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Research article

Inferring multilocal typologies of agrosystems and farmers' practices: A methodological basis for the setting of participatory breeding designs

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A B S T R A C T

Family farms play an essential role in agroecological transition in Sahelian countries and worldwide. They present diversified features in terms of socio-economic organization, agro-biodiversity management and cropping systems diversity. Decentralized participatory breeding approaches aim to sustain the diversity of varieties adapted for such smallholder farmers' contexts. However the lack of clear target population of environments limits the focus and the efficiency of these approaches given the large diversification of the local contexts. In this study, we surveyed variables linked to agrosystems, crop management options and farmers' criteria of varietal evaluation from 254 family farms sampled along 13 locations spanning the target area of a decentralized participatory breeding program of cowpea crop (*Vigna unguiculata* L. Walp) in Niger. The objective of our study was to infer typologies of family farms in the study area based on relevant variables supporting the setting of target population of environments (TPEs) to be considered in the breeding program. We used factorial analysis of mixed data (FAMD) and the Discriminant Analysis of Principal Components (DAPC) to infer the clusters. Chi square test, analysis of variance and generalized linear model were used to identify key variables discriminating the clusters. These clusters were geographically mapped to analyze their multilocal distribution. So, we identified and characterized four clusters structuring the diversity of the local agrosystems (Typologie G), five clusters structuring the diversity of cowpea cropping management options (Typologie C) and five clusters structuring the diversity of criteria used by farmers to evaluate the performance of cowpea varieties in the local contexts (Typologie P). Typology G distinguished farms based on discriminating variables linked for instance to secondary activities, cultivated species, soil fertility management practices and farm resources including land and livestock. Typology C distinguished farms based on cowpea management pratices including the secondary crop intercropped with cowpea (sorghum, Guinea sorrel, sesame or groundnut) and the use of cowpea harvest products (seeds, haulms, hulls). Typology P was based on discriminating performance criteria including cycle length, insect resistance, striga resistance, drought

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resistance, haulm production and economic value of cowpea variety. This methodology provides a robust and replicable way for the definition of clusters capturing the diversity of farms and local contexts. We discussed the perspective of using these clusters to set target population of environments for decentralized breeding programs.

1. Introduction

The transitions to sustainable agricultural and food systems could be supported by participatory research approaches [1]. Decentralized and/or participatory breeding strategies aim to make available a diversity of cultivars adapted to local contexts and farmers' preferences [2,3]. These strategies imply a better understanding and inclusion of local criteria in the breeding programmes. This favors both the co-creation and the sharing of knowledge between breeders, farmers, agronomists, sociologists and extension workers. While the interest in these approaches is growing [4], designing clear, generic, and robust methodologies to include local knowledge and local needs in a decentralized breeding programme remains a significant challenge.

In Sahelian countries, family farms ensure the food security of millions of people [5,6]. The majority of people lives in rural areas and practices agriculture as their main activity and source of income. Fieldwork is mainly carried out by family members [7], with a limited amount of help from salaried workers [8] or from the local community. Crop cultivation is generally coupled with livestock, making the systems mixed farming systems [5]. Besides, family farms included various activities such as the transformation of agricultural products, handicrafts or small trade, which are generally individual activities [8]. In addition, family farms are also characterized by social factors, such as the number of members in the household [9]. Within family farms, members are interdependent, and the collective profit is prioritized over individual profit [10].

Given the complexity and the diversity of farms, typology approaches are being used to describe family farms [9]. Typological construction is a process of classifying, describing and comparing family farms based on considered criteria [11,12]. So far, several typologies have been proposed to classify farms based on criteria considered as essential by the researchers. These criteria are sometimes not sufficient to allow understanding the dynamic development of farms [13]. To better understand the diversity of farming strategies, farm types should be categorized and analysed within their operating context [13]. Family farms are known to be mobile

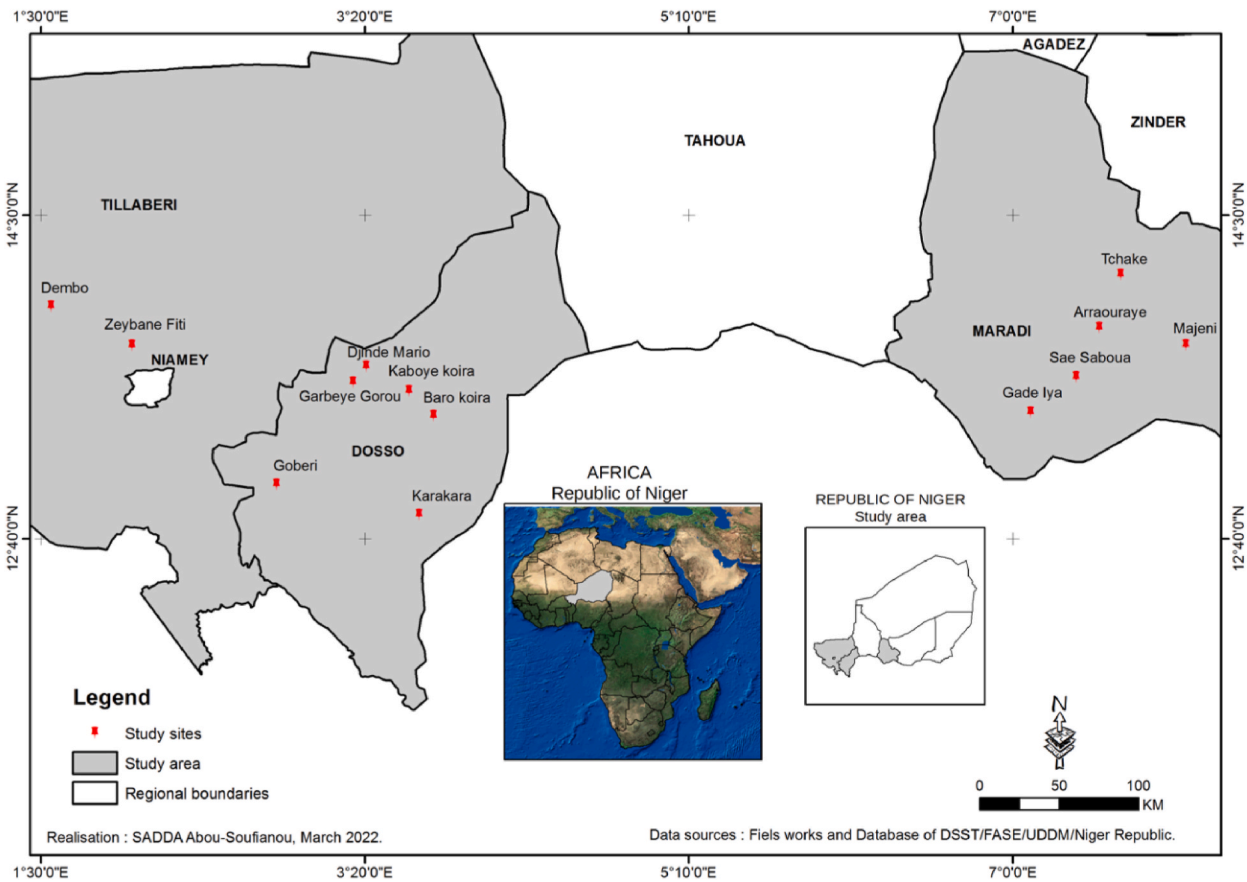

Fig. 1. Locations of the study.

targets [14] and the typology that results is instantaneous in time [15]. Furthermore, given the rapid evolution of socio-economic conditions and the characteristics of farms, a periodic update of these typologies is necessary [16].

