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On-station and on-farm participatory evaluation and selection of stable and high-yielding Bambara groundnut in Burkina Faso

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Introduction: Low yield is often claimed as one of the most important challenges for Bambara groundnut production in West Africa. To address the lack of high-yielding genotypes of Bambara groundnut in Burkina Faso, participatory evaluation and selection through multilocation trials is an important step to be taken. The present study aims at the participatory evaluation and selection of high-yielding and stable Bambara groundnut landraces in Burkina Faso.

Methods: A BGN collection was evaluated involving 274 growers through multilocation trials, including on-station and on-farm trials. Through semi-structured interviews, the most important trait for BGN selection and the growers' most preferred genotypes were identified. The collection was subjected to genetic stability and adaptability analysis based on the most important trait identified by growers.

Results: The study highlighted that crop yield is the most important selection trait for growers across the locations. In some locations, the on-farm agronomic performances (crop yield) were very similar to those observed on the research station, indicating that these locations could be favorable for BGN production.

Conclusion: Genotypes SLEO1 and BIKZ1 were identified as the most promising ones in terms of yield performance, farmers' preferences, and genetic stability across the environments. They can be disseminated to growers in Bambara groundnut production areas in Burkina Faso.

KEYWORDS
climate resilience, food security, high-yielding varieties, NUS, opportunity crop, participatory breeding, sub-Saharan Africa, SUSTLIVES

1 Introduction

Climate change is projected to affect sub-Saharan Africa in different ways. West Africa is expected to face severe impacts on food production—including crop yield decreases, land degradation, droughts, floods, rainfall variation, pest and disease pressure, and biodiversity loss—leading to food and nutritional insecurity (Serdeczny et al., 2017). Yet, sub-Saharan Africa is dealing with a rapidly growing population, predominantly of young people, to feed. An increase in food demand of more than 50 percent is expected in developing countries by 2050, implying the need for a quantitative and qualitative increase in food supply (FAO, 2017).

Promoting neglected and underutilized species (NUS) is increasingly considered a sustainable alternative for climate change adaptation, ecosystem resilience, food and nutritional security, and economic development in West Africa (Naino Jika et al., 2023; El Bilali et al., 2024a; El Bilali et al., 2024b). NUS have recently been categorized as native, locally adapted, climate-resilient, nutrient-rich, and cost-effective species (Ali and Bhattacharjee, 2023; Proietti et al., 2025). Bambara groundnut [BGN, *Vigna subterranea* (L.) Verdc], is a neglected and underutilized legume species that originates from West Africa (Chivenge et al., 2015; Siwale et al., 2022; Proietti et al., 2025). The common name—Bambara groundnut—seems to derive from the "Bambara" tribe (Temegne et al., 2018), whose geographical distribution area includes Mali, Burkina Faso, Côte d'Ivoire, Guinea, and Senegal.

BGN is a promising legume crop that is increasingly being studied due to its agronomic, medicinal, socio-economic, and nutritional importance (Mayes et al., 2019; Kanninkpo et al., 2022; Chelangat et al., 2023; Naino Jika et al., 2023; El Bilali et al., 2024a). It is considered to be a climate-resilient crop to address food and nutritional security (Paulos et al., 2022; Ogbuagu et al., 2023; Khan et al., 2024). It is used as food and medicine in many countries of West Africa (Temegne et al., 2018). It has an important role in communities' lives and is part of culinary habits and traditions (Temegne et al., 2018). It contributes to food and nutritional security for rural populations (Arise, 2016). BGN contributes to the empowerment of women who are primarily responsible for cultivating, selling, and processing (El Bilali et al., 2024a). It has a remarkable capacity for adaptation; tolerant to drought, pest, and disease, it is known for its ability to grow on poor soils, where cereals cannot thrive (Mayes et al., 2019; El Bilali et al., 2024a).

Despite the many proven benefits of BGN, ranging from improving ecosystems and women's living conditions to food and nutritional security, many constraints hinder the development of the crop value chains in Africa (Majola et al., 2021; El Bilali et al., 2024a). Regarding production, the main challenges include pests and diseases management, difficult access to land and quality seeds, etc. Low yield is claimed to be a big challenge for BGN production (Nhamo et al., 2022; Pasipanodya et al., 2022; El Bilali et al., 2024a). Research on BGN is lagging, and the varietal development is in its infancy (Pasipanodya et al., 2022). It is crucial to develop research on Bambara groundnut in Africa to address these challenges and constraints (El Bilali et al., 2024a). Seed is the first agricultural input. Therefore, research on seed system development must be particularly encouraged.

