DEVELOPING MULTILINE COWPEA VARIETIES ADAPTED TO LOCAL CROPPING SYSTEMS AND SPECIFIC FARMERS' PRODUCTION GOALS THROUGH PARTICIPATORY BREEDING

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[DESARROLLO DE VARIEDADES MULTILÍNEA DE CAUPÍ ADAPTADAS A SISTEMAS DE CULTIVO LOCALES Y OBJETIVOS DE PRODUCCIÓN ESPECÍFICOS DE AGRICULTORES MEDIANTE MEJORAMIENTO PARTICIPATIVO]

Rahilatou Moussa Tchoffo[1,2,3,4], Abdoul-Aziz Saïdou[2,3,4,*], Souleymane Abdou[5], Mahamadou Nourou Saadou Souley[2,6], Hadiara Hamadou Hamidou[1,2,3,4], Boureima Seyni[2,7], Yacouba Tanda[7], Mamane Aminou Ali[6], Mahamadou Sanoussi Hassane[7], Nouhou Salifou Jangorzo[2], Hassane Bil-Assanou Issoufou[2], Helene I. Joly[4] and Yacoubou Bakasso[1]

[1] Faculté des Sciences et Techniques, Université Abdou Moumouni, BP 10662, Niamey, Niger.
[2] UMR DAP, Université Dan Dicko Dankoulodo de Maradi (UDDM), BP 465 Maradi, Niger.
[3] Centre Imaan of support in transdisciplinary research (Imaan Research), Koira Kano Nord, Niamey, Niger. Email: abdoul-aziz.saidou@imaan-group.com
[4] AGAP Institut, Univ Montpellier, CIRAD, INRAE, L'Institut Agro, F-34398 Montpellier, France.
[5] Institut National de la Recherche Agronomique du Niger (INRAN), BP 429 Niamey, Niger.
[6] Fédération des unions de producteurs de Maradi (FUMA Gaskiya), Ali Dan Sofo, Maradi, Niger.
[7] Fédération des unions de groupements paysans du Niger (FUGPN Mooriben), Plateau, Niamey, Niger.
**Corresponding author*

SUMMARY

Background. Decentralized participatory breeding approach facilitate the development of varieties better suited for a diversity of farmers' contexts. To enhance breeding efficiency, formal methodological settings are needed to include, at early stage of selection, particular local practices and farmers' preferences. **Objective.** Evaluate how location, farmers' profile and local cropping system could be taken into account to optimize selection of cowpea varieties in a decentralized context. **Methodology:** Twenty-two candidate multiline varieties of cowpea (*Vigna unguiculata L.* Walp) were developed from a biparental family of recombinant inbred lines. These varieties were subjected to selection under edaphic and climatic conditions of three locations and two cropping systems (intercropping *versus* sole cropping). Trials were carried out in collaboration with farmers' federations. Participatory evaluations were conducted over two years by the three groups of farmers defined by the following production goals: grains production as priority ("Grain priority profile"), fodder as priority ("Fodder priority profile") and grain quality as priority ("Food processing priority profile"). **Results.** The statistical analysis supported significant effects of location and cropping system on the agronomic traits, with interactions effects involving the variety. A strong correlation was observed between the varietal choices of the two farmers' profiles which prioritized respectively grain and food processing. These farmers preferred varieties with higher grain yield and best grain quality. Farmers who prioritized fodder preferred more specific varieties, characterized by highest haulm yield. **Implications.** The clustering of farmers into specific profiles is an efficient method which allow expressing their diversified production goals through participatory evaluation. This led to more specific varietal choices for each of the profiles. **Conclusion.** This study set cropping systems and farmer profiles as formal design factors at early breeding stage. These factors acted efficiently to support the process of varietal choice. The

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ORCID = Rahilatou Moussa Tchoffo: http://orcid.org/0009-0008-7139-3012, **Abdoul-Aziz Saïdou** : http://orcid.org/0000-0002-1215-6075, **Souleymane Abdou**: http://orcid.org/0000-0002-2105-4564, **Mahamadou Nourou Saadou Souley**: http://orcid.org/0009-0000-7743-9757, **Hadiara Hamadou Hamidou**: http://orcid.org/0000-0001-5292-6823, **Boureima Seyni**: http://orcid.org/0009-0001-8609-3951, **Mamane Aminou Ali**: http://orcid.org/0009-0003-2735-1038, **Mahamadou Sanoussi Hassane**: http://orcid.org/0009-0009-7992-4882, **Nouhou Salifou Jangorzo**: http://orcid.org/0000-0002-8349-0847, **Hassane Bil-Assanou Issoufou**: http://orcid.org/0000-0002-0506-2724, **Helene I. Joly**: http://orcid.org/0000-0003-0453-2728, **Yacoubou Bakasso**: http://orcid.org/0000-0001-8116-1532

participatory approach highlighted the congruence and complementary between farmers' and researchers' knowledges. It helped identifying, for intercropping and sole cropping systems respectively, the most suitable varieties preferred by each of three respective farmers' group.
Key words: *Vigna unguiculata L.* Walp; cropping system; decentralized selection; participatory breeding; farmer profiles.

RESUMEN

Antecedentes. El enfoque participativo y descentralizado del fitomejoramiento facilita el desarrollo de variedades mejor adaptadas a diversos contextos de los agricultores. Para mejorar la eficacia del fitomejoramiento es necesario establecer marcos metodológicos formales que incluyan, en las primeras fases de la selección, prácticas locales específicas y preferencias de los agricultores. **Objetivo**. Evaluar la ubicación, perfil de agricultores y sistema de cultivo local podrían tenerse en cuenta para optimizar la selección de variedades de caupí en un contexto descentralizado. **Metodología.** Se desarrollaron 22 variedades candidatas multilínea de caupí (*Vigna unguiculata* L. Walp) a partir de una familia biparental de líneas endógamas recombinantes. Estas variedades se sometieron a selección en condiciones edáficas y climáticas de tres localidades y dos sistemas de cultivo (cultivo intercalado frente a monocultivo). Los ensayos se llevaron a cabo en colaboración con federaciones de agricultores. Durante dos años se realizaron evaluaciones participativas de tres grupos de agricultores definidos por los siguientes objetivos de producción: producción prioritaria de cereales, producción prioritaria de forraje y calidad prioritaria del grano. **Resultados.** El análisis estadístico mostró efectos significativos en la localización y el sistema de cultivo en caracteres agronómicos, y con efectos de interacción con la variedad. Se observó una fuerte correlación entre las elecciones varietales de los dos perfiles de agricultores que priorizaban el grano y la transformación alimentaria. Estos agricultores prefirieron variedades con mayor rendimiento de grano y mejor calidad de grano. Los agricultores que priorizaron el forraje prefirieron variedades más específicas, caracterizadas por un mayor rendimiento. **Implicaciones.** La agrupación de los agricultores en perfiles específicos es un método eficaz que permite expresar sus objetivos de producción diversificados a través de la evaluación participativa. Esto permitirá realizar elecciones variedades más específicas para cada uno de los perfiles. **Conclusiones.** Se establecieron los sistemas de cultivo y los perfiles de los agricultores como factores formales de diseño en la fase inicial de selección. Estos factores actuaron eficazmente para apoyar el proceso de elección varietal. El enfoque participativo resalta la congruencia y complementariedad entre los conocimientos de los agricultores es investigadores. Lo que permitió identificar, para los sistemas de cultivo intercalado y monocultivo, las variedades más adecuadas preferidas por cada uno de los tres grupos de agricultores.
Palabras clave : *Vigna unguiculata L.* Walp; sistema de cultivo; selección descentralizada; fitomejoramiento participativo; perfiles de agricultores.