The southern central part of Niger (region of Maradi) and the western part (regions of Dosso and Tillaberi) present diversified farmers' pratices. These practices are developed and maintained by different local communities representing a social and cultural diversity and living in contrasting agroecological zones (rainfall decrease from north to south with consequences on biodiversity and agriculture). Strategies of decentralized breeding generally associates diverse scientific fields and diverse local expertises through the involvement of academic and farmers organizations. Individual farmers are involved in the different steps of participatory breeding through the organizations to which they are affiliated. This include their contribution to agrosystems' diagnosis, breeding priorities' definition, target traits choice, plant material choice for crosses, trial design and implantation, trial evaluation and results discussion. Such a framework provides a case study model to investigate the methodological framework of decentralized breeding. Particularly, we addressed in the current paper the challenge of how to find a methodological basis to clearly set the target population of environments for decentralized participatory breeding in such a multilocal context with a large diversity of family farms' characteristics, farmers' practices and preferences. The target population of environments (TPE) is defined as the set of environments, including spatial and temporal variability, to which improved crop varieties developed by a breeding program need to be adapted [17–19]. In the context of participatory breeding, the inclusion of local agrosystems diversity and local crop management options in the setting of TPEs is a crucial issue. We hypothesized that the multivariate analysis of multilocation survey data on family farms characteristics, farmers' pratices and farmers' preferences allows consistent inference of farms' clusters representating specific targets populations environments. The objectives of the current study were thus: i) To infer a clustering of family farms based on general farms' characteristics including social factors, farm's resources and cropping systems (hereafter, ***G**eneral typology of family farms* or Typology G); ii) To infer a clustering of family farms based on the variability of cowpea cropping management options (***C**owpea management-based farms' typology* or Typology C); iii) To infer a clustering of family farms based on the variability of criteria used by farmers to characterize the performance of cowpea varieties (*Cowpea **p**erformance criteria-based farms' typology* or Typology P); and iv) To analyze the link of farms' typologies and discuss the opportunities and perspectives of using these typologies as a methodological tool for the setting of target population of environments in the framework of a decentralized participatory breeding strategy.

2. Material and methods

2.1. Survey

Eight villages of western Niger (Dosso and Tillaberi regions) and five villages of south centre of Niger (Maradi region) where concerned by the study (Fig. 1). These villages were involved in a decentralized breeding programme which is part of a trans-disciplinary research programme supported by the Collaborative Crop Research Programme (CCRP, McKnight Foundation). They were sampled based on two main sets of criteria: soil and climate variation (to ensure the covering different ecological zones, locations in the north being driest than the southern ones) and farmers' organizations strategic priorities (we choosed villages where farmers are more interested by cowpea and associated cropping systems). In collaboration with the farmers' organizations FUGPN Mooriben (in the western zone) and FUMA Gaskiya (in the south centre zone), twenty family farms were surveyed in each village except in the villages of Goberi (25) and Gadé Iya (10). From the 20 respondents, 15 were members of the considered farmers' organizations, and five were either independent farmers or affiliated to another federation. Surveys were performed on family farms constituted of one or more households sharing the same fields. The household was made up of parents (husband and wife(s)), kids and possibly adult children living under the same head of household. One adult family farm member responds to the survey as a representative of the family; he could be (or not) the head of the family farm. The variables include in the survey were chosen based on general knowledge and expertise about Sahelian family farms in general and cowpea crop in particular.

The empricial process of decentralized participatory breeding and the survey underlying this study were conducted into 13 villages spanning three regions of Niger (Tillaberi, Dosso and Maradi with respectively 2, 6 and 5 villages). Note that aridity generally decreases from north to south in Niger, part of the Sahelian climate zone.

2.2. Datasets and methodology used to build the typologies

To infer clusters representating the diversity of family farms in the studied multilocal context, we classified the variables from the survey into three thematic datasets. The first dataset (used to infer Typology G) contained general characteristics of the farms, including social, economic, soil, agrobiodiversity and farm infrastructures variables. The second dataset (Typology C) contained the variables describing the management options used by farmers for cowpea cropping. The third dataset (Typology P) contained the criteria used by farmers to characterize the performance of cowpea varieties.

2.2.1. General farms' data set

The dataset for general farms' typology included social data (age, main occupation, and secondary occupation of the respondent, number of households and number of people in the farm), farm resources data (number of fields, area of the main field, total area of the fields), soil texture and fertility management data (main field and a randomly chosen field soil texture and fertility level, soil fertilizating methods) and diversity of cultivated crop species including cultivated species, number of varieties and crop species ranks.

A total of 133 variables, consisting in 85 main variables (used to compute multivariate dimension) and 48 supplementary variables (used to contribute interpreting the results) were used for this general typology. Among the supplemental variables used to interpret