To date, landraces are widely cultivated in West Africa because of the lack of high-producing varieties, leading to low productivity and low yields (Pasipanodya et al., 2022). To address these challenges, participatory varietal selection is an important preliminary step to be taken. Indeed, it is one of the most rapid and cost-effective ways for breeders, farmers, and agronomists to identify suitable varieties (Moussa et al., 2023) while ensuring better adoption by the final users.

Generally, participatory varietal selections have been carried out only at the research level and only in research institutions (on-station), but without taking into account the effect of environmental variability. Although on-station participatory selection is relevant, it has its limits. Indeed, because of genotype-environment interactions, genotypes identified as high-yielding in a controlled environment (research station) may not be so in a farming condition. Therefore, some studies were carried out on the stability of BGN yield using Genotype and Genotype–Environment interaction analysis (Linus et al., 2023). However, unfortunately, the previous studies on BGN yield stability have not been combined with participatory varietal selection involving farmers (Linus et al., 2023).

Multilocation trials, including on-station and on-farm trials, combined with participatory varietal selection, could be more relevant and make it possible to select high-yielding genotypes both on-station and on-farm and to better take into account growers' preferences in the choice of varieties to be released. Therefore, the study aims to: (i) identify the key selection criteria used by BGN growers in Burkina Faso for varietal adoption and cultivation; (ii) determine farmers' preferred genotypes through participatory evaluation; (iii) assess the agronomic performance of a diverse BGN collection across multiple villages in Burkina Faso; (iv) evaluate genotype × environment interactions; (v) estimate the stability of the BGN collection across test environments; and (vi) select superior and stable landraces that combine high agronomic performance with strong farmer preference for potential recommendation and dissemination in Burkina Faso.

2 Materials and methods

2.1 Plant material

Fifteen Bambara groundnut landraces collected in Burkina Faso were used for the study (Figure 1). They were chosen from the germplasms of the University Joseph KI-ZERBO (UJKZ) and the Institute of Environment and Agricultural Research (INERA) based on the farmers' preferences, the yielding potential, and the socio-cultural importance (Ouoba et al., 2016, 2018). Indeed, landraces with cream-colored seeds are the consumers' preferred ones, while those with light-brown tripes on a dark-red background are widely used in certain socio-cultural practices (Kiebre et al., 2025). The black landraces are the least used in Burkina Faso. However, they are claimed to be very nutrient-rich (Kiebre et al., 2025). The landraces used for the study are shown in Figure 1, and their characteristics are listed in Table 1.

2.2 Experimental sites

2.2.1 On-station evaluation site

A trial was set up on July 5, 2023, in the SUSTLIVES project experimental station located at Gampela (12.41187 N and 1.352925 W) in the Sudano–Sahelian zone. The experiment was conducted during the rainy season, from July to December 2023. The soil texture was predominantly silty–sandy (25.49–27.46% of silt and 58.82–62.75% of sand) with a slightly acidic pH of 5.7 and a depth of 50–60 cm (Kiebre et al., 2019; Kiebre et al., 2025). From August to September, the rainfall