INTRODUCTION

Participatory and decentralized breeding programs with farmer's involvement in selection process are now widely considered essential. These programs develop varieties adapted to local conditions and corresponding to farmers' needs (Morris and Bellon, 2004; Witcombe *et al.*, 2005; Ceccarelli and Grando, 2007). They rely on the complementary skills and knowledge of professional breeders, farmers and other possible stakeholders (Wolfe *et al.*, 2008; Ceccarelli and Grando, 2009).

Farmers' preferences for varietal traits are diverse depending on production systems, agroecological and socioeconomic conditions and farmers' production goals (Fufa *et al.*, 2010; Slagboom *et al.*, 2016; Christinck *et al.*, 2017; Krishna and Veettil, 2022). The criteria can include adaptability, use and processing ease, quality and market demand (Fufa *et al.*, 2010). A successful participatory breeding tries to meet specific needs of each farmers' group and facilitate the adoption of new varieties or technologies (Kammoun, 2014; Christinck *et al.*, 2017; Tegbaru *et al.*, 2020).

Farmers use a large diversity of local practices for crop management. While noticeable efforts have been made in the development of participatory evaluation methods (Ceccarelli and Grando, 2007; Trouche *et al.*, 2008), few breeding programs include these local practices in selection (Wolfe *et al.*, 2008; Omoigui *et al.*, 2023; Ongom *et al.*, 2023).

The limited success of varieties selected according to their performance under crop management practices different from those applied by farmers is one of the factors explaining low adoption rate of improved varieties (Baoua *et al.*, 2021). For instance, in cowpea crop, most of these varieties developed under sole cropping are not necessarily suited for intercropping (Ntare, 1989; Goshime, Solomon and Alemayehu, 2020; Kammoun *et al.*, 2021; Kiær *et al.*, 2022). Therefore, selection of genotypes both under sole and intercropping is of paramount importance to enhance yield and varietal adoption (Goshime, Solomon and Alemayehu, 2020; Haug *et al.*, 2021). Considering local cropping systems in the process of participatory and decentralized selection could increase its effectiveness (Wolfe *et al.*, 2008). A methodology has been recently proposed to cope with this challenge, by including cropping systems and farmers' profile as formal selective pressures in decentralized breeding designs (Hamidou *et al.*, 2023).

In addition to the above, in Niger, cowpea is the most important legume crop and the second crop in terms of cultivated area after pearl millet. It is grown mostly in association with other crops, including pearl millet and sorghum, in about on 84 % to 96.6 % of farms according to the regions (Baoua *et al*., 2021; Hamidou *et al*., 2023).

In the present study, a decentralized breeding was designed to develop cowpea varieties in three locations of Niger, respectively under sole and intercropping, considering three farmer profiles in each location. The F5 progeny of the cowpea landrace *Lakkade* crossed with an improved donor parent (IT07K-292-10) was used to develop, for these specific contexts, twenty-two candidate multiline varieties with the mixture of morphologically homogeneous recombinant inbred lines. The objectives were: i) to assess the performance of candidate cowpea varieties under selective pressure of two local cropping systems; ii) compare the varietal choices made by farmer profiles to fit their respective ideotypes; iii) analyze the relation between farmers scoring and agronomic measurements. These two assumptions were formulated: i) submitting candidate varieties to diverse cropping systems at an early stage in the variety development is an efficient selection pressure leading to varieties with specific cropping system adaptation; ii) performing participatory evaluation with separate farmer profiles allows the setting of specific ideotypes corresponding to their respective production goals.

MATERIAL AND METHODS

Process of developing candidate varieties for participatory breeding

Biparental crosses between CS133 (*Lakkade*) and CS098 (IT07K-292-10) were carried out. CS133 is a landrace widely used in Maradi region, identified during a participatory diagnosis. This landrace is well adapted to local conditions, tolerant to *Striga gesnerioïdes* (Willd.) Vatke, with good grain and fodder yields, but its grains are of medium size. However, it is very late maturing, causing conflicts with transhumant livestock farmers. The donor parent (CS098) is an improved variety from International Institute of Tropical Agriculture (IITA) with reduced cycle and improved grain quality.

The crosses were carried out at Maradi station, during 2016 rainy season to obtain the F1 generations (Tchoffo, Abdou and Saidou, 2018). Single seed descent method with open self-pollination was used to advance the population from F1 to F4 generation, using two cycles per year (rainfed and dry season). No intentional selection for a given character was carried out at these stages in order to conserve more diversity for decentralized trials. So, in F2, all harvested grains were included to obtain the F3. The same number of grains from each F3 (and respectively F4) plant were mixed to constitute the seed stock sown to obtain the next generation.

Twenty-two candidate multiline varieties were constituted based on similarity for six agro-morphological traits noted in 303 F4 individual progenies obtained during 2018 rainy season trial (Table 1). The traits considered were cycle duration, grain yield, seed color, eye color, eye diameter and seed coat texture.

Participatory and decentralized experimental design

To submit the multiline varieties to local environmental selection pressures, a decentralized participatory trial was carried out in three locations during 2019 and 2020 rainfed seasons. The chosen sites were Arawraye, Tchake and Sarkin Bindiga located in the south central of Niger (Maradi region). Farmers of these locations are members of Fuma Gaskiya, a farmers' organization; they were involved in CowpeaSquare breeding program during participatory diagnosis, germplasm collection, setting of selection criteria, trial designing and installation, trial evaluation and varietal selection. The three locations cover a North-South rainfall gradient (Figure *S1*), with sandy soils (Table S1, Sadda *et al.*, 2021).

The experimental design was a split plot. The main plots corresponded to the cropping systems (sole cowpea cropping and cowpea-pearl millet intercropping). The distance between plots was 4 m. The modality of intercropping, one row of pearl millet interposed with one row of cowpea, was defined in collaboration with farmers during a participatory workshop. The subplots corresponded to candidate multiline cowpea varieties. The two parents were included as checks and randomized with the progenies. Each variety was sown in an experimental plot of 36 m². In sole cowpea cropping, seven rows of seven hills of cowpea were sown per plot, corresponding to a low density of about 13,611 hills per hectare. In intercropping, seven rows x seven hills, and six rows x six hills were sown respectively, for pearl millet (~13,611 hills per hectare) and cowpea (10,000 hills per hectare). The plots were separated by a distance of 2 m. The most adopted improved variety of pearl millet (HKP) was used in all trials. This split plot was replicated in three locations, with no repetition per location. No fertilizer and no pesticide were used.

Table 1. Agromorphological traits in twenty-two candidate multiline cowpea varieties.