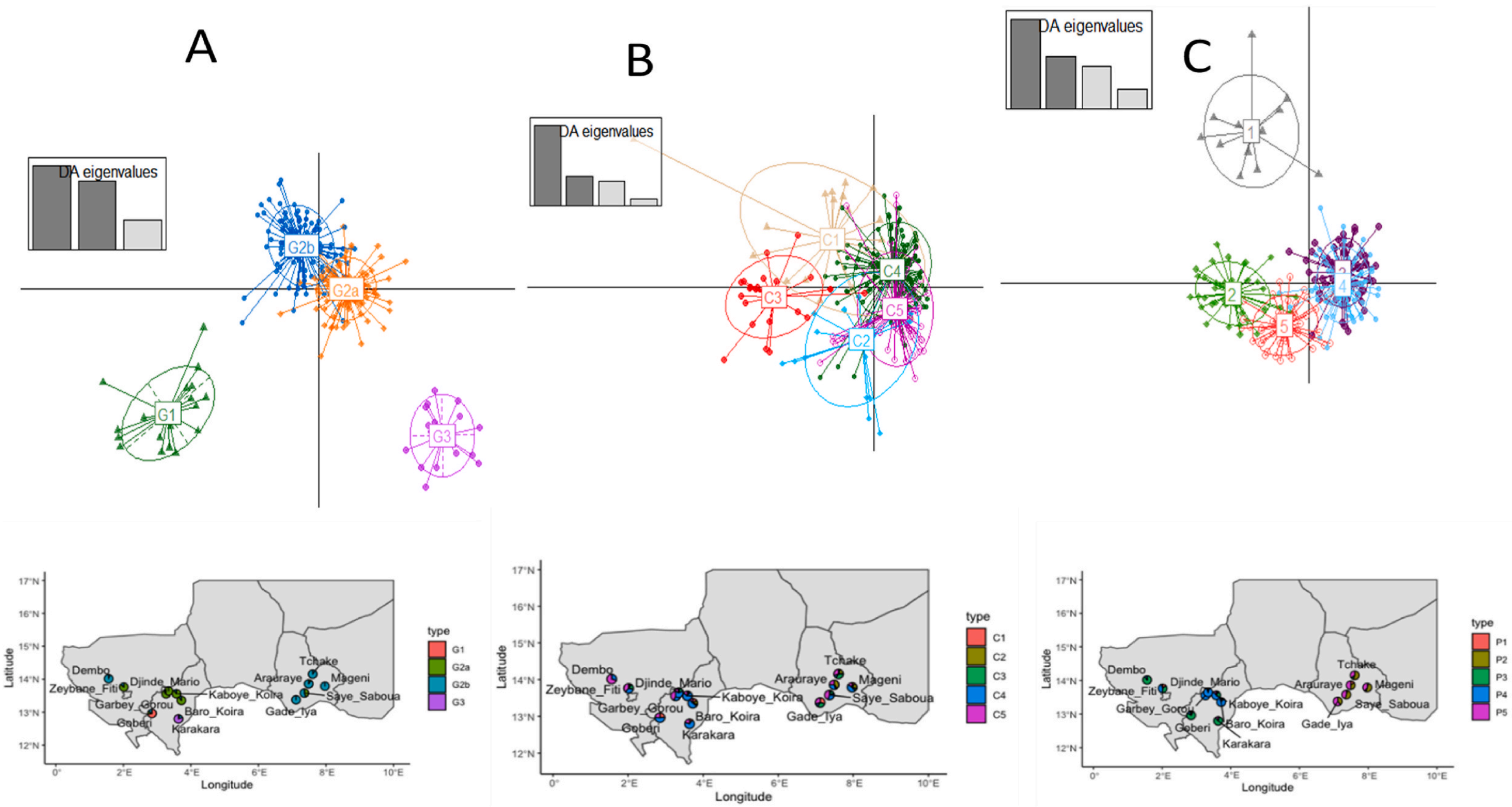

Fig. 2. Three typologies of family farms in the west and central south of Niger.

the clustering results, we have also social and geographical variables such as the geographic area, the region, the village, the individual membership to farmers' organization, the sex of the respondent, the ethnolinguistic group, and the status (function) of the respondent in the farm. The variables such as "number of horses per farm" and "number of camels per farm" presented rare modalities considered as outliers; they were excluded from the clustering analysis (only one farm had a horse; and only two farms had camels, one and eight respectively). Similarly, only the crop species cultivated by at least 2.5% of the farmers were included in the analysis. Hence, six species were discarded from the clustering analysis based on this threshold, corresponding to sugar cane (*Saccharum officinarum*), date palm (*Phoenix dactylifera*), soybean (*Glycine max*), taro (*Colocasia esculenta*), green bean (*Phaseolus vulgaris*), and cucumber (*Cucumis sativus*).

2.2.2. Cowpea management data set

To infer family farms structure according to local cowpea crop management pratices, a combination of four data subsets comprising a total of 15 variables and corresponding to 4 categories of cowpea cropping management pratices was used. The first subset consisted of crop species associated in intercropping with cowpea, such as pearl millet (*Pennicetum glaucum*), Guinea sorrel (*Hibiscus sabdarifa*), sorghum (*Sorghum bicolor*), groundnut (*Arachis hypogaea*), and sesame (*Sesamum indicum*). The second subset concerned the presence-absence of particular practices related to sowing, notably the application pesticide treatment to cowpea seeds before sowing (cowpea seeds are treated generally with a chemical powder called in local language "raya iri or ajalin koussa" to prevent rodents from digging up the seeds), thinning and transplanting. The third subset included the number of cowpea varieties cultivated by each farm and the number of cowpea seeds to be sown in monoculture and association cropping systems. The use of cowpea-harvested products (grain, haulm and hull) for sale and/or for self-consumption, which could have indirect effect on the practices, was included as the fourth subset.

2.2.3. Farmers' criteria of cowpea performance data set

To cluster the farms based on the criteria they used to characterize cowpea varieties performance, we used as prior survey information the list of criteria already established in the studied areas through focus groups realized in the framework of CowpeaSquare project [20]. The list was extended in our survey to include new criteria not listed before. A total of 13 criteria described by 75 proximal parameters commonly used by farmers to characterize cowpea varieties were then included. These criteria were as follows: cycle duration (5 proximal variables), grain production (3 proximal variables), hull production (5 proximal variables), haulm production (7 proximal variables), resistance to insects (8 proximal variables), resistance to *Striga gesneriodes* (7 proximal variables), drought tolerance (7 proximal variables), tolerance to flood (6 proximal variables), biofertilizing power (5 proximal variables), low amendment requirement (4 proximal variables), seed quality (7 proximal variables), seed filling (4 proximal variables) and seed economic value (7 proximal variables).

2.3. Statistical analysis

For each typology, factorial analysis of mixed data (FAMD) was used to cluster the family farms based on qualitative and quantitative variables [21]. Eighteen (18) farms have missing data for the total area of the fields. The method missMDA (R package FactoMineR) was used to imputate this missing information as a prediction based on the multivariate data. The number of retained principal components (PC) accounted for 70% of the cumulative variance. The function *findclusters* (library adegenet) was used to infer the optimal number K of clusters for each typology analysis (using 10,000 runs). Discriminant Analysis of Principal Components (DAPC) was used to describe the obtained clusters. ANOVA (analysis of variance) and GLM (General linear model) were used to identify the quantitative variables that discriminate the clusters (at *P*-value threshold of 0.05). The Chi-square test was used to identify discriminating qualitative variables. To assess the relationship between the three typologies, contingency tables were constructed to assess the relation between the clusters sets among typologies.

3. Results

In this study, a total of 254 family farms were surveyed, corresponding to 164 farms from the western zone of Niger (Dosso and Tillaberi regions) and 90 farms from the central-southern zone (Maradi region). Among these, 69 family farms were represented for the survey by members of the farmers federation FUMA Gaskiya (Maradi region) and 126 farms were represented by respondents who were members of the farmers federation FUGPN Mooriben (Dosso and Tillaberi regions); 59 farms were represented by independent farmers (not affiliated to any of these two federations).

The three defined sets of data allowed the inference of three respectives typologies based on multivariate clustering (Fig. 2): i) General typology of family farms in a multilocal farmers context (A); ii) Typology of family farms based on farmers pratices of cowpea management (B); and iii) Typology of family farms based on local cowpea performance criteria (C).

We presented the inferred clusters based on DAPC projection and geographic map (Fig. 2). The general typology identifies the most important local agrosystems (Fig. 2A) and show the geographical trend in family farms similarity. Each villages was dominated in general by one main local agrosystems, at the exception of the villages of Goberi and Kakara which showed more intra-village diversification. The local options of intercropping and crop managements for cowpea (Fig. 2B) and the proximal variables used by farmers to assess varietal performances (Fig. 2C) appeared more diversified between villages and among family farms into the same villages.

