 2. Food and non-food plant species encountered in peasant agroforestry fields in the Luki Biosphere Reserve and surrounding areas. T (tree), S (shrub), sS (subshrub), L (liana), aH (annual herb), vH (vivacious herb). •Species in the Sterculiaceae are now placed in the Malvaceae.

Species	Food	Handicraft	Wood-energy	Timber	Pharmacological	CI scores	Organ scores	Adjusted scores	Rank 1	Rank 2
Arachis hypogaea	287	0	0	0	1	0.8205	1.0174	0.8348	2	38
Capsicum annuum	110	0	0	0	0	0.3134	1.1455	0.359	7	30
Colocasia esculenta	144	0	0	0	0	0.4103	1.4406	0.591	6	18
Dioscorea alata	239	0	0	0	1	0.6866	1.029	0.7066	4	36
Ipomea batatas	95	0	0	0	0	0.2707	1.3023	0.3525	9	25
Lycopersicon esculentum	88	0	0	0	0	0.2507	1.1818	0.2963	10	29
Manihot esculenta	318	0	0	0	0	0.906	1.7143	1.5531	1	14
Musa acuminata	218	0	0	0	0	0.6211	1.0286	0.6388	5	37
Vigna unguiculata	103	0	0	0	0	0.2934	1	0.2934	8	40
Zea mays	284	0	0	0	0	0.8091	1.007	0.8148	3	39

Table 3. Utilization scores of the top 10 on the list of important food species at the household level in Mayombe and the Batéké Plateau. CI (Index of cultural importance); see text for explanations of rank value.

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
Scores						
CI scores min–max	0.0028 – 0.00569	0.00284 – 0.06267	0.00284 – 0.07977	0.2507—0,4102	0.0028 – 0.1595	0.6210 – 0.9059
Organ scores min–max	1 -2	1 -3	1—2,5	1 – 1.44	0.5 – 2.125	1.007 – 1.714
Adjusted scores	< 0.0055	< 0.05145	< 0.0698	< 0.3793	< 0.1176	> 0.41023
Food						
Yes	0%	0.09%	1.58%	31%	2.98%	77%
No	100%	99.91%	98.42%	69%	97.02%	23%
Pharmacological						
Yes	0%	36.36%	100%	0%	0%	40%
No	100%	63.636	0%	100%	100%	60%
Timber						
Yes	0%	100%	0%	0%	0%	20%
No	100%	0%	100%	100%	100%	80%
Wood energy						
Yes	100%	9.09%	0%	0%	0%	0%
No	0%	90.909%	100%	100%	100%	100%
Handicraft						
Yes	0%	18.18%	15.384%	0%	2.7%	0%
No	100%	81.818%	84.615%	100%	97.297%	100%

Table 4. Classification of the Genetic Resources (GRs) based on the k-Prototype algorithm for mixed data types.

Variables	Odds ratio	25%	95%
Few households	0.1308	0.0184	0.9152
Mayombe ecozone	5.7231	0.586	767.39
Without socio-cultural value	3.3465	0.305	465.573

Table 5. Odds ratios of the logistic regression.

Number of simulations	Estimated coefficient	Lower terminal	Upper terminal
100 000	0,1359996	0,1359317	0,1360676

Table 6. Kendall's correlation test.