Candidate variety code	Candidate variety short code	Number of lines bulked	Flowering cycle duration*	Grain yield class**	Seed color	Eye color	Eye diameter	Aspect of seed coat
CWS-RIL-31-38_17	17	5	Intermediate	Common yield	Light red	Marron	Thick	Smooth
CWS-RIL-31-38_2	2	70	Intermediate	Common yield	White	Marron	Thick	Rough
CWS-RIL-31-38_20	20	2	Intermediate	Very high yield	Light red	Marron	Thick	Smooth
CWS-RIL-31-38_3	3	38	Early	Common yield	White	Marron	Thick	Rough
CWS-RIL-31-38_34	34	30	Intermediate	Common yield	White	Marron	Thin	Rough
CWS-RIL-31-38_35	35	15	Early	Common yield	White	Marron	Thin	Rough
CWS-RIL-31-38_36	36	24	Late	Common yield	White	Marron	Thin	Rough
CWS-RIL-31-38_37	37	2	Intermediate	Very high yield	White	Marron	Thin	Rough
CWS-RIL-31-38_38	38	3	Early	Very high yield	White	Marron	Thin	Rough
CWS-RIL-31-38_4	4	38	Late	Common yield	White	Marron	Thick	Rough
CWS-RIL-31-38_43	43	7	Intermediate	Common yield	White black spotted	Marron	Thin	Rough
CWS-RIL-31-38_44	44	7	Early	Common yield	White black spotted	Marron	Thin	Rough
CWS-RIL-31-38_45	45	12	Late	Common yield	White black spotted	Marron	Thin	Rough
CWS-RIL-31-38_46	46	1	Intermediate	Very high yield	White black spotted	Marron	Thin	Rough

Candidate variety code	Candidate variety short code	Number of lines bulked	Flowering cycle duration*	Grain yield class**	Seed color	Eye color	Eye diameter	Aspect of seed coat
CWS-RIL-31-38_48	48	15	Intermediate	Common yield	White marron spotted	Marron	Thin	Rough
CWS-RIL-31-38_49	49	10	Early	Common yield	White marron spotted	Marron	Thin	Rough
CWS-RIL-31-38_5	5	2	Intermediate	Very high yield	White	Marron	Thick	Rough
CWS-RIL-31-38_50	50	13	Late	Common yield	White marron spotted	Marron	Thin	Rough
CWS-RIL-31-38_52	52	1	Early	Very high yield	White marron spotted	Marron	Thin	Rough
CWS-RIL-31-38_56	56	3	Early	Common yield	White	Black	Thin	Rough
CWS-RIL-31-38_6	6	4	Early	Very high yield	White	Marron	Thick	Rough
CWS-RIL-31-38_7	7	1	Late	Very high yield	White	Marron	Thick	Rough

*For cycle duration: Early corresponds to duration of 46-55 days between sowing and flowering; Intermediate duration was between 56-65 days; Late duration was superior to 65 days.
**For grain yield class: Common yield corresponded to production value between quantile 5 % and quantile 95 %; Very high yield corresponded to production value superior or equal to quantile 95 %.

Agronomic data collection

The data collected are: number of alive plants per plot, number of plants infested by *S. gesnerioïdes*, grain production per plot, fodder production per plot (haulm), hundred-seeds weight. All the variables were measured by plot (n=24), cropping system (2), location (3) and year (2).

Participatory evaluation method

In order to take into account, the specific needs of the farmers in the development of varietal ideotypes, farmers were categorized according to their production goals. Even though all farmers were interested by both grains and fodder, they differed in the use and the relative importance given to each product. Three profiles were then defined: i) "Grain priority profile", farmers group who grow cowpea mainly for its grains that can be used for family consumption and/or for sell; ii) "Fodder priority profile", farmers who grow cowpea mainly for its fodder also to sell and/or to feed animals; iii) "Food processing priority profile", farmers who grow cowpea especially for processing; women predominate in this group.

For participatory evaluation, five to ten farmers from each profile were asked about their intention to adopt the candidate variety after plot visit followed by collective discussion and individual notation of the performance of cowpea varieties. This variable was named *adoption interest*. At this level, the number of farmers with an intention to adopt the variety was registered, while also specifying the total number of voters. At the end of evaluation for each cropping system, farmers from each profile were through all the plots and chose by consensus the three best varieties, variable named like "Top3" hereafter.

Statistical analysis

The analysis of each agronomic trait (grain yield, haulm yield and hundred-seeds weight) was carried out using a mixed model fitted with lme4 package (Bates *et al.*, 2015). The package lmerTest (Kuznetsova, Brockhoff and Christensen, 2017) was used to test the significance of the factors. The model was set as follows:

$$Y_{ijkr} = \mu + L_i + A_j + S_k + L_i \times A_j + L_i \times S_k + A_j \times S_k + L_i \times A_j \times S_k + (1|G_r) + (L_i|S_k \times G_r) + (A_j|L_i \times G_r) + e_{ijkr}$$
;

where Y is the trait of interest; μ is the intercept; L_i is the effect of i^{th} location; A_j is the effect of j^{th} year; S_k is the effect of k^{th} cropping system; G_r is the effect of r^{th} genotype; and e is the residual error.

The best linear unbiased predictors (BLUPs) were then computed and plotted. The number of voters has been rescaled to an equivalent basis of 100 voters to make all evaluations comparable despite sample size differences. A correlation matrix comparing scores between farmer profiles was constructed and visualized (correlograms, *corrplot* R function).

The Top3 varieties choices were analyzed to identify same *versus* specific choices among the three farmer profiles. Specific choices are defined as choices made by only one profile. These corresponded to choices made by only one profile. Then, for each of these profiles, the distribution of the agronomic traits was compared between Top3 varieties and the others. A Factorial Analysis of Mixed Data (FAMD) was performed on the data from the Top3 varieties to explore the association between agronomical traits and to analyze the similarities of the choices of the three farmer profiles. This helped describing *a posteriori* the ideotypes for each farmer profile. All analyses were carried out with R software (R Core Team, 2022).

RESULTS

An original decentralized breeding approach is presented. This participatory approach developed innovative varietal model for cowpea consisting in multiline varieties, selected for specific local environments, local cropping systems and farmer profiles. Both agronomic and farmer evaluation data were used to assess the twenty-two candidate multiline cowpea varieties into three locations.

Phenotypic variability of candidate multiline cowpea varieties

The analysis of variance showed significant effect of location, year, cropping system and some of their interactions on grain yield, haulm yield and hundred seed weight (Table S2). Notably, significant effect of genotype x cropping system interaction was observed for grain yield. The donor parent variety IT07K-292-10 (CS098) had lower haulm yield than local parent *Lakkade* (CS133), in all cropping systems and locations (Figure 1). The observed hundred-seeds weight of donor parent variety IT07K-292-10 decreased from 16.17±1.36 g in sole cropping to 14.15±2.37 g in intercropping; while that of the local variety *Lakkade* was approximately the same between the two cropping systems, 15.39±1.19 g in sole cropping versus 14.41±1.96 g in intercropping.