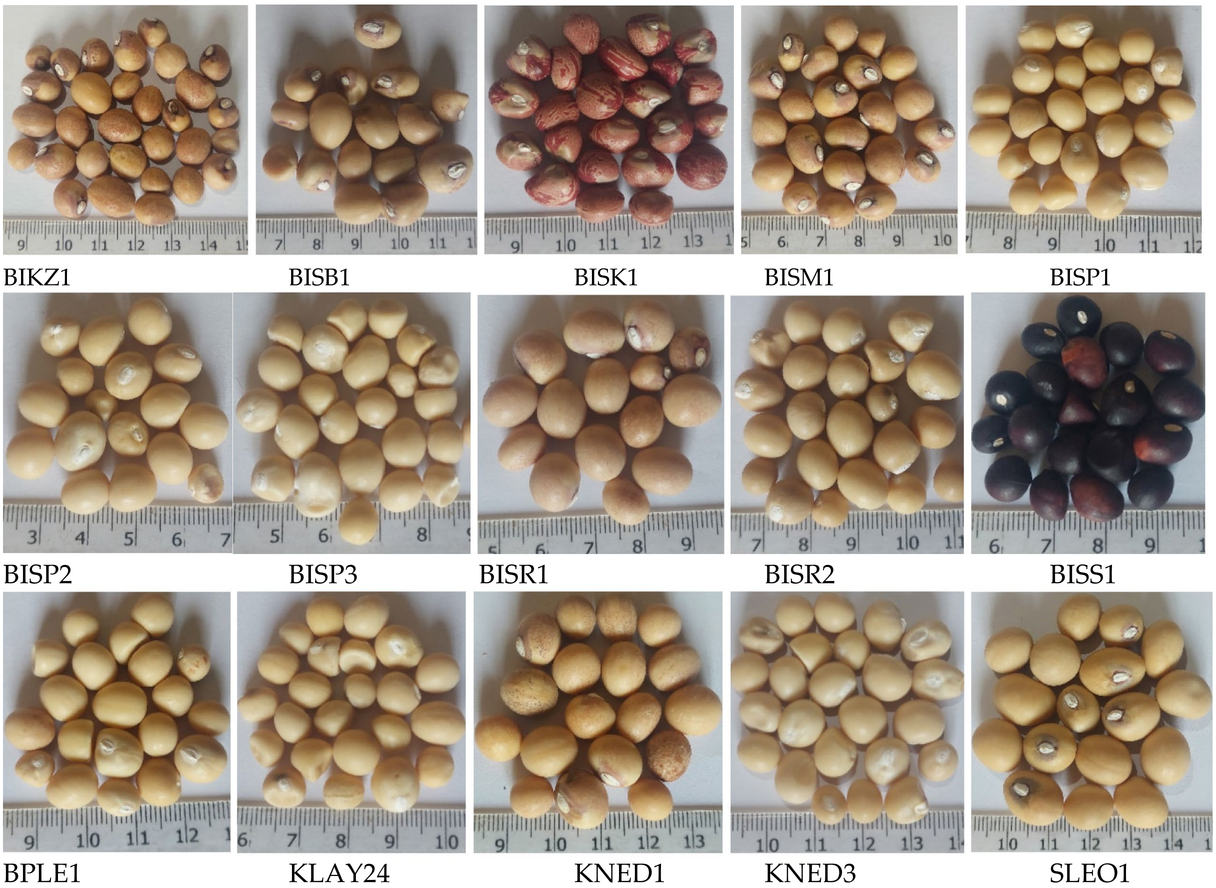

FIGURE 1
BGN seed and seed coat features among genotypes selected to be included in the study.

was up to 583.5 mm, with 253.5 mm for August, 158 mm for July, 130 mm for September, and 42 mm for October. The minimal temperatures varied from 12.5 to 23.3 °C, and the maximal temperatures ranged from 33.3 to 34.6 °C.

2.2.2 On-farm participatory evaluation and varietal selection locations

Trials were implemented on farmers' fields in 10 villages across four provinces located in four regions in Burkina Faso (Figure 2). The villages involved in the study were identified based on:

- The existence of six NUS (viz. Bambara groundnut, sweet potato, Frafra potato, amaranth, roselle, and moringa) previously identified as of interest in Burkina Faso (El Bilali et al., 2023).
- The existence of NUS producers' organizations in the villages.

In each village, a village assembly, involving the NUS producers, was organized with the help of the village development council (CVD), which identified and mobilized the producers. The assembly served as a framework to identify a site for the participatory evaluation and varietal selection and to choose one NUS (viz. Bambara groundnut) out of the six of interest based on the score of interest assigned to them by the participants. The experiment was conducted during the rainy season, from July to December in 2023.

Pella and Pelbilin villages are located in the Pella Department, the Boulkiemdé province, and the Center-West region of Burkina Faso. The average annual rainfall was 750.5 mm for 41 rainy days. The temperatures ranged from 16 to 45 °C.

Nidaga and Menega villages are located in the Kokologho Department, the Boulkiemdé province, and the Center-West region of Burkina Faso. The average annual rainfall was 835.5 mm for 48 rainy days. The temperatures vary from 16.2 to 39.7 °C.

Nedogo is located in the Pabré Department, the Kadiogo province, in the Central region of Burkina Faso. The average annual rainfall was 666.42 mm for 42 rainy days. The temperatures varied from 16 to 37 °C.

Koubri is located in the Koubri Department, Kadiogo province, in the Central region of Burkina Faso. The average annual rainfall was 618 mm for 44 rainy days. The temperatures varied from 16 to 39 °C.