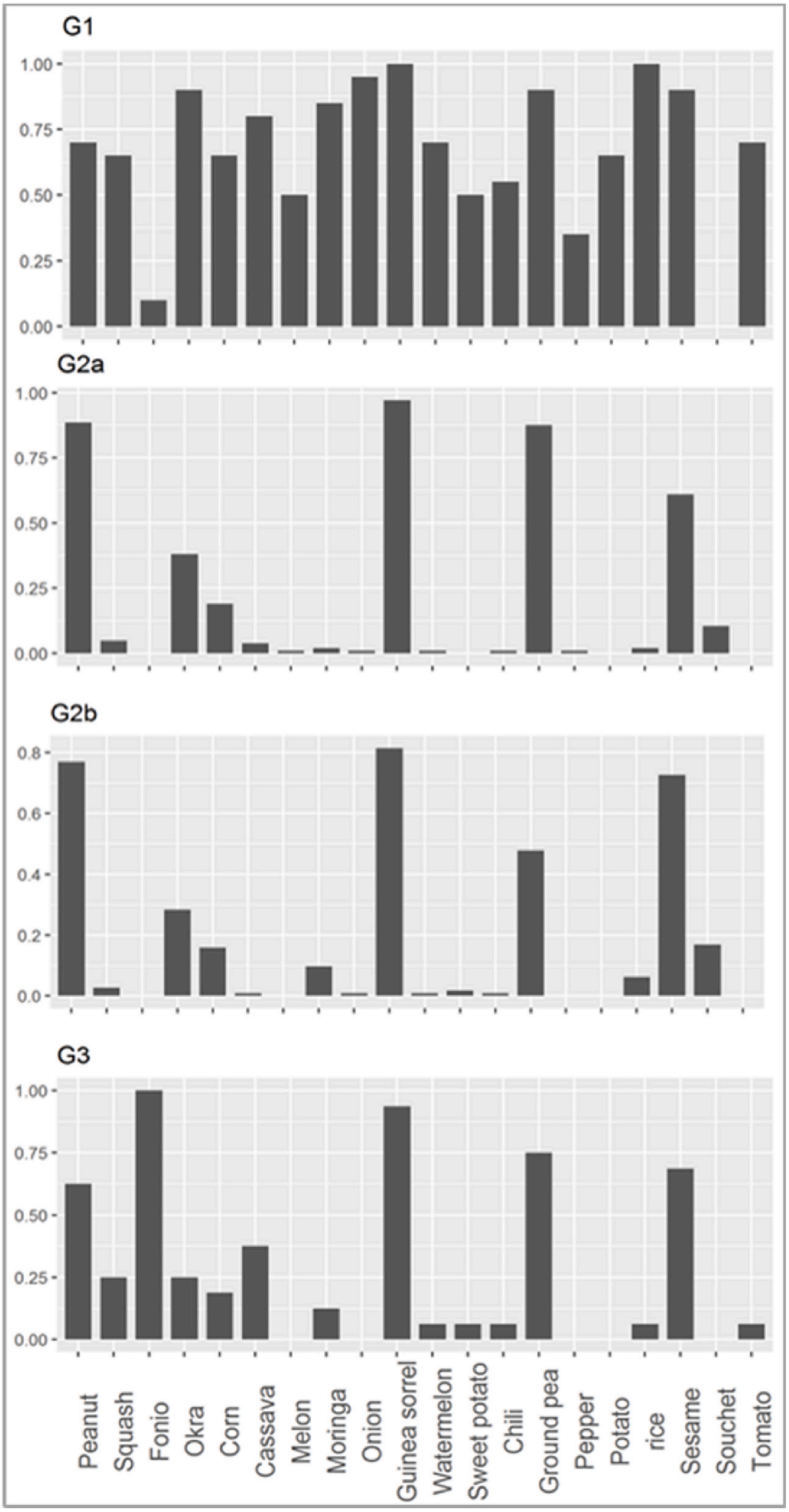

Fig. 3. Proportion of farms cultivating each crop among the four clusters of the general typology. The twenty species (X-axis) for which a significant difference in cultivation proportions (Y-axis) was found between clusters are represented.

3.1. General typology of family farms in a multilocal farmers context (Typology G)

Based on social factors, farms resources, soil management options and diversity of cultivated crop species in the farms, we identified four clusters G1 (20 farms), G2a (105 farms), G2b (113 farms) and G3 (16 farms). The G2a and G2b clusters were the closest and had large sizes (Fig. 2A).

Out of 41 quantitative variables, 25 variables were discriminant and significantly differentiated the clusters (Table S1; ANOVA, $P < 0.05$). From 92 qualitative variables, 58 variables significantly differentiated the clusters (Table S2; Chi Square test, $P < 0.05$). Among the social factors included in FAMD computation, the most discriminating between clusters were the number of households composing the family farm (Table S1) and the secondary professional activity (Table S2). In terms of farms resources, clusters differed mainly based on the area of the main field, the total area of fields, the number of fields, and the number of cattles (Table S1). Clusters differed also by soils texture and fertility level of the fields as well as the technique of soil fertilization (the use of chemical fertilizer, fallow, compost and crop residues).

The clustering was based on multivariate analysis of three sets of survey data on the same sample of 254 farms (see text). DAPC projections of the three respective typologies are represented on the top (first and second dimensions are shown in each analysis); and the corresponding geographic map projections are represented on the down. A) General typology of family farms. B) Typology of farms based on cowpea diversity management. C) Typology of farms based on the criteria used by farmers to assess the performance of cowpea varieties.

The diversity of cultivated crops (number of different species in the farm) differed also significantly (Table S2). Some variables, such as the number of persons in the family farm, did not discriminate clusters (all clusters have a mean of 15 persons per farm). Among the 30 cultivated species, pearl millet and cowpea were cultivated on all farms, so their presence was not discriminant.

In the cluster G1 ($n = 20$), the dominant soil texture as reported by the survey (farmer declaration) was sandy soils which characterized 80% of the main fields and also 80% of the randomly sampled fields. About 40% of the main fields in the family farms constituting this cluster are fertile (respectively 35% of randomly sampled fields), but 25% of the main fields had low fertility (respectively 10% in randomly chosen fields). About 15% of main fields and 35% of randomly chosen fields had soils with high fertility. Pearl millet is the main crop in all of the farms; cowpea is the second most cultivated crop across 75% of the farms (Table S3). Farmers from this cluster cultivate the largest diversity of crop species, due to the presence in their farms of irrigated crops such as squash (*Cucurbita pepo*), okra (*Abelmoschus esculentus*), maize (*Zea mays*), cassava (Manihot esculenta), melon (*Cucumis melo*), moringa (*Moringa oleifera*), onion (*Allium cepa*), watermelon (*Citrullus lanatus*), sweet patato (*Ipomoea batatas*), chilli (*Capsicum annuum*), bell pepper (*Capsicum annuum*), patato (*Solanum tuberosum*), rice (*Oryza sativa*), sesame (*Sesamum indicum*), and tomato (*Solanum lycopersicum*) (Fig. 3). In this cluster, livestock breeding was the most practiced secondary activity (65%), followed by other secondary