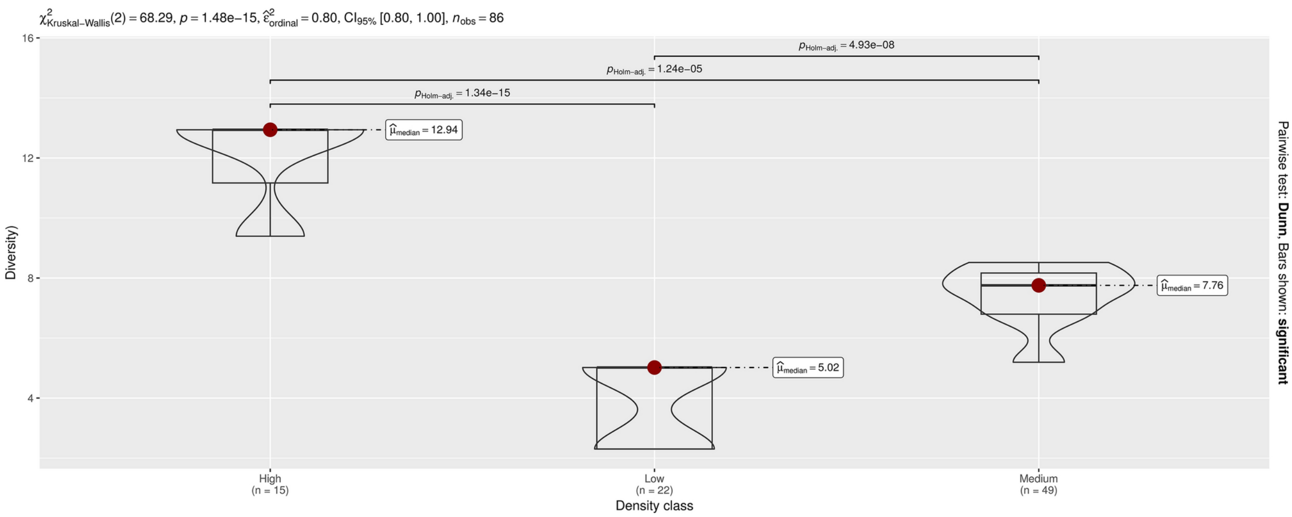

Fig. 1. Difference between groups, Kruskall Wallis test.

an index of 1.0. Finally, 25% of peasant agroforestry fields have a diversity index of over 0.53. As for the number of species per peasant agroforestry field, it ranges from a minimum of two species to a maximum of 17 species. The average number of species per peasant agroforestry field remains close to seven, with a small margin of three species. In 50% of units, there are more than six species.

Links between diversity and population density

We chose a non-parametric approach to detect links between the specific diversity of a peasant agroforestry field and the population density around the Luki Biosphere Reserve.. The data were analyzed using a correlation test based on Kendall's ranks. The results are presented in Table 6.

The confidence interval at the 5% level (i.e. 95% confidence level) does not include zero (0), indicating a link between the two variables.

To reach a clear conclusion on the association between the two variables, it is important to analyze this link while considering the effect of these sub-groups. The Kruskall–Wallis test is used for this purpose.

Figure 1 clearly shows a variation in average diversity based on density. The study found that villages with low population density have lower diversity compared to those with higher density. This result is consistent with the findings of the Kendall test and is supported by the highly significant Kruskal–Wallis test.

Based on these bivariate analyses, the hypothesis of a link between the specific diversity of a field and the population density of the villages surrounding the Luki Biosphere Reserve is strongly supported. Furthermore, this association is positive.

Modelling the relationship between species diversity and population density in villages surrounding the Luki biosphere reserve

To simultaneously relate the specific diversity of a field to the population density of the villages surrounding the Luki Biosphere Reserve, a linear regression model has been fitted to the data. The model was globally significant (P-value $< 2 \times 10^{-16}$; $R^2 = 72.62\%$). The results show that when density increases by 1%, diversity increases by 0.00135. In other words, when density doubles, diversity increases by 0.135.

Seasonality

The agricultural calendar, agricultural activities in support of livelihoods, and periodic problems that are linked to agrobiodiversity management have made it possible to document seasonality.

To better understand the agricultural calendar according to the opinions gathered in the focus groups in the different villages, we focused on the five important crops with high CI scores, namely, *Manihot esculenta*, *Arachis hypogaea*, *Zea mays*, *Dioscorea alata*, and *Musa acuminata*. It is worth noting that ongoing global changes, in particular rainfall-related disturbances, are modifying men's and women's perceptions of the ideal cropping season, depending upon the ecozone and village, with a potential effect on cropping times and the availability of foodstuffs on the market.

Overall, households are engaged in land preparation activities three to five months prior to planting in the villages of Mbakana, Kimufu, and Mangala. We also noted that harvesting activities extend throughout the year according to focus group participants in Mbakana. Sale activities in Mayombe are spread out between January and October. Harvesting takes place at the end of each growing season (April to July and November to January). In Mayombe (Kimufu and Mangala), harvesting activities occur from January to March. It should be noted that harvests of crops such as okra and eggplant, once mature, take place every two weeks. The overall observation is also that agricultural activities cover almost all twelve months of the year and have different implications in terms of the efforts of men and women.