Loumbila is located in the Loumbila Department, the Oubritenga province, in the Central Plateau region. The average annual rainfall recorded was 730 mm for 40 rainy days. The temperatures ranged from 17.1 to 37 °C.

Kolgondiesse is located in the Ziniaré Department, the Oubritenga province, in the Central Plateau region. The annual rainfall was 779.15 mm for 42 rainy days while the temperatures ranged from 17.29 to 39.83 °C.

TABLE 1 Information related to BGN genotypes evaluated.

Landraces	Seed shape	Seed size	Seed color	± and eye color	Eye appearance	Origin
BIKZ1	Round	Medium	Grey spots on a cream background	Grey eye	Shape of a butterfly	
BISB1	Oval	Large	Grey spots on a cream background	Grey eye	Shape of a butterfly	
BISK1	Round	Small	Light-brown stripes on a dark-red background	Grey eye	Shape of a butterfly	
BISM1	Round	Medium	Grey spots on a cream background	Grey eye	Shape of a butterfly	INERA
BISP1	Round	Small	Cream	No eye	–	
BISP2	Round	Small	Cream	No eye	–	
BISP3	Round	Small	Cream	No eye	–	
BISR1	Round	Medium	Grey spots on a cream background	Grey eye	Shape of a butterfly	
BISR2	Round	Small	Cream	No eye	–	
BISS1	Oval	Large	Black	No eye	–	
BPLE1	Round	Small	Cream	No eye	–	
KLAY24	Round	Small	Cream	No eye	–	
KNED1	Oval	Medium	Grey spots on a cream background	Grey eye	Shape of a butterfly	UJKZ
KNED3	Round	Small	Cream	No eye	–	
SLEO1	Oval	Large	Cream	Grey eye	Shape of a triangle	

UJKZ, University Joseph KI-ZERBO; INERA, Institute of Environment and Agricultural Research.

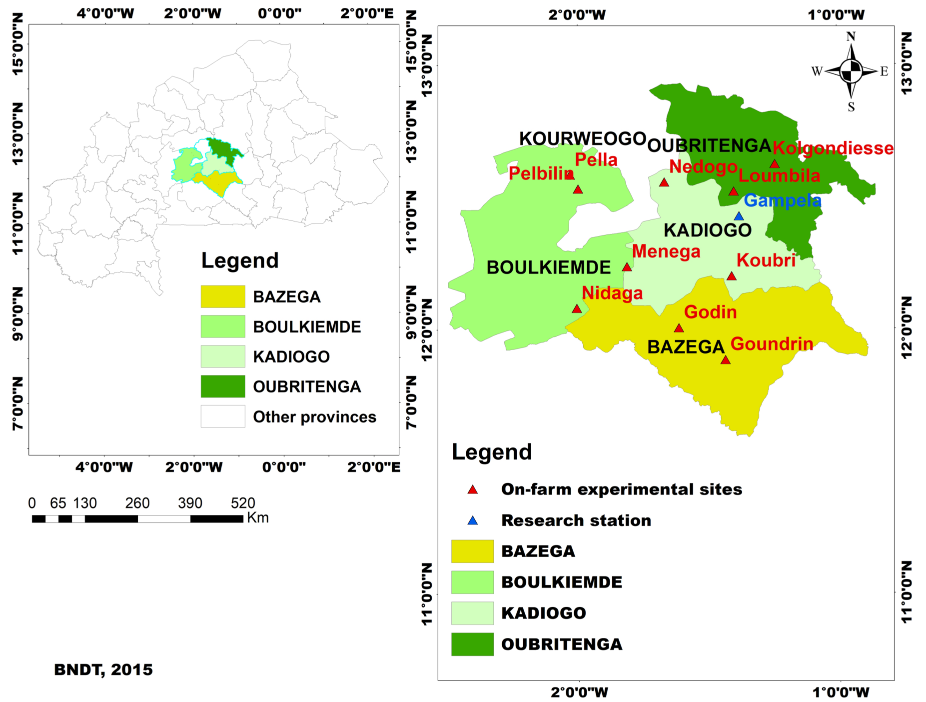

FIGURE 2
Evaluation and participatory varietal selection locations.

Goundrin is located in the Kombissiri Department, and Godin is in the Saponé Department. Both Departments are located in the Bazéga province and the Center-South region. The average annual rainfall was 851 mm for 56 rainy days. The temperatures varied from 16 to 38.8 °C.

All the locations are characterized by degraded soils, high temperatures, and irregular rainfall, resulting in droughts, especially at the end of the rainy season. Geographic data used in this study are from INSD (2022).