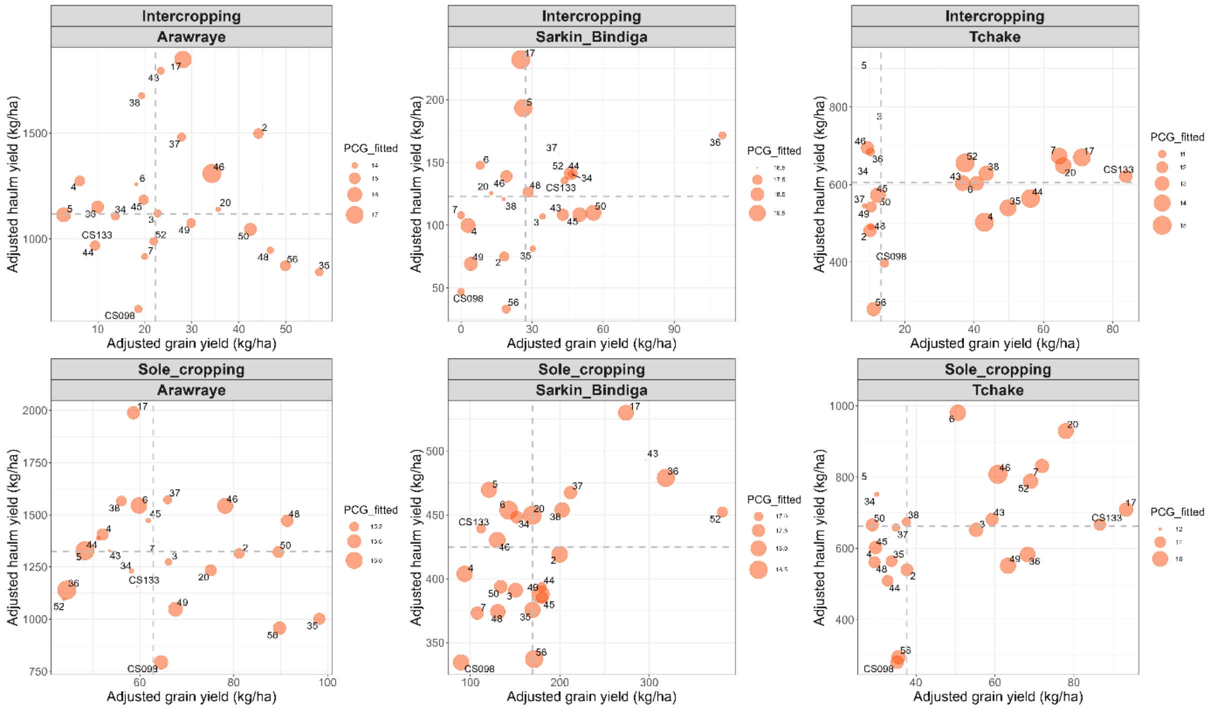

Figure 1. Agronomic characteristics of candidate multiline cowpea varieties by cropping system, during two years and three locations. Fitted values adjusted by mixed linear model are shown. *The size of the circle is proportional to 100 seeds weight (PCG).

Correlation matrix between the three farmer profiles

The analysis of farmer evaluation data was performed on Arawraye and Tchake locations. In each location, five to ten farmers per profile had participated each year to fields evaluation.

The food processing and grain priority profiles expressed similar adoption interest, as shown by significant correlation between their choices (Figure 2). The correlation coefficient between these two profiles varied from 0.40 to 0.71 according to location and cropping system. The correlation between the fodder priority profile and these two profiles was low, with a correlation coefficient varying from 0.15 to 0.38. Over locations, the average correlation coefficient between three farmer profiles was higher in sole cropping (r=0.4) than in intercropping (r=0.3).

Varietal choices of three farmer profiles

The analysis of Top3 data revealed that the farmer profiles could have the same choices and specific choices for each of them (Figure 3). The grain and the food processing priority profiles had a high number of same choices; however, for a given variety selected by two or three farmer profiles, the rank differed by farmer profiles. It is the case for the candidate variety CWS_RIL-31-38_2, in Arawraye, ranked as first variety by food processing priority profile, but ranked in second and third position by grain and fodder priority profile, respectively. At Tchake, the candidate variety CWS_RIL-31-38_56 was chosen in Top3 by all the three farmer profiles, but was ranked first, second and third respectively by grain, fodder and food processing priority profiles.

Specific choices of Top3 were also noted for each of the farmer profiles, particularly for fodder priority profile. For instance, the three varieties selected as Top3 in sole cropping at Arawraye in 2019, they were not included in Top3 by the two other profiles. For grain and food processing profiles, in the two locations, five varieties were chosen within the twelve choices and were specific for each farmer profiles (Figure 3).

The multivariate analysis (FAMD) revealed that the structure of agronomic traits of the Top3 varieties varied among the farmer profiles (Figure 4). Varieties chosen by fodder priority profile were clearly distinguished. These varieties were characterized by low grain yield; but with high haulm yield in contrast to the choices of grain and food processing priority profiles. The agronomic characteristics of the Top3 selected by these two last farmer profiles were almost similar. The food processing priority profile tended to select more varieties with medium grain and haulm yields, whereas farmers of grain priority profile selected mostly varieties with higher grain yield and lower haulm yield.