Relying only upon agricultural production, in the strictest sense of the term, was inadequate to sustain the livelihoods of households. This is why families resort to hunting in Mayombe throughout the year, according to the men's focus group of Mangala village. The men's focus group also revealed that fishing is practiced between June and September, and fruit picking takes place in Mayombe between December and February. Harvesting of firewood and carbonization (charcoal-making) are carried out throughout the year in Mayombe. It should be noted that for both men and women focus groups in Mbakana, fishing, hunting, NTFP (Non-Timber Forest Product) collection, and charcoal burning are performed throughout the year. Edible fruits are harvested between March and January. We found that the question about household livelihood support activities presented some sensitivities for men in Kimufu, a village in the Tsumba-Kituti enclave of the Luki Biosphere Reserve. According to the women of Mbakana, fishing, hunting and artisanal timber cutting are secondary activities that are practiced year-round by some families. As a survival activity, most families or households have only agriculture to resort to in the strictest sense of the word. Households are interested in crops such as eggplant, okra, maize, and cassava.

Litter fall, pest attacks, floods, drought, and proliferation of plant and animal diseases are cited as possible problems that are related to agrobiodiversity management. The women and men who took part in the various focus groups have been able to suggest the periods during which these problems were identified. For the villages in the Mayombe ecozone, both women and men felt that plant diseases and pest attacks (e.g., Gambian pocket rats, cane rats) occur throughout the year. According to the men's opinions in Mbakana. this is not at all the case for this village on the Batéké Plateau. The major and permanent problem that is frequently cited is the poor quality of the soil. The women of Mbakana do not all agree regarding the sources of these problems. The plant diseases that were cited by women and men in Mangala and Kimufu are the presence of various fungi that are responsible for cassava rot (i.e., *Lasiodiplodia theobromae*, *Cylindrocarpon candidum*, *Aspergillus niger*, *A*. *flavus*; *Fusarium solani*[47,48], and a range of diseases referred to as witches' broom (*Candidatus* phytoplasma aurantifolia, *Candidatus* phytoplasma palmicola, or basidiomycete fungi), which affect their productivity. They also reported yam mosaic virus (*Potyvirus*) and anthracnose (*Colletotrichum gloeosporioides*). Gambian pocket rat (*Cricetomys gambianus*) and the large cane rat (*Thryonomys swinderianus*) were cited as periodic crop pests in the Mayombe ecozone. However, the women of Mangala acknowledged that the Gambia pocket rat and the African civet (*Civettictis civetta*) are involved in seed dissemination. For the men of Mangala, drought is considered as irregular and due to climate change, which is affecting food crop production.

Discussion

Assessing the importance of yam in the agrobiodiversity of the Luki Biosphere Reserve area in Mayombe and in the village of Ibi on the Batéké Plateau first provided an overview of the diversity of plant, animal, and fish species that are found in these two ecozones. Second, it highlighted the importance of yams in the biodiversity that was recorded. It enabled us to assess its contribution to securing livelihoods, and, finally, to identify the influence of seasonality on livelihoods.

Our investigations reveal that the food resources that were identified are essentially composed of PGRs. Both ZGRs and FRs are subject to strong anthropogenic pressures and are diminishing, thereby reducing their contribution to food security, nutrition, and improved livelihoods. In the case of livestock, the threats of swine fever to pig farming and influenza to chicken farming was mentioned almost unanimously by respondents in the Mayombe and Batéké Plateau ecozones. These threats are foremost among the constraints to increased adoption of livestock farming by small-scale farmers as a source of protein and livelihood. In many parts of the country, the reduction in livestock numbers, whether small or large, is commonplace. For the former Bandundu province, which is a province bordering on the provinces where we conducted our investigations between 2000 and 2014, production of goats, pigs and sheep in this province declined respectively by − 1.2%, − 6.2% and − 1.7%[49]. This equates to an annual decline of − 0.1%; − 0.3% and − 0.1%, respectively. A study carried out in South Kivu, in eastern DRC, explains this decline in livestock numbers by the high population density, recent conflicts and poverty[50]. Scarcity and constraints on access to good-quality grazing land are also cited, particularly in conflict zones of eastern DRC[51,52]. Mpanzu et al.[53] mention the lack of innovation and technical support for small-scale farmers. The decline in livestock diversity can be explained by various factors, depending upon their geographic, environmental, security and political contexts.

FRs (fish resources) are a rare and prized commodity around Luki Biosphere Reserve. This has also been observed in Mbakana. Some ten years ago, the poverty and low diversity of fish in the Luki river was revealed[54], based on the discrepancy that was observed between published data and results that were obtained in the field. FRs are supplied by a few traders who obtain frozen fish imported from major cities such as Kinshasa for the Batéké Plateau ecozone, and the towns of Boma and Matadi for the Mayombe ecozone. Men and women living around the Luki Biosphere Reserve in Mayombe unanimously affirm that *Scomberomorus maculatus* (Atlantic Spanish mackerel), commonly known as "makuala" (in lingala language), and *Trachurus trachurus*, commonly known as Atlantic Horse mackerel, are the two fish species that abound in local markets, sometimes in salted form. The men of Mangala village compare the makuala to a cow to show just how valuable this FR is to their protein diet.