Regarding the characteristics that differentiate the villages, there is, first, climatic variations (especially rainfall). The annual rainfall varies from 600 mm (for the villages in the north) to 1,000 mm (for the villages in the south). Then, some villages (Koubri, Loumbila, and Nedogo) are close to the capital, Ouagadougou, and, therefore, are influenced by urbanization, while the others are far from the capital and are typical rural areas. The sowing dates and the soil characteristics are shown in Table 2.

2.3 Experimental design and procedures

The experiment was conducted using a randomized complete block design (RCBD) with three replications at each location (on farmers' fields and on the research station). The distance between successive replications was 1 m. In each replication, each landrace was represented by a row of 5 m on which 11 seeds of BGN were sown. The inter-row spacing was 50 cm, and the intra-row spacing was 30 cm. Pest and disease management were carried out based on methods commonly used in Burkina Faso, including biopesticides and hand weeding. Before starting the experiment, the soil was plowed, and organic manure at 5 tons per hectare was applied. The dose of 5 tons was defined in accordance with the local practices.

2.4 Phenotypic traits studied

On-farm and on-station evaluations were carried out using seven quantitative traits (Table 3). The number of days to 50% flowering stage and the number of days to 95% maturity levels were measured on the entire row for each landrace. The other quantitative variables, such as seed length, seed width, number of seeds per plant, seed weight per plant, and seed yield, were measured on five plants in the row. Measurements were conducted according to the instructions of the BGN descriptor (IPGRI/IITA/BAMNET, 2000) and previous studies (Kiebre et al., 2025).

TABLE 2 Sowing dates and soil characteristics according to locations.

Provinces	Villages	Sowing dates	Soil characteristics
Kadiogo	Koubri	13/07/2023	Silty-clayey
	Nedogo	05/07/2023	Silty-sandy
Boulkiemdé	Nidaga	11/07/2023	Clayey
	Menega	10/07/2023	Sandy-loamy
	Pelbilin	13/07/2023	Sandy-loamy
	Pella	12/07/2023	Sandy-loamy
Oubritenga	Kolgondiesse	18/07/2023	Sandy-loamy
	Loumbila	12/07/2023	Silty-sandy
Bazèga	Goundrin	09/07/2023	Sandy-loamy
	Godin	09/07/2023	Sandy-loamy

2.5 Identification of the most important selection criterion for BGN growers

Individual semi-structured interviews were conducted to gain insights into the perception of farmers' most important criterion for BGN selection. In each village, the study involved around 30 BGN growers. The identification of the most important selection criterion involved choosing three key selection criteria, to which scores were assigned according to the importance given to each criterion by the participant (Kiebre et al., 2025):

(i) For the most important criterion, the score attributed was 7.
(ii) For the second most important criterion, the score attributed was 5.
(iii) For the third most important criterion, the score attributed was 3.

Then, all the criteria identified by the growers were listed and the overall score for each criterion was calculated by adding up the individual scores. Based on the scores, the most important criterion was identified. During the interviews, an individual questionnaire was used to record data on various aspects, including demographic characteristics of participants.

2.6 Identification of the growers' most preferred genotypes

The participatory varietal selection was conducted on-farm in each village. In each village, approximately 30 participants were involved. Seeds from each landrace were harvested, dried and, then, subjected to participatory selection. For each grower, the identification of the genotypes of interest involved choosing three genotypes, to which scores were assigned according to the order of participants' preferences (Kiebre et al., 2025):

(1) For the most preferred genotype, the score attributed was 7.
(2) For the second most preferred genotype, the score attributed was 5.
(3) For the third most preferred genotype, the score attributed was 3.

Then, all the genotypes selected by the growers were listed, and the overall score for each genotype was calculated by adding up the

TABLE 3 Phenotypic traits used for evaluations.

N	Phenotypic trait	Measurement
1	Number of days to 50% flowering	Determined by recording the number of days following sowing until 50% of the plants in a row had at least one open flower
2	Number of days to 95% maturity	Determined by counting the number of days following sowing until the pods of 95% of the plants in a row reached maturity.
3	Number of seeds per plant	Determined by counting the total number of seeds produced by a plant
4	Seed weight per plant	Seeds produced by each plant were dried, then weighed using an electronic scale
5	Seed length	Measured using a caliper
6	Seed width	Measured using a caliper
7	Seed yield	Representing the weight of seeds produced per elementary plot and extrapolated over 1 ha.

individual scores. Based on the scores, the most preferred genotype was identified.