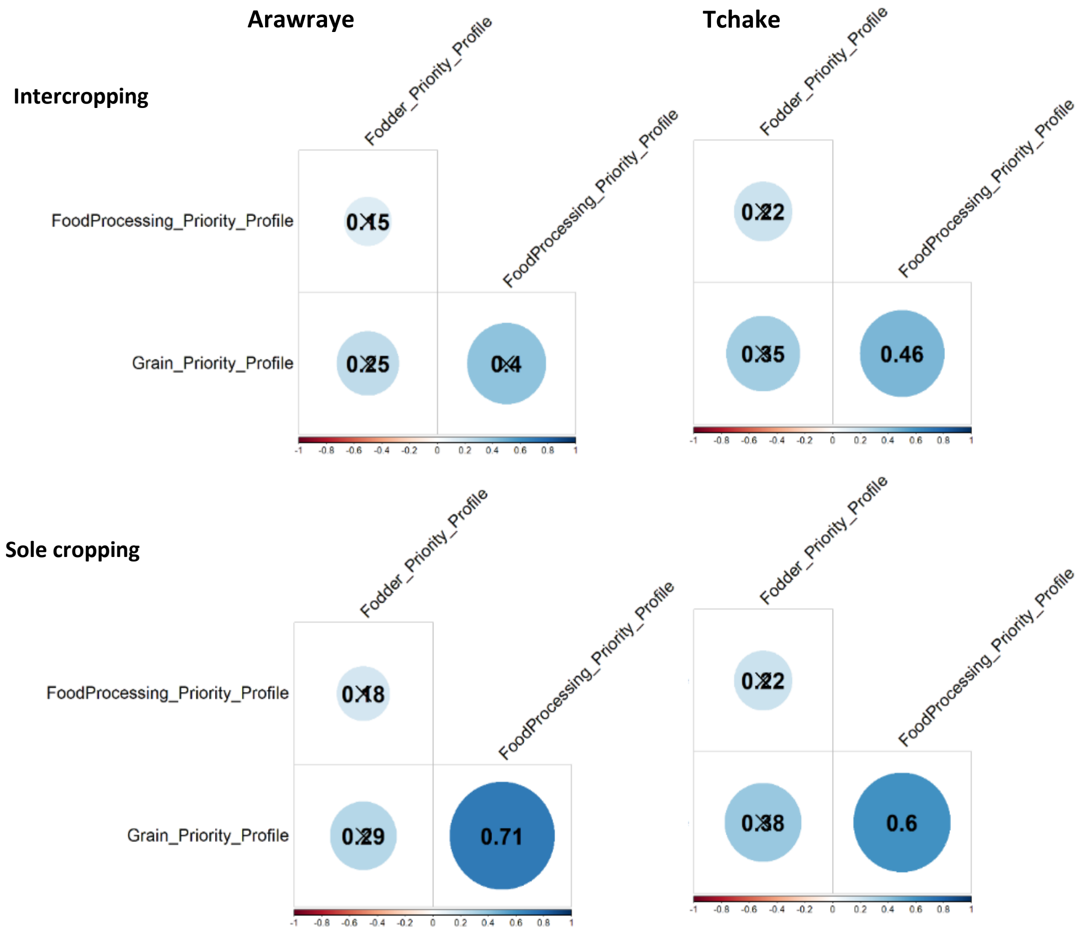

Figure 2. Correlations of plot evaluation scores between three farmer profiles into both cropping systems for two years at Arawraye and Tchake locations. Positive correlations are displayed in blue and negative correlations in red as indicated by the color legend at the bottom of the correlogram. The color intensity and circle size are proportional to the correlation coefficients. Correlation coefficients marked with a cross have a non-significant p-value.

Relationship between farmers' evaluation and agronomic evaluation

In both cropping system, the Top3 varieties selected by farmers had an average grain yield higher than that of the non-selected varieties (Figure S2), particularly for grain and food processing priority profiles. In intercropping, four out the six varieties selected by grain priority profile were among the best grain yielding varieties (Figure 5A). The same trend was true for three varieties within the selected ones in sole cropping. But these selected varieties had a very low haulm yield, except the candidates' varieties CWS_RIL-31-38_2 and CWS_RIL-31-38_48, which appeared to be dual-purpose varieties with good characteristics in grain and haulm yields, respectively in intercropping and sole cropping (Figure 5A). In contrast, at Tchake, in intercropping, the majority of Top3 varieties (four out six) of this grain priority profile had a medium grain yield (Figure 5B). In sole cropping, the two selected varieties were the best in grain yield, and the two others had characteristics of dual-purpose varieties. For food processing priority profile, the same trends were observed with grain priority profile at both locations.

For the farmers that have fodder as priority, the haulm yield of their Top3 varieties was slightly higher than that of the non-selected varieties (Figure S3). These Top3 varieties selected by fodder priority profile were not exclusively the best in haulm yield at Arawraye. All yield classes have been identified (Figure 4A). In both cropping systems, the four selected varieties (two in intercropping and two in sole cropping) had the best haulm yields with very low grain yields. In each cropping system, a dual-purpose variety was identified. Some varieties selected had a haulm yield below the median, but with a high grain yield. At Tchake, the farmers tend to choose varieties that have good grain and haulm yields (Figure 5B).

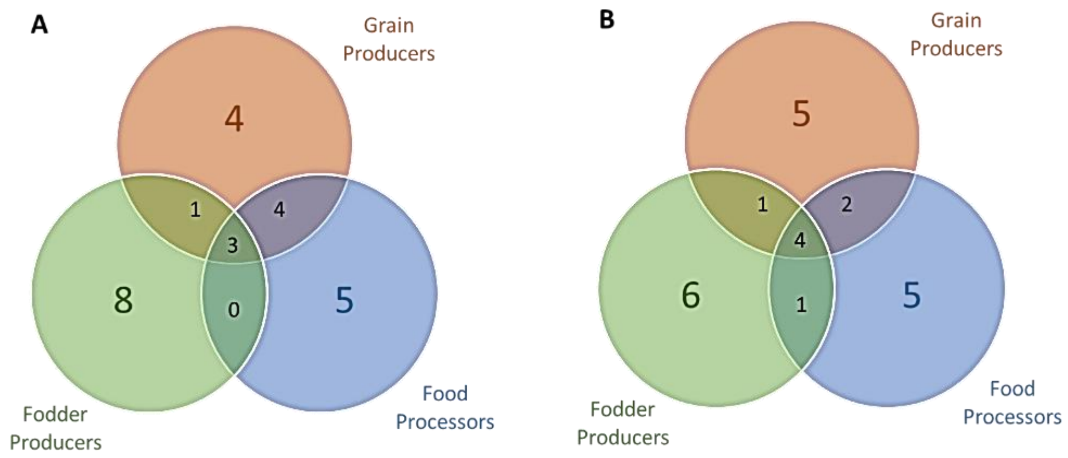

Figure 3. Same and specific choices of Top3 varieties for three farmer profiles, across the two years and two cropping systems for Arawraye (A) and Tchake (B) locations.

Figure 4. Principal component analysis of agronomic traits for Top3 selected by each farmer profiles, during two years and two cropping systems for Arawraye and Tchake locations. *Low yield: production value is inferior or equal to quantile 1/3 of the observed distribution (all data). Common yield: production value is between quantile 1/3 and quantile 2/3. Hight yield: production value is superior or equal to quantile 2/3.

A trend of higher median seed weight in Top3 varieties was observed for all the farmer profiles in both cropping systems, compared to the not selected varieties (Figure S4). However, the Wilcoxon test detected these differences as no significant (Figure S4).

DISCUSSION

The diversity of farmer practices, including cropping systems, constitutes an important part of the target environment to be taken into account in decentralized breeding context (Hamidou *et al.*, 2023). Several studies components between sole cropping and intercropping of cowpea with cereals may be due to competition between the two associated species (Legwaila, Marokane and Mojeremane, 2012;