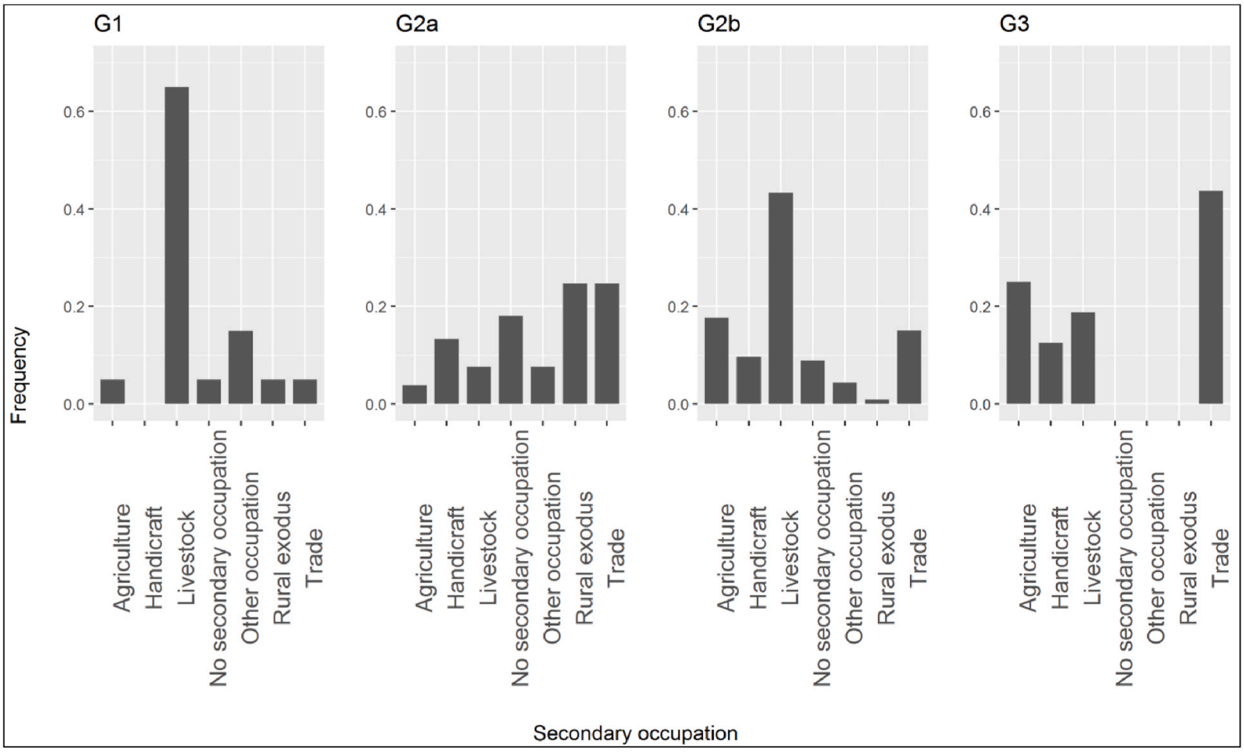

Fig. 4. Secondary activity of family farms respondents by general typology cluster. The proportion of farms for which the respondent declared a given secondary activity is presented for each cluster.

activities such as painting and masonry (Fig. 4).

About 25% of G2a respondents (n = 105) had rural exodus as secondary activity and 18% of respondent farmers in this cluster did not have a secondary activity (Fig. 4). For 29%, the main fields in their family farms are dominated by clay soils with an intermediate level of fertility. A part of 73% use chemical fertilizers, while 59% use fallow to enrich their farms (Table S2). Cowpea is the first crop grown on 18% of the farms of this cluster. The cultivation of groundnut characterizes specifically G2a where this crop is ranked as the third most important crop by 40% of the farms.

The respondents of the cluster G2b (n = 113) cited livestock breeding as secondary activity. This cluster is composed of farms that own an important number of fields (Fig. 5) with small area for each field. Most of these farmers do not have cattle. The dominant texture of the randomly sampled fields in this cluster is clay for 34% of the family farms. This field is fertile for 42% of family farms and poor for 25% of them. They essentially use compost to enrich their fields. The cultivation of tiger nut (French: *souchet*) characterizes specifically this cluster (17% of farms) compared to the other groups where this species tends to be absent. Cowpea was the second or third crop for 45% of the farms in this cluster.

Most of the respondents from G3 (n = 16) were characterized by trade as secondary occupation (44%). The cluster is composed of family farms with a high number of varieties of fonio (*Digitaria exilis*) and sesame. Comparing to the other clusters, their main field has the largest area (Table S3). The texture of the main field is sandy for 94%; these fields were perceived as fertile for 50% of the respondents. For fertilization, 85% used crop residues (Table S2). All farmers cultivate fonio while 44%, 38%, and 19% rank it as 2nd, 3rd, or 4th crop.

3.2. *Typology of family farms based on farmers pratices of cowpea crop management (Typology C)*

Based on the multivariate analysis of the data on the crop management pratices that farmers apply to cultivate cowpea in their family farms, five clusters were identified, with respective sizes of 20, 21, 26, 113, and 74 family farms (Fig. 2B). There were significant differences between these clusters for several practices of cowpea management (Table S4, Table S5 and Table S6). For instance, these clusters differed by the crops used in intercropping with cowpea (Fig. 6), except pearl millet which is used by all farms. The number of seeds used when sowing, as well as the practice of counting and the treatment of seeds before sowing differed also (Table S5 and Table S6). Besides, the clusters also differed by the final use of the harvested products, notably haulm and hull.

The cluster C1 (n = 20) was made up of family farms sowing an average of eight cowpea seeds per seed hole. Farms belonging to this cluster use mainly Guinea sorrel in intercropping with cowpea. The cluster C2 (n = 21) characterized the family farms using mainly sesame in association with cowpea. About 81% of farmers in this cluster treated cowpea seeds before sowing. However, 62% of the farmers from this cluster do not count cowpea seeds before sowing. Cluster C3 (n = 26) and cluster C5 (n = 74) were characterized by the intercropping of cowpea with sorghum, in addition to pearl millet. But, the family farms in the cluster C3 have the lowest percentage of farms that use hull and haulm for self-consumption (around 15% of farms), while about 67% of the farms in the cluster C5 use harvested seeds for self-consumption. The cluster C4 (n = 113) differs from the others in the practice of seed counting, thinning, and seed treatment. It comprises family farms that use the least harvested seeds for self-consumption (less than 40% of farms).

After pearl millet which is the main crop intercropped with cowpea for 84% of the farms irrespective of the clusters, the secondary crops intercropped with cowpea are shown. The main secondary crops according to the respective clusters are sorrel (for cluster C1), sesame (C2), and sorghum (C3 and C5). Farms from cluster C4 do not have in general a secondary associated crop apart from pearl millet.

3.3. *Typology of family farms based on local criteria used by farmers to assess the performance of cowpea varieties (Typology P)*

Based on 75 proximal variables used by farmers to evaluate the varieties and linked to the 13 criteria of cowpea performance

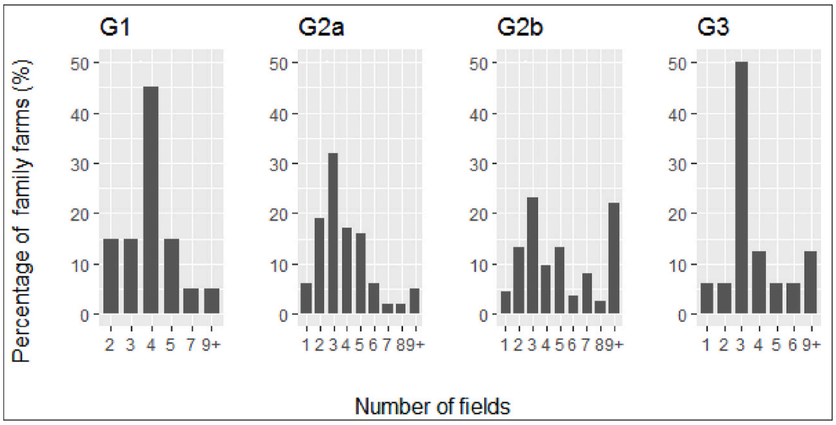

Fig. 5. Number of fields owned by family farms among the four clusters of general typology.