Segregated focus group discussions (men and women) were conducted in each village to explore group criteria and to support and validate the information recorded from individual interviews.

2.7 Data analysis

The socio-demographic characteristics of farmers involved in the study were described using the data recorded on socio-demographics. The data recorded were related to the number of participants involved, participants' age, and gender. They were used to conduct descriptive statistics, including frequencies, means, and percentages. All the individual selection criteria and the individual preferred genotypes were listed across locations. The overall score of each selection criterion and each preferred genotype was calculated by adding up the individual scores attributed by each participant, making it possible to identify the growers' most important selection criterion (i.e., crop yield) and their most preferred genotypes. Then, the scores were used to perform a Chi-square test in order to assess the differences in farmers' preferences across locations.

The agro-morphological data were analyzed using R (4.4.2) software. Descriptive statistics, including means, frequencies, and percentages, were conducted for all variables. The Shapiro–Wilk test was used to test the normality of data recorded (Ghasemi and Zahediasl, 2012). A two-way analysis of variance (Genotypes, Locations, G × E) was conducted, using the Newman–Keuls test ($p < 0.01$), on agromorphological data, making it possible to identify significant differences across landraces and locations and to evaluate Genotype (G) × Environment (E) interaction level. The blocks and the locations were considered as random.

The stability and adaptability of the crop yield (identified as the growers' most important criterion) were assessed using the Annicchiarico method (Annicchiarico, 1992) through the estimation of a confidence index (Wi) across the locations. The confidence index of Annicchiarico (1992) was estimated as: $Wi = Y(i.)\ (\%) - Z(1-\alpha)\ (\sigma i)$; where: Wi = genotypic confidence index of genotype i; $Y(i.)$ (%) = relative mean of genotype i across the locations; $Z(1-\alpha)$ = quantile of the Z distribution at $\alpha = 0.95$, and σi = relative standard deviation of genotype i across the locations. Based on the Wi, the genotypes were ranked from 1 (most performing) to 15 (least performing). So, the rank 1 was attributed to the genotype with the highest estimated Wi, while the rank 15 was given to the one with the lowest estimated Wi. The package Metan was used to run stability analysis. A GGE biplot was run, and the resulting graph, "which-won-where" enabled the establishment of relationships between the studied genotypes and the environments, and also to identify mega-environments. A GGE "ranking" biplot was performed to show stable genotypes according to locations. The package ggplot2 was used to visualize the biplot graphs.

3 Results

3.1 On-farm participatory varietal selection across locations and identification of the most important selection criterion

3.1.1 Socio-demographic characteristics of the participants

Overall, 274 producers from different age groups, including women and men, were involved in the study (Table 4). The number of participants ranged from 24 to 34 across locations, with an average of 30 participants per location. Participants were fairly gender-balanced except those from Pelbilin, Kolgondiesse, and Goundrin where women were more numerous than men. The participants' ages ranged from 17 to 88, with an average of 39.86–45.83 across the locations. The participants were age-balanced from one location to another (Table 4).

3.1.2 Identification of the growers' most important selection criterion across the locations

Overall, eight key criteria were listed by BGN growers for varietal selection in Burkina Faso (Table 5). Their importance varied from one locality to another ($p < 2.2 \times 10^{-17}$). Overall, the most important criterion was seed yield. It was followed by market value, plant cycle (short), seed size (large), seed color (cream), cooking duration (short), drought resistance, and cultural value (Table 5). However, it is worth noting that drought resistance and cultural value seem to be more important criteria of interest in Goundrin and Kolgondiesse, respectively, than in the other locations.

TABLE 4 Socio-demographic characteristics of participants.

Locations	Number of women	Number of men	Total	Age (min–max)	Average age
Koubri	23	10	33	22–74	42.78
Loumbila	15	15	30	17–72	43
Nedogo	17	15	32	18–75	45.3
Nidaga	16	15	31	19–61	39.86
Menega	18	13	31	25–72	45.83
Pelbilin	21	9	30	21–73	43.76
Kolgondiesse	32	2	34	20–60	35.29
Goundrin	21	8	29	20–88	44.66
Godin	14	10	24	23–78	44.2
Overall	177	97	274	17–88	42.74

TABLE 5 Results of the chi-square test conducted using the scores of the criteria of interest across the locations.