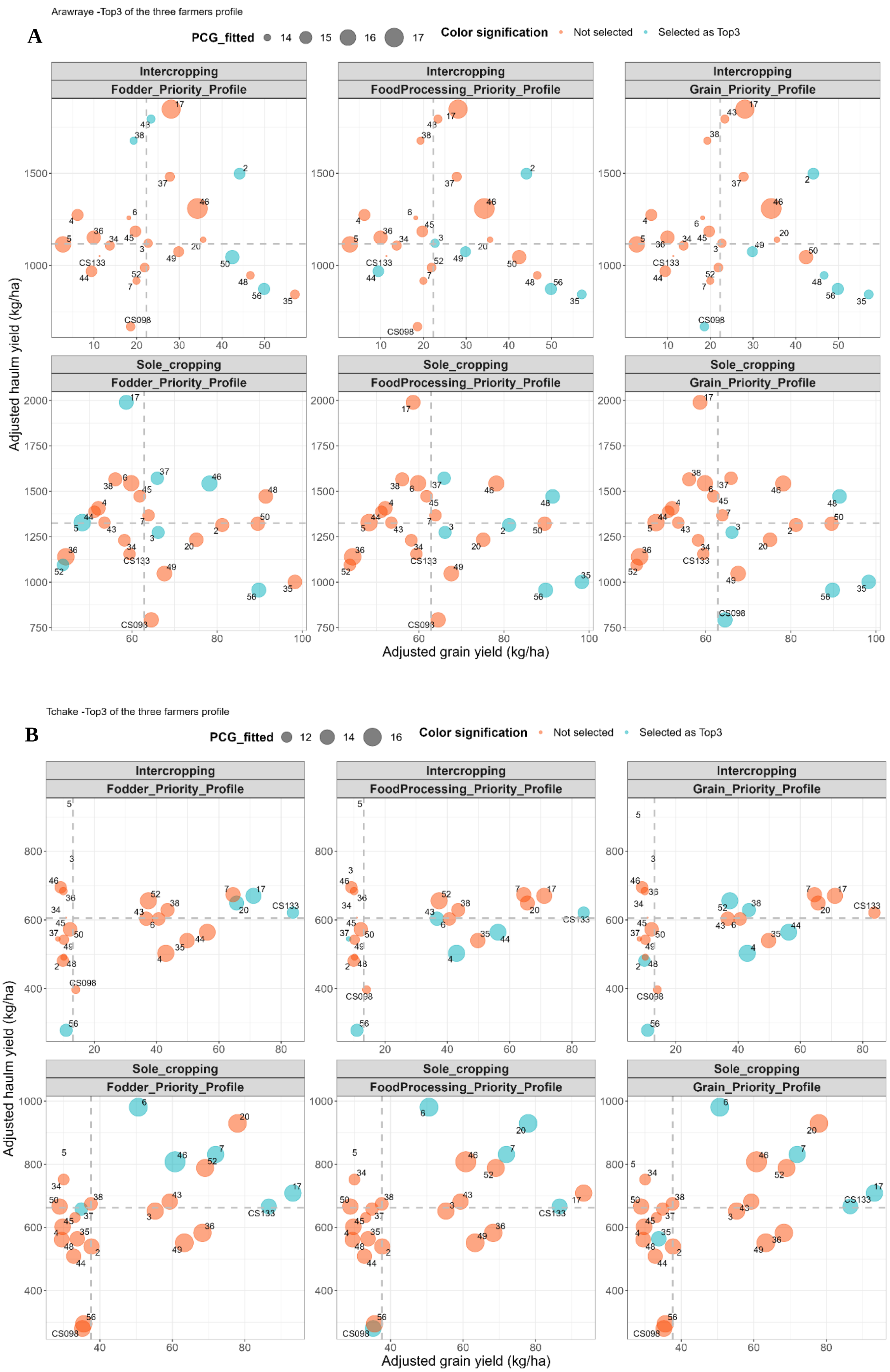

Figure 5. Agronomic characteristics of candidate multiline cowpea varieties by cropping system at Arawraye (A) and Tchake (B) locations. *The size of the circle is proportional to 100 seeds weight (PCG). Fitted values (from the mixed model) are plotted. In orange: varieties not selected by each of the three farmer profiles. In blue: varieties selected as Top3 by each of the three farmer profiles.

Takim, 2012), to shading effect (Undie, Uwah and Attoe, 2012), or to radiation interception (Degri, Sharah and Dauda, 2012; Ewansiha, Kamara and Onyibe, 2014).

Recent experimental studies emphasized the importance of setting cropping system as options during cowpea selection (Omoigui *et al.*, 2023; Ongom *et al.*, 2023). These studies showed that taking into account the cropping system during trials help identifying the best specific varieties for intercropping and sole cropping. The current paper introduced three original points to further advance the state-of-art in this problem. First, cropping system and decentralized multilocation testing are introduced earlier in this design, before complete genetic fixation of the recombinant inbred lines (F5 generation). This early introduction ensures that cropping system and location act as effective selection pressures contributing to candidate variety adaptation during its development, and better supporting breeder decision. Second, participatory evaluation based on farmer notation is included in the current study, supporting the decision based on classical agronomic measurements. Third, the multiline varietal model has the advantage of presenting several inbred lines (so several genotypes) inside each variety, even if the bulked inbred lines are respectively fixed. This original varietal model is thus expected to allow adaptive evolution even after variety release, based on the possibility of genotype frequency variation in each variety in response to farmer and/or environment selection.

In the current study, the significant interaction of variety and cropping system found for grain yield indicate that a variety can be good in grain yield in sole cropping and bad in intercropping or the opposite. This also implies that among the greatest grain yields in intercropping, only a proportion would have been selected and other rejected on the basis of their grain yields in sole cropping. Previous studies also reported a significative genotype x cropping system interaction, and indicated that the best varieties for sole cropping are not necessarily the best ones for intercropping (Kammoun, 2014; Goshime, Solomon and Alemayehu, 2020).

The hundred-seeds weight of the variety IT07K-292-10 (CS098, donor parent) was higher compared to that of the local parent *Lakkade* (CS133), which allowed the introgression of higher grain weight in the progenies. However, the hundred-seeds weight of CS098 was considerably reduced in intercropping system, compared to CS133 indicating that the local parent is better adapted to intercropping. *Lakkade is a landrace* consisting to a population variety. This finding was actually expected; due to the predominance of intercropping in Niger. The landraces evolve generally under this system, which lead to best genetic adaptation to intercropping. The cropping system in which the variety is grown has an effect on the expression of its agronomic traits (Demie *et al.*, 2022).

Farmers are not a homogeneous group. Based on their production goals, they may belong to different "market segments" or subgroups of producers with similar preferences (Orr *et al.*, 2018). In this study, all farmers are interested by both grain and fodder, but with different relative importance. Famers select their preferred varieties through the combination of various traits (Ishikawa *et al.*, 2019). The results indicated that each of the three farmer profiles had specific choices, however the choices of fodder priority profile were more discriminant. Indeed, the agronomic characterization of the Top3 of three farmer profiles confirmed that fodder priority profile choices were distinguished from the two others' profiles. Farmers from this group are specialized in fodder production for livestock feeding. They need varieties with large and high number of leaves (producing haulm after drying), a lot of branches (several ramifications) and with stay-green phenotype at maturity (Abdoulaye, 2018; Hamidou *et al.*, 2023).

Grains constitute the primary product for family diet and food processing. The grain and food processing profiles are all primarily interested in grain production. This explains the significant correlation observed between the two farmers' profile. Farmers of grain priority profile selected mostly high grain yield varieties with low haulm yield. They sell a part of the grains produced into markets and are interested by the economic value (Tignegre, 2010). Varieties with large grains are particularly appreciated for their easy packaging and market value. Grain quality is more specifically important for women processors. Women tend to select varieties with medium grain and haulm yield. Their preference for haulm yielding varieties may be partly explained by the fact cowpea leaves are used for human consumption (Ishikawa *et al.*, 2019; 2020) and to rear small ruminants.