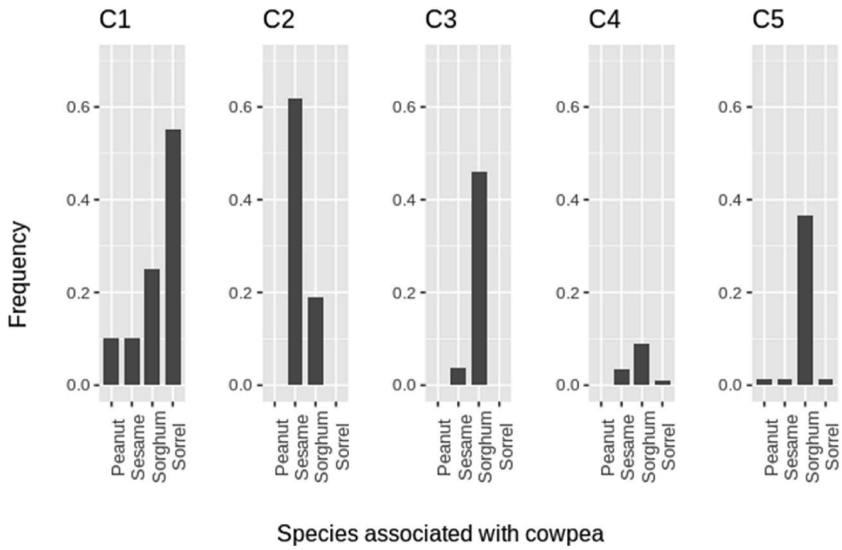

Fig. 6. Secondary intercropped crops with cowpea by cluster.

assessment, the FAMD analysis inferred five clusters of family farms with the following sizes: 12, 43, 73, 78 and 48 farms (Fig. 2C). These clusters differed in terms of the sets of proximal variables used to characterize the performances of cowpea varieties (Table 1; Table S7).

In general, all the considered criteria constitute key characterization criteria for the farms. However, the number of proximal variables used to assess each criterion different among clusters. P1 and P2 cited more proximal variables to assess resistance to *Striga gesneriodes*, resistance to insects, tolerance to drought and tolerance to flood. P3 and P4 cited in general a lower number of proximal variables. Also, the nature of the proximal variables used to assess each criterion differed according to clusters (Table S7).

Resistance to insects is related to the period of the development cycle (81%), leaf width (67%), and leaf density (60%) according to farmers of P2. But 50% of farmers of P5 said that it is also related to the thickness of the hull. This criterion is also characterized by plant hardiness for 58% of farmers in P1.

According to farmers of P2, resistance to *Striga gesnerioides* is determined by leaf density (53% of the farms in the cluster); it is also determined by cycle duration (88%), hardiness (51%) and abundance of striga plants (67%). This resistance is determined by leaves colour (93%) for P5 farmers.

Tolerance to flood is measured by leaf density, leaf colour and pod quantity for respectively 69%, 72% and 69% of the farms in P2.

In the cluster P4, 50% of farmers use the density of the leaves to determines the production of haulm, and 66% determined it by the duration of the cycle. As well as the latest parameters, farmers of P5 evaluated this criterion by leaf persistence (77%). In the cluster P2, 95% and 93% of farmers considered that haulm production is notably determined by leaf width or leaf persistence. For these farmers, the economic value of a variety is determined by the taste, cooking time, and diversity of transformation processes. This economic value is influenced by the conservation time, according to 83% of farmers in cluster P1, and the color of the seed according to 85% of farmers in cluster P5.

Table 1
Farmers agronomic performance characterization criteria.

Criterion of variety evaluation	Total number of proximal variables per criterion (all clusters)	P1	P2	P3	P4	P5
Biofertilizing power	**5**	5	5	3	5	5
Cycle duration	**5**	5	4	3	3	4
Grain production	**3**	3	3	3	3	3
Haulm production	**7**	6	6	6	6	6
Hull production	**5**	3	4	4	4	4
Low amendment requirement	**4**	4	3	4	4	4
Resistance to insects	**8**	7	5	3	3	6
Resistance to striga	**7**	7	6	3	4	5
Seed economic value	**7**	7	7	5	5	7
Seed filling	**4**	2	3	3	3	3
Seed quality	**7**	6	6	5	4	6
Tolerance to drought	**7**	7	7	4	3	7
Tolerance to flood	**6**	6	4	5	5	5
Total number of proximal variables per cluster	**75**	**68**	**63**	**51**	**52**	**65**

The number of proximal variables used by at least 10% of family farms in each cluster we considered and counted.

Drought sensitivity is determined by leaf color (93%), cycle duration (93%) and leaf width (69%) as per P2 farmers (90%).

3.4. Association between the general typology and the typology based on cowpea management diversity

To assess the relationship between the general typology and the typology based on cowpea management diversity, we constructed a contingency table for the various clusters found (Table 2). Farms, where the respondent has livestock as a secondary activity (G1), had a large diversity of cultivated species. They use more than half of the cowpea seeds harvested for trade (C4), and almost all of the haulm and hulls harvested are used for the consumption of the animals grown in the farm.

Farms with many fields (G2b) generally fertilize their plots with compost and mostly use sorghum (C5) in intercropping. In this cluster, harvested cowpea grains are used mainly for self-consumption.

Farms where the respondent has trade as a secondary activity (G3) have the largest crop areas and use crop residues to fertilize their soil. Haulm and hulls, from the harvest, are used for trade (C3).

3.4.1. Association between the general typology and farmers characterization of cowpea performance typology

We crossed the distributions of clusters from the general typology and the typology of the criteria used by farmers to characterize the performance of cowpea varieties (Table 3). For 80% (G1) and 94% (G3) of farmers, the soil of the main field has sandy texture. Their main field is fertile, and their random field is very fertile when it comes to soil fertility level. For fertilizing their fields, they use crop residues and chemical fertilizer. Those farmers were essentially associated to P3 and regarded cycle duration as an insignificant assessment criterion. This cluster is composed of a mixture of clusters G1, G2a, G2b and G3 in almost equal proportions, meaning in each of these clusters there are farms for whom the cycle duration is not a key criterion for cowpea variety characterization. Most of the respondents which are in Cluster P4 are from G2a, while the majority of the farms in Cluster P5 are from G2b. These farmers used all of the characterisation criteria. The P2 cluster is predominantly composed of G2b farms, for which resistance to striga is not generally a key criterion. Of the G2b farms in P2, 42% fertilize their fields with chemical fertilizer and 42% of them use compost. Most of farmers for whom all of the criteria are used for characterizing cowpea varieties (P4) have their main and randomly fields with an average fertility (G2a). They use chemical for fertilizing their fields (73%) and they practice fallow (59%). From our result we can emphasize that farmers use many key characterization criteria in common. Nevertheless, some respondents do not consider certain criteria as important for the characterization of cowpea varieties. It appears from these results that there is a relationship between the criteria for characterizing the varieties of cowpea and the texture and the level of fertility of the soils as well as the method of soil fertilization.