Locations	Seed color	Seed size	Seed yield	Plant cycle	Drought resistance	Cooking duration	Market value	Cultural value	Chi²	df	p-value
Koubri	102	47	67	38	30	41	42	5			
Loumbila	21	27	49	34	27	24	26	16			
Nedogo	57	44	131	26	52	25	86	20			
Nidaga	66	70	77	81	68	75	71	41			
Menega	42	43	63	66	52	74	55	14	476.9	56	$<2.2 \times 10^{-17}$
Pelbilin	41	144	142	145	93	125	129	21			
Kolgondiesse	110	74	117	114	95	75	105	103			
Goundrin	140	142	141	122	133	115	113	13			
Godin	96	98	97	84	36	55	108	37			
Total score	675	689	884	710	586	609	734	270			
Rank	5	4	1	3	7	6	2	8			

TABLE 6 Results of the chi-square test conducted using genotypes' scores across the locations.

Land.	Koubri	Loum.	Nedo.	Nida	Mene.	Pelbi.	Kolg.	Gound.	Godin	Score	Chi²	df	p-value
BIKZ1	13	22	11	34	61	66	20	5	10	242			
BISB1	28	93	63	85	118	60	83	20	30	580			
BISK1	71	0	11	41	30	48	13	51	34	299			
BISM1	14	99	15	0	18	21	93	3	3	266			
BISP1	109	14	67	36	43	20	86	34	34	443			
BISP2	58	91	38	53	27	9	49	65	38	428			
BISP3	28	0	22	0	0	12	24	31	12	129	1838.8	112	$<2.2 \times 10^{-16}$
BISR1	25	7	41	8	15	30	13	9	5	153			
BISR2	20	40	3	11	14	10	34	27	42	201			
BISS1	9	0	3	14	0	0	7	3	3	39			
BPLE1	5	14	38	15	15	38	31	22	55	233			
KLAY24	49	5	48	21	53	37	27	57	13	310			
KNED1	3	36	3	42	13	30	12	17	5	161			
KNED3	40	0	33	48	45	16	15	39	26	262			
SLEO1	14	5	99	59	20	53	3	61	50	364			

Nedo., Nedogo; Mene., Menega; Gound., Goundrin; Loum., Loumbila; Kol., Kolgondiesse; Pelbi., Pelbilin.

3.1.3 Identification of the growers' most preferred genotypes across the locations

Overall, BISB1, BISP1, BISP2, SLEO1, and KLAY24 recorded the highest preference scores. However, the specific preferences in genotypes varied significantly ($p < 6.753 \times 10^{-12}$) according to locations (Table 6). In Koubri, BISP1 recorded the highest score, followed by BISK1 and BISP2 and KLAY24, while in Loumbila, the highest score was attributed to BISM1, followed by BISB1, BISP2, and BISR2. SLEO1 was the most preferred genotype in Nedogo. It was followed by BISP1 and BISB1. In Nidaga and Menega, the farmers' top choice was BISB1. It was followed by SLEO1 and BIKZ1, respectively. BISP2 and KLAY24 were the third choice, respectively, in Nidaga and Menega. In Pelbilin, the three most preferred genotypes were BIKZ1, BISB1, and SLEO1, whereas the three most preferred ones in Kolgondiesse were BISM1, BISP1, and BISB1. In Goundrin BISP2, SLEO1, KLAY24, and BISK1 recorded the highest scores, whereas in Godin, BPLE1, SLEO1, BISR2 were the most preferred genotypes (Table 6).

There are genotypes that were not chosen, not even once, in some localities. For example, BISK1, BISP3, BISS1, and KNED3 were not chosen even once in Loumbila. Out of the 15 genotypes, 11 were chosen as of interest in Loumbila. In Nidaga and Menega, out of the 15 genotypes, 13 were chosen as of interest. Genotypes BISM1 and BISP3 were not chosen even once in Nidaga, while BISP3 and BISS1 were not included in the list of genotypes of interest in Menega. In Pelbilin, all the genotypes were chosen as of interest except BISS1.

3.1.4 Identification of the growers' most preferred genotypes according to gender

Regarding gender, the preferences in landraces varied significantly ($p < 6.753 \times 10^{-12}$) according to women and men (Table 7), although

TABLE 7 Results of the chi-square test performed using genotypes' scores across gender.