Calorie and micronutrient requirements are major concerns for around 80% of small-scale farmers in Africa[55]. Crops such as yams are perceived by the households under study, particularly in Mayombe, as being of relatively high importance due to their potential as a source of carbohydrates, proteins, vitamins and minerals. Above all, they are presumed to be a crop with high income-generating potential[56–58]. In contrast, yams remain poorly represented in peasant agroforestry fields. We note that there is a contrast between the fact that yams are perceived as a relatively important crop and the fact that they are poorly represented in peasant agroforestry fields. This leads us to understand that the low importance of yams in peasant agroforestry fields is not necessarily associated with the loss of traditional knowledge about yams. This loss, if it existed, would in this case follow a relatively slower dynamics than that visibly illustrated by the low representation of yams in peasant agroforestry fields. Therefore, the low importance of yams in peasant agroforestry fields is plausibly seen as a phenomenon that is linked to many other factors, including land insecurity and soil degradation in our two ecozones. Perceptions of ecological and socio-cultural values do not appear to be major determinants in the choice of food crops, including yams, in Mayombe and on the Batéké Plateau ecozones.

Based on statistics of important staple crops from 1995 to 2014 for the former Bandundu province, Diaw and Franks[49] reported results that confirm the relative importance of yam production for the years studied. They found that cassava and groundnuts ranked first in terms of production. These crops are followed respectively by yam, maize, sweet potato, paddy rice and plantain. Cornet[59] reports that over the last four decades, interest in yams has grown considerably. This is evidenced in West Africa by strong demand in both urban and rural communities[59]. Numerous studies suggest, however, that yam production will decline as fertile land becomes increasingly scarce. Studies by Travis et al.[13] reported "a 50% loss in productivity in around 6 years, due to soil infertility." Other studies predicted a decrease of 18 to 33% for the decade 2041–2050[60,61]. In this respect, studies by Danquah et al.[14] covering Nigeria, Côte d'Ivoire and Ghana are quite revealing with regard to the constraints surrounding the maintenance of yam productivity, concluding that the rare cases of increased yam productivity that were found were associated with increases in cultivated area. The question of soil fertility requirements remains debatable for Cornet[59], however, as the adequacy of yam requirements in terms of mineral nutrition is often not taken into account[62].

In view of the low representativeness of **Dioscoreaceae**, it should be noted that numerous studies confirm that the families **Fabaceae** and **Moraceae** are the most abundant in our study areas, and even in the Congo Basin[63,64]. Our results show that little progress has been made in terms of popularizing under-represented families, as pointed out almost 30 years ago by Lubini et al.[32]. Indeed, these authors noted that some forty indigenous food species (from the families **Zingiberaceae**, **Verbenaceae**, **Cucurbitaceae**, **Moraceae** and **Sterculiaceae**) were still not cultivated even though they contribute to household food resilience. It should be noted, however, that families not cultivated for food purposes in our study area may still be used to a greater extent for ethnopharmacological purposes. In this respect, at Mont Amba in Kinshasa, it has been reported that the following families are the most widely used in traditional ethnopharmacology: **Zingiberaceae**, **Clusiaceae**, **Iridaceae**, **Apocynaceae**, **Rubiaceae** and **Simaroudaceae**[65]. The use of neglected local food resources can contribute electively to "social and economic empowerment"[66].

We found that households in our study areas do not primarily turn to yams to secure their livelihoods. One reason for this is that yams are not traditionally anchored in the culinary culture of the Batéké Plateau in the DRC, and are not grown there at all, except in very isolated areas next to the few dwellings. Coursey, quoted by Cornet[59], describes this form of yam protoculture as a first step in the transition to the practice of such cultivation on a larger scale[9]. The situation of yams in the Batéké Plateau ecozone contrasts with that of Mayombe in the DRC. Yam is one of the main food crops that are grown by households in Mayombe ecozone. Households, particularly in Mayombe ecozone, are nevertheless attempting to diversify their production, which also enables them to minimize the potential constraints that are associated with specialization in a single crop[67]. Several studies argue that "the livelihood portfolio of households in Africa is highly complex, with varying degrees of diversification of agricultural and non-agricultural income sources"[68–71]. Furthermore, it should be noted that in the Mayombe context, population density is a factor influencing the conservation of agricultural diversity cultivated in peasant agroforestry fields. However, the precariousness of land tenure can be an obstacle and requires migration to more intelligently managed peasant agroforestry fields that can address multiple land concerns including availability and access. This move is necessary, even though our survey results indicate inequality in access to GRs and land resources, which are essential for GR production.