4. Discussion

This study surveyed 254 family farms in 13 rural locations (villages) to infer the structure of family farms based respectively on their general characteristics (Typology G), the local crop management practices (Typology C) and the criteria used by farmers to assess varietal performance (Typology P). The typology G inferred the main types of local agrosystems based on the differences in terms of the social and economic family profiles, the agricultural resources of the farms (land, cattles etc.), the types and characterics of the soils, the set of cultivated crops (crop diversity) and general crop management options (4 clusters G1, G2a, G2b and G3). The typology C identified the main types of family farms according to the specific intercropping systemes and crop management options used for cowpea cultivation (5 clusters, C1 to C5). The typology P inferred the clustering of these farms based on the specific phenotypic criteria the farmers use to assess the performance of cowpea varieties (5 clusters, P1 to P5). Based on the structure (clusters) identified by each typology, we characterized the discriminating variables and calculated the difference in their distribution (frequencies and means) according to the clusters.

These results is a significant insight in the analysis of the diversity of local agrosystems and their specific features. The understanding of this diversity of local agrosystems, its structure and its characterization provides a valuable tool that could reinforce the methodological framework of decentralized breeding. The clusters of family farms are a very good proxy for the setting of target population of environments necessary to orientate and organize the participatory and decentralized breeding design. Considering this structure, the transdisciplinary teams composed of breeders, researchers from support disciplines (soil science, ecophysiology and social science) and farmers could use the typologies to define the set of specific environments for which the breeding programme is working. They could also set the most relevant intercropping systems and crop management options for each the future varieties need

Table 2
Cross-tabulation of the number of family farms in the clusters of general typology (G) *versus* those of cowpea management typology (C).

	General typology (G)					
	Clusters	G1	G2a	G2b	G3	Total
Cowpea managment typology (C)	C1	4	6	8	2	**20**
	C2	0	5	16	0	**21**
	C3	0	8	18	0	**26**
	C4	10	59	32	12	**113**
	C5	6	27	39	2	**74**
	Total	**20**	**105**	**113**	**16**	**254**

The numbers of family farms common to the general typology clusters and the cowpea management typology clusters are shown.

Table 3
Cross-tabulation of numbers of family farms for general typology clusters versus cowpea performance characterization typology clusters.

	General typology					
	Clusters	G1	G2a	G2b	G3	Total
Farmers characterization typology	P1	1	4	6	1	**12**
	P2	0	9	34	0	**43**
	P3	16	16	27	14	**73**
	P4	1	70	7	0	**78**
	P5	2	6	39	1	**48**
	Total	**20**	**105**	**113**	**16**	**254**

The numbers of family farms common to the general typology clusters and the farmers criteria used to characterizations cowpea varieties typology are shown.

to adapt (Typology C). The cropping system is part of the selection environment and could be used explicitly as a selection pressure in the context of decentralized breeding. Intercrops combinations are one of the major components of these cropping systems. In addition, these informative typologies of family farms could be very useful when assessing the level of agroecological transition and or the evaluation of the durability of the production systems and the food system as well [1]. Furthermore, the understanding of typology P provides a knowledge on the most important phenotype based on farmers knowledge be taken into account during varietal selection processes.

In the following, we discuss the implications of the three typologies on the understanding and the characterization of the diversity of local contexts which constitute the target population of environments in the framework of a decentralized participatory breeding.

4.1. How are target local agrosystems diversified and structured?

We proposed to use the inferred typology of family farms based on general characteristics of the farms to understand the structure and the diversity of local agrosystems. The multivariate analysis was based on a large set of variable describing the key components of the agrosystems. The most discriminating criteria of family farms were household size, livestock resources, and the number and area of fields. Several typology studies have previously identified these characteristics as important [11,22]. All respondents have other occupations besides farming. These secondary activities enable farmers to diversify their sources of income to avoid land saturation risks and to valorize the environment better, as reported previously [8,22,23]. The G2a cluster's secondary activity is rural exodus during the dry season, which is a common habit, particularly in the village of Baro Koira, which borders Nigeria. According to famers it is a strategy for diversifying the family income. Importantly, secondary activities like rural exodus allows youth to invest in the family farms capacity building and capital improvement [24].

The texture and fertility of soils contributed also greatly to farms discrimination. In Sub-Saharan Africa, family farms differ in terms of the quality of their lands [7]. Soil characterization across farms is an important element in farm typology studies. Generally, the trends express as farmers perception are in agreement with laboratory-based soil fertility indices [13,25]. To improve the fertility of their fields, farmers used mostly crop residues, followed by the use of compost and the use of organic manure. According to farmers, the fallow is increasingly being abandoned due to land saturation. The farms of G1 were characterized by the texture of their main field, which is largely sandy and has low fertility. These fields are typically located far from the households, making manure delivery problematic. On the other hand, homefields are more fertile since they acquire organic matter from village waste. The family farms were also characterized by their cultivated crops. Farmers from the G1 cluster cultivated a wide range of crops, taking advantage of the possibility of irrigation provided by the water facilities of the valley of Dallol nearby. For farmers of cluster G2a, the diversity of cultivated crops was lower, and tiger nut ("souchet") and groundnut were the most represented. Even though it is not obvious in their main and secondary occupations, these are cash crops because only 25% of farmers have commerce as a secondary activity. Farmers say that crop diversification is the most commonly practised agricultural risk management strategy used by farmers as confirmed the study of [26] in Niger. Mixed cropping minimizes damage from pests and diseases and favours compensatory effects from differences between plants [27]. The cultivation of fonio characterizes the G3 group, a cereal crop whose main production regions in Niger are Dosso and Tillabéry. This crop significantly contributes to fighting hunger in lean seasons [28].

4.2. How are intercropping systems and crop management diversified and structured in the target local agrostems?

All farms practice cowpea association with pearl millet, making this intercropping system not discriminating but the most important. Intercropping is a traditional practice. Some farmers use this practice due to the lack of land and labor, but also for crop diversification, crop complementarity and soil fertilization as reported in Burkina Faso for instance Ref. [29]. Besides, this practice contributes greatly to preserving varietal diversity [30]. Counting seeds before sowing was one of the farms most distinguishing features. Some farmers sow a large quantity of seeds, which is a very common practice to ensure plantule emergence. The farms of cluster C4 are characterized by techniques such as treatment of the seed and counting prior to sowing and thinning. According to these farmers, those are new practices they adopted from research or development projects. Development project intervention promotes the introduction of new varieties and strategies for cowpea production [30].