CONCLUSION

The current study reported a successful process of development of twenty-two candidate multiline varieties of cowpea through a decentralized participatory breeding in Niger. The study supported several points. First, using the cropping system as a formal selection pressure applied early in the breeding scheme, it was able to identify sets of candidate varieties specifically suited for pearl millet-cowpea intercropping and, respectively, for sole cropping. Second, specific evaluation with three farmer profiles made the process more inclusive.

This allowed the identification of varieties fitting the specific production goals of each profile. The varieties chosen by farmers from grain priority corresponded to ideotypes with higher grain yield and low haulm yield. The varieties chosen by food processing priority profile, involving women predominantly, corresponded to ideotypes with medium grain and haulm yields and higher grain quality. Farmers from fodder priority profile preferred ideotypes with higher haulm yield and low grain yield. This result confirmed the relevance of farmers profile categorization and its formal inclusion into breeding protocol. Third, the consideration of agronomic and farmer evaluations reinforced the integration of scientific and farmers knowledges to better inform and support decision making in breeding. These results highlighted the importance of formal methodological settings in breeding design to consider local cropping systems, farmer profiles diversity, local knowledge and enhance selection efficiency.

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Data availability. Data are available on demand addressed by email to the corresponding author.

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SUPPLEMENTARY TABLES AND FIGURES

SUPPLEMENTARY TABLES

Table S1. Trials management and edaphic conditions of the locations.

Year	**2019**			**2020**		
Locations	**Sarkin Bindidga**	**Arawraye**	**Tchake**	**Sarkin Bindidga**	**Arawraye**	**Tchake**
Date of sowing	28 July	05 August	07 August	21 July	19 July	23 July
Fertilization	No fertilizer used			No fertilizer used		
Soil type*	Soil with dominant sandy texture (86.85 ± 0.4) and limited clay (5.07 ± 0.0) and silt 8.09 ± 0.4	Soil with dominant sandy texture (94.16 ± 0.3) and limited clay (0.76 ± 0.0) and silt (5.0 8 ± 0.3)	Soil with dominant sandy texture (95.90 ± 0.3) and limited clay (0.79 ± 0.0) and silt 3.31 ± 0.3	Soil with dominant sandy texture (86.85 ± 0.4) and limited clay (5.07 ± 0.0) and silt 8.09 ± 0.4	Soil with dominant sandy texture (94.16 ± 0.3) and limited clay (0.76 ± 0.0) and silt (5.0 8 ± 0.3)	Soil with dominant sandy texture (95.90 ± 0.3) and limited clay (0.79 ± 0.0) and silt 3.31 ± 0.3

***Soil data were extracted from Sadda *et al.* (2021). Further details on soils could be found in this paper (see Text).**

Table S2. Main and interaction effects of location, cropping system, year, and variety on agronomic traits of cowpea varieties (P-values of significance tests).

	Grain yield	Haulm yield	100 seed weight
Location	***	***	***
Year	***	***	***
Cropping system	***	**	*
Location x Year	***	***	***
Location x Cropping system	***	*	*
Year x Cropping system	***	*	ns
Location x Year x Cropping system	***	ns	**
1 | Variety	ns	ns	ns
Location | Cropping system x Variety	**	ns	ns
Year | Location x Variety	***	***	.

*The terms at the right of the sign "|" corresponded to random effects. The terms at the left are the random intercepts. Asterisks represent the degree of significance; ns: not significant p-value.

SUPPLEMENTARY FIGURES

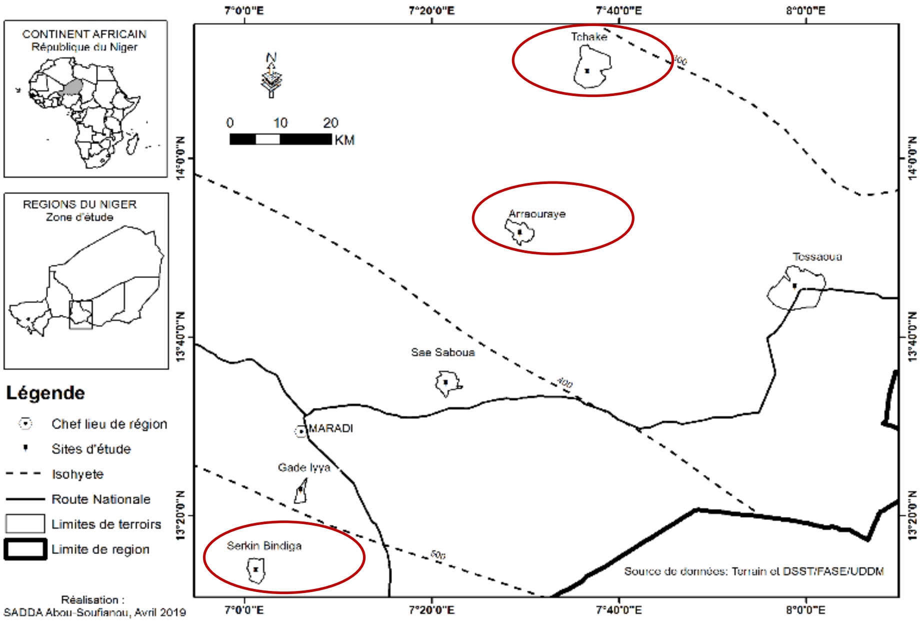

Figure S1. Experimental locations. The three villages are highlighted by a red circle: Tchake is located in the north (arid location), Arraoraye in the middle (spelled "Arawraye" in the text), and Serkin Bindiga in the south (wettest location, spelled "Sarkin Bindiga" in the text).