A wealth of literature, however, maintains that yams really do have enormous potential to contribute to improved livelihoods[57,72], but require greater consideration regarding the determinants of their cultivation, notably: "soil fertility management, lack of irrigation, abandonment of staking, difficulty of maintaining fields, management of possible diseases that may attack yams, improvement of the shelf life of yam tubers, reduction of post-harvest losses and reduction of high transport costs, etc."[13,14,62,72].

The United Nations' Sustainable Development Goals 1 and 2, respectively, aim to eradicate poverty and hunger in all their forms. In Africa, these two objectives, which are considered to be at the heart of the continent's development, involve small-scale farmers[68], whose agricultural operations are still largely rain-fed[70]. This traditional form of agriculture, which is also itinerant and, in many cases, burnt-out, threatens the livelihoods of small-scale farmers and global food security due to its high dependence on rainfall in a context of climatic variability[70,73,74].

In a context of high household dependence on GRs for their livelihoods, we have observed that adherence to the agricultural calendar is not strictly maintained. This is due to many uncertainties that are associated with the occurrence of extreme events such as drought, floods, heat waves, and so on. These disruptions that are experienced by households throughout the year are prompting some men in the villages under study, particularly in Mayombe, to turn more to charcoal burning. This practice may be unsustainable, but it provides a secure income throughout the year. Slash-and-burn agriculture and carbonization are the main factors exerting pressure on Mayombe's forest remnants, threatening food and nutritional security and livelihoods in the short-, medium- and long-term[75,76]. This conversion, in a context where more than half of the Congolese population (62%) live on around 2 USD per day[77], is also reinforced by increasing attacks by crop pests, the proliferation of plant diseases, animal plagues and, above all, declining fertility, as revealed at Mbakana on the Batéké Plateau ecozone. Faced with income instability that is accentuated by climate change and its consequences, securing sustainable livelihoods for small-scale farmers is a major development challenge. It requires the articulation and better integration, in specific contexts, of knowledge, practices and policies in terms of pest control, climate-adaptive measures for integrated water and fertility management, fully involving smallholders as co-actors and beneficiaries[78].

Conclusion

This study assessed the importance of yams in the use of agrobiodiversity in Mayombe and Batéké Plateau ecozones. It revealed that yams are poorly represented in Mayombe and almost non-existent in the Batéké Plateau. This low level of representation does not necessarily correlate with traditional knowledge regarding the use of GRs that is held by households to this day. Despite the importance of yams for food security, nutrition and income generation, this crop is not central to the livelihood security strategies of the households that were studied. Households mainly resort to diversification of agricultural production as the main means of generating "agricultural" income. The latter is supplemented by income from other non-agricultural sources. Climate change and the emergence of crop pests are encouraging people to turn to unsustainable charcoal burning, which in turn is contributing to deforestation, along with shifting cultivation, particularly in Mayombe. Biodiversity-rich yam-based peasant agroforestry systems with a high degree of complexity are resilient systems that can provide sustainable means of substance while promoting better coexistence of uses to fundamentally meet food, nutrition, health, and energy needs, while preserving the environment. This study argues for a quantification of the effects of climate change and its consequences on Mayombe yam-based cropping systems in securing livelihoods. The suitability of land for yam cultivation under different conditions in Mayombe and Batéké Plateau ecozones also needs to be assessed.

Data availability

The authors declare that all supplementary materials associated with the results presented in this article have been made available in the supplementary files.

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BNV: Conceptualization, Methodology, Visualization, Writing—Original draft, Investigation, Data analysis. PA: Writing—revision and editing. SB: Funding, Writing—revision and editing. MNN: Conceptualization, Writing—revision and editing. DPK: Supervision, Validation, Funding.

Competing interests
The authors declare no competing interests.

Ethical approval
This study was conducted in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. The research protocol was reviewed and approved by the Research Ethics Committee of Université Laval (Approval number: 2020-146/23-07-2020).

Informed consent
Informed consent was obtained from all individual participants included in the study. Participants were provided with comprehensive information regarding the purpose, procedures, potential risks, and benefits of the study. They were assured of their right to withdraw from the study at any time without any consequences.

Additional information
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