In the current study, cowpea was associated with several crops in cropping systems, though the dominant intercropping was with pearl millet (95%, 76% and 90% of farms for respectively C1, C2 and C4 clusters), followed by sorghum (46% and 39% for respectively C3 and C5 clusters). These results are consistent with those of [26,31] which found a predominance of associations with these two crops in the crop cultivation areas of Niger. The farmers of the C1 cluster associated cowpea with Guinea sorrel, while the C2 cluster farmers associated cowpea with sesame. Since Guinea sorrel and sesame are commercial crops, their combination allows farmers to meet some cash needs. Furthermore, this cultural practice is also explained by farmers desire to reduce the risk of extremely poor harvests, bearing in mind that if the season in a particular year is not suitable for one of the crops, it may nevertheless be favorable for the others. A recent report in Niger indicated that intercropping is a strategy used by farmers to cope with drought, pests, and diseases [31]. Intercropping occupies nearly 77.3% of the arable lands in Niger [26]. For harvested cowpea seeds, there are no significant differences between farms in clusters C1, C2, C3, and C4. Farmers use nearly half of their seeds for self-consumption and sell the rest since long-term storage conditions are limited. According to them, sale of harvested products enables farmers to purchase cereals like maize, pearl millet, or sorghum as reported by Ref. [32]. For farmers in Niger self-consumption is a precautionary strategy against the risk of rising product price [26].

4.3. Which phenotypic traits are important for farmers and which proximal variables they use to assess these phenotypes ?

Cowpea cycle duration is a key discriminating factor for family farms. It is typically assessed by flowering, branching, and pod production. Therefore, farmers define an early cowpea variety as the one that tillers, blooms, and fructifies first among numerous other varieties. Farmers use early maturing genotypes as an alternate drought-resistance strategy in the northern and southern regions of Burkina Faso [33] and in the main cowpea production areas of Niger [34]. According to these producers, early varieties are less sensitive to insects since they complete their cycle before the insects emerge. However, in other contexts, farmers prefer late maturing varieties, which are thought to be more resistant to insects, striga, and drought since the invasion time does not coincide with the blooming or fructification stages of cowpea [34].

Our results showed that resistance to insects is one of the most important criteria for farmers when evaluating cowpea varieties performances (P2, P3, P5). Similar observations were earlier reported in Benin [35].

The resistance of the crop to *Striga gesneriodes* is the most important criterion for P4 family farms. According to these farmers, early varieties avoid drought as they already have mature pods when striga emerge, allowing them to withstand the attack. On the other hand, some respondents believe that rampant or branchy varieties are more resistant since they suffocate the striga. Since striga is not a threat in some areas, a cowpea variety resistance to striga is not a necessary attribute (P1). Some farmers believe striga thrives on poor and infertile soils; therefore, fields must be fallowed. Fertilizer application is another method for controlling striga infestation, and some farmers still remove striga manually as soon as it appears. In addition to the soil fertility level, the emergence of striga plant depends on the variety, and the environment [36].

Drought resistance is also a significant factor in selecting cowpea varieties (P4 and P5). Drought constitutes a major obstacle to cowpea production in Niger [34]. As per the majority of farmers, crop tolerance to drought is greatly influenced by soil texture. Thus, sandy soils are often more favorable than clay soils. For some farmers, cowpea varieties, erect and rampant are more sensitive to drought at seedling stage. Although rampant varieties are more resistant to drought as they cover the soil and conserve humidity.

Farmers also evaluate cowpea varieties based on haulm yield (P1, P4 and P5). This characteristic is determined by the size and width of the leaves and the number of branches on the plant [20]. found that leaf density, branching and leaf persistence are the most common criteria used by the farmers to evaluate the haulm productivity [37]. revealed that cowpea fodder yield and grain yield in Cameroon were key considerations for farmers. In the current study, seed and hull production were key attributes for nearly all family farms. Nevertheless [33], revealed that haulm production was not regarded as a key selection criterion for farmers in Burkina Faso. Cowpea leaves, despite being utilized as livestock feed, are also used in the human food industry.

The economic value of cowpea varieties is also an important determinant for family farms. It is defined by the seed color, size, and quality [37]. Similar results were observed in Benin, where most farmers preferred red cowpea seeds as special for making porridge, a particular dish well appreciated in the country [38]. In Burkina Faso, white cowpea seeds are preferred by 93.8% of farmers in the north and 70.6% of farmers in the south [33]. However, in our study, according to some farmers the economic value is measured by taste, cooking duration, and processing diversity [35,38]. finded that taste is one of the most important criteria of preference for farmers when choosing cowpea varieties in southern Benin. Farmers also evaluate cowpea varieties based on traits that were not included in our study, like familiarity with the variety, seed eye color, branch size, and port type (rampant or erect). This confirms the need to identify farmers knowledge before intervening in the selection process with farmers. Farmer participation is necessary to improve breeding efficiency. It is very difficult for a breeder to anticipate farmers preferences [27].

5. Conclusion and perspectives

We analysed a model case of multilocal network composed of 254 family farms spanning 13 locations in the western and central-southern Niger to infer farms typologies based on the diversity of local agrosystems, farmers crop management options and farmers criteria of variety evaluation. These farms differ significantly in terms of secondary activity, field and livestock resources, soil fertility management, and crop diversification. Five types of family farms were identified based on cowpea local practices, diversity of crops used in intercropping with cowpea and the final use of cowpea harvested products. Five types of farms were also defined based on key characterization criteria and on the number of proximal variables used to assess each criterion. The general typology and the typologies based on cowpea diversity management indicate that secondary activity and management practices are tightly linked. There is a direct relationship between secondary activity and crop diversification. Field fertility management and agricultural resources are also inextricably linked. There is a relationship between farms key criteria for characterizing the varieties of cowpea and the texture and the level of fertility of the soils and the method of soil fertilization.

These inferred typologies provided significant insights in the understanding and the methodological characterization of the local agrosystems based on cowpea (in intercropping with a diversity of cereal and non-cereal crops). Such results constitute key bases for a methodologically robust setting of target population of environments in the context of decentralized breeding.

We propose, as a perspective to the current study, to associate the general typology, the crop management practices typology and the local evaluation criteria typology to set a reasonable number of the key types of targets environments. This association could be done by alternative methods: i) the direct crossing of the obtained clusters (but this has the inconvenient of providing numerous small target population of environments, including environments with non significant sample size); ii) the inclusion of the three datasets into the same multivariate analysis to infer an integrative clustering; and/or iii) an expert method of synthesis, which will use the raw combination of independent typologies or the integrative clusters as an elementary data which will be used as a material by the transdisciplinary teams involved in breeding programme to discuss and set the final target environments. The integration of local data of soil and climate variability (partially and indirectly captured by the geographical location in this study) could also be considered for further studies.

Author contribution statement

Abdoul-Aziz SAIDOU, Hélène I. JOLY, Yacoubou Bakasso and Hadiara HAMADOU HAMIDOU: Conceived and designed the experiments.

Hadiara HAMADOU HAMIDOU, Rahilatou MOUSSA TCHOFFO, Mahaman Sanoussi SANI ISSA and Mahamadou Nourou SAADOU SOULEY: Performed the experiments.

Hadiara HAMADOU HAMIDOU and Abdoul-Aziz SAIDOU: Analyzed and interpreted the data.

Abdoul-Aziz SAIDOU: Contributed reagents, materials, analysis tools or data.

Hadiara HAMADOU HAMIDOU, Abdoul-Aziz SAIDOU, Hélène I. JOLY and Yacoubou Bakasso: Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interest's statement

The authors declare no competing interests.

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Appendix A. Supplementary data

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