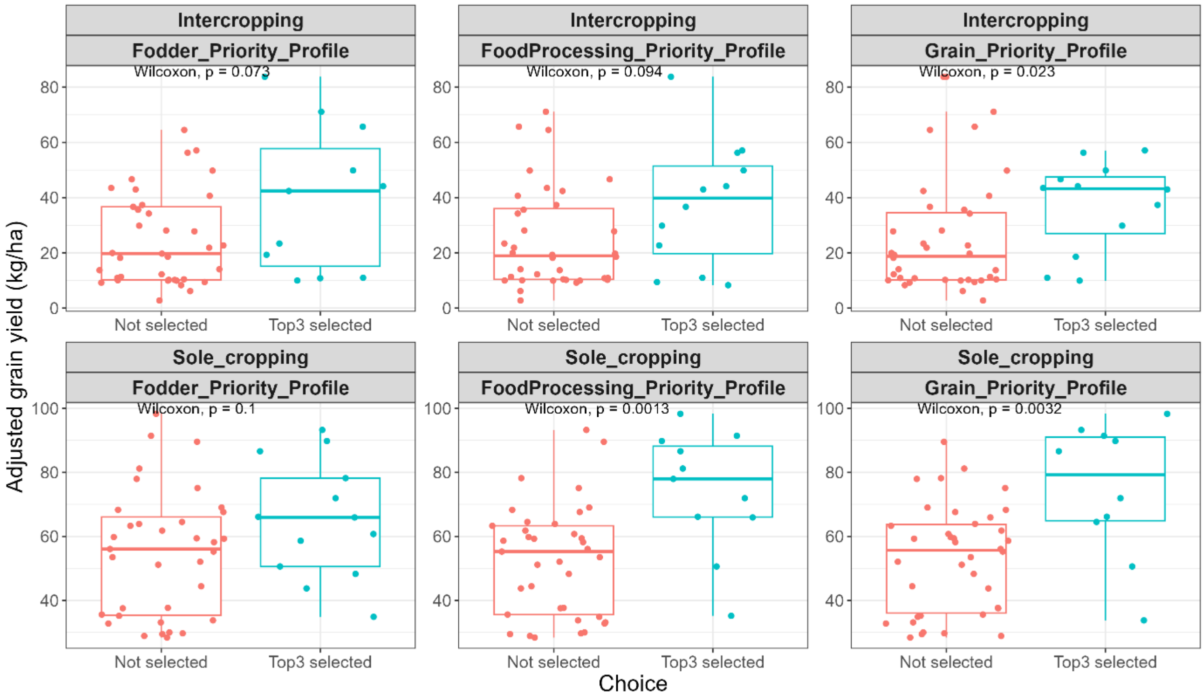

Figure S2. Adjusted grain yield of candidate varieties selected as Top3 by farmers' profiles in two respective cropping systems, compared to adjusted grain yield of non-selected varieties over two locations (Arawraye and Tchake).

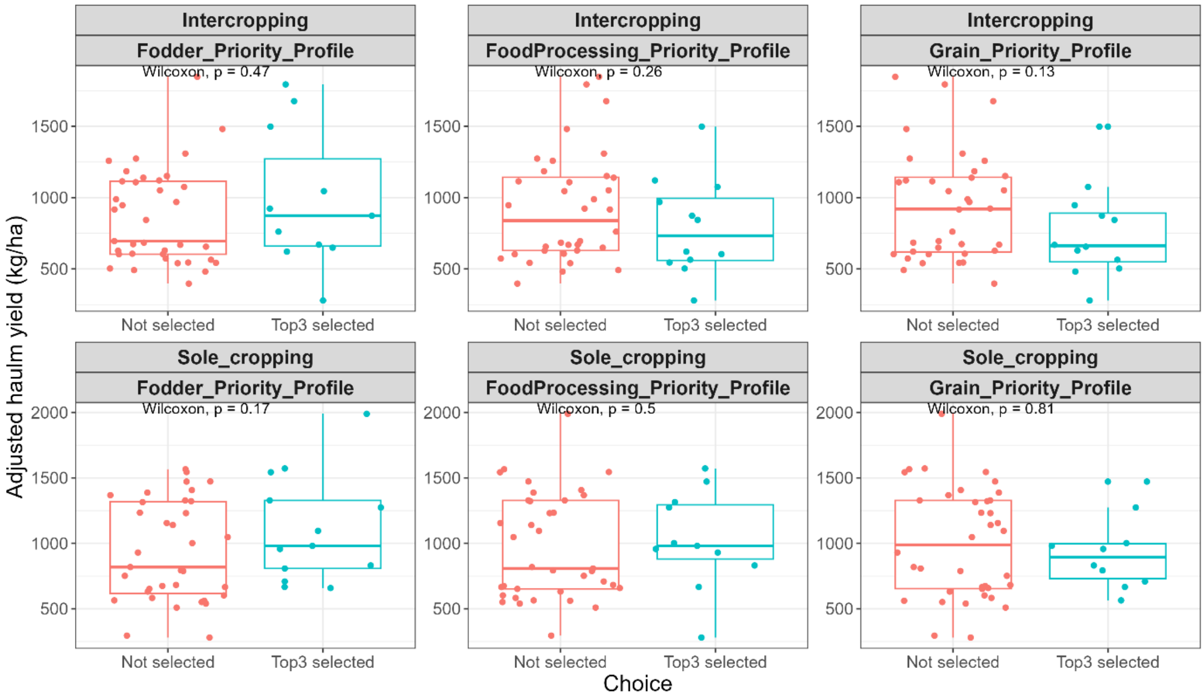

Figure S3. Adjusted haulm yield of candidate varieties selected as Top3 by farmers' profiles in two respective cropping systems compared to adjusted haulm yield of non-selected varieties over two locations (Arawraye and Tchake).

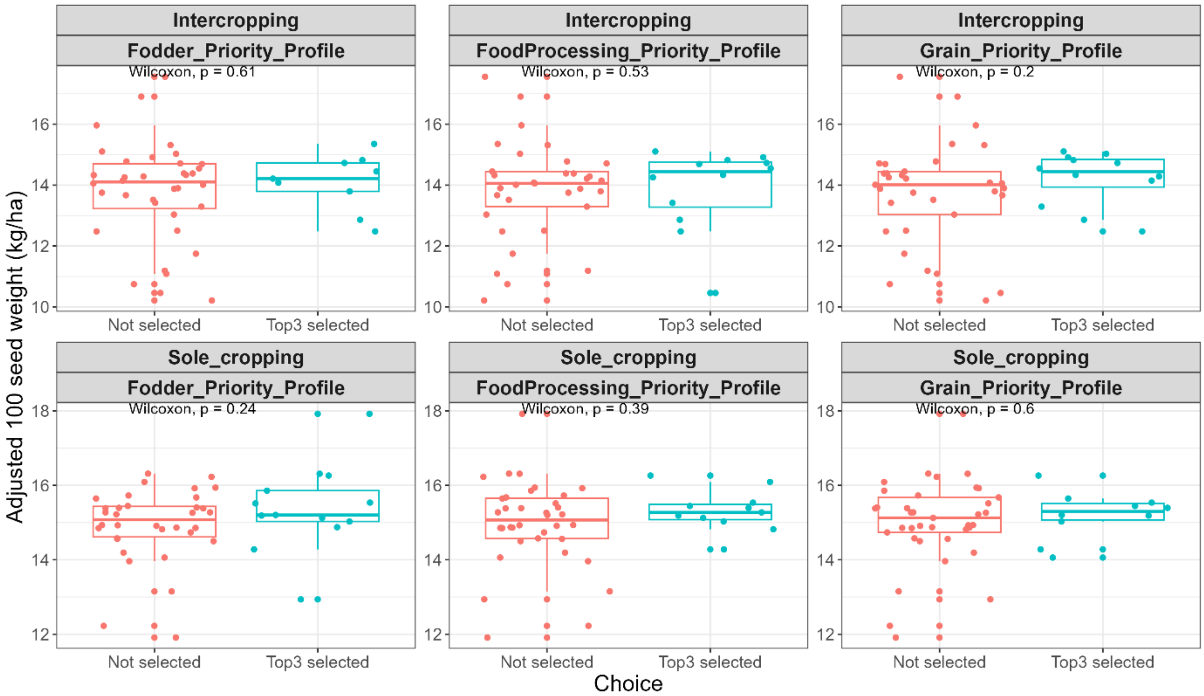

Figure S4. Adjusted hundred-seeds weight of candidate varieties selected as Top3 by farmers' profiles in two respective cropping systems compared to adjusted hundred-seeds weight of non-selected varieties over two locations (Arawraye and Tchake).