Landraces	Women	Men	Score	Rank	Chi²	df	p-value
BIKZ1	170	72	242	9			
BISB1	365	215	580	1			
BISK1	145	154	299	6			
BISM1	161	105	266	7			
BISP1	244	199	443	2			
BISP2	295	133	428	3			
BISP3	100	29	129	14	83.344	14	$<6{,}753 \times 10^{-12}$
BISR1	95	58	153	13			
BISR2	123	78	201	11			
BISS1	16	23	39	15			
BPLE1	137	96	233	10			
KLAY24	168	142	310	5			
KNED1	113	48	161	12			
KNED3	147	115	262	8			
SLEO1	224	140	364	4			

BISB1 was the top preferred genotype for both women and men. The women's most preferred genotypes also included BISP2, BISP1, SLEO1, and BIKZ1. For men, they included BISP1, BISK1, KLAY24, and SLEO1. So, BISB1, BISP1, and SLEO1 were common to both women and men. However, BIKZ1 and BISP2 are specific to women, whereas KLAY24 and BISK1 are specific to men. It is worth noting that all the genotypes were listed at least once by both men and women as of interest (Table 7). Overall, BISB1, BISP1, BISP2, SLEO1, and KLAY24 were the most preferred genotypes.

3.1.5 Focus group discussions (FGDs) across locations

The FGDs made it possible to support or confirm some of the individual points of view. No significant differences in perception were noted between the segregated focus groups (men and women). In general, dark-colored seeds and too small seed size were listed as less appreciated traits. In addition, long cooking duration and flatulence were underlined as the most undesirable traits in Bambara groundnut. The most desirable criteria are high yield and cream-colored seed. Certain genotypes were identified by farmers as the most climate-smart genotypes, hence the local name "*konkuul-zalem*" (you will never go back home from the field empty-handed) given to them. However, their morphological characteristics varied across the locations, indicating a possible confusion between the varieties. The FGDs exhibited a supposed existence of nutritional variability according to the landraces, with the dark-colored ones as the most nutritious. In general, the information from FGDs did not vary significantly across villages.

Socio-cultural factors influencing and maintaining BGN diversity were identified by participants. It is reported that Bambara groundnut is associated with many cultural practices, including taboos and beliefs, in the study areas. Taboos and negative beliefs mainly affect young people and women who must meet certain conditions before being allowed to cultivate Bambara groundnut. The information recorded during FGDs did not vary significantly between villages, although producers in Pella appear to be freer from taboos and negative beliefs than those in the other villages.

3.2 Agronomic performances of genotypes across the locations

3.2.1 Yield performances and seed number per plan according to the genotypes and the environments

Significant differences were observed across the genotypes ($p < 0.5812 \times 10^{-3}$) and across the locations ($p < 2.2 \times 10^{-16}$), with significant interaction between the environments and the genotypes observed ($<4.427 \times 10^{-5}$). Overall, the average yield varied significantly from 448.12 to 2476.01 kg/ha (Table 8). On the station, the average yield ranged from 943.05 to 1506.67 kg/ha, and most of the genotypes, up to 73.34%, recorded more than 1,000 kg/ha. In farmers' fields, more significant variations between genotypes were observed according to the locations, ranging from 448.12 to more than 2,000 kg/ha.

Related to the number per plant, it also varied significantly according to the genotypes (2.94×10^{-6}) and the study location ($<2.2 \times 10^{-16}$) with a very significant interaction between the locations and the genotypes (2.115×10^{-3}). Seed number per plant ranged from 11 to 67.

In general, the best performances were observed in Pella and Pelbilin, both located in the department of Pella, Goundrin in the department of Kombissiri, and at the research station (Gampela).

3.2.2 Seed dimensions and seed weight per plant according to the locations

Seed length varied significantly according to the landraces ($<2.2 \times 10^{-16}$) and the environments ($<2.2 \times 10^{-16}$), with high interaction between seed length and environments ($<2.2 \times 10^{-16}$). Regarding

TABLE 8 Yield performances of the genotypes across the locations and results of the analysis of variance.

Land.	Gam.	Godin	Gound.	Koubri	Loum.	Menega	Nedogo	Nidaga	Pelbilin	Pella	Kolg.
BISP2	1506.67	874.14	1901.84	–	999.07	1089.41	552.08	514.14	978.81	1425.23	698.67
BISR1	1407.67	1221.24	1961.8	643.83	1030.24	1076.38	536.89	1074.17	1315.95	1134.27	1228.61
BISB1	1342.30	803.74	1544.45	853.89	859.74	998.87	914.30	559.25	1777.86	1156.23	614.81
BIKZ1	1207.07	896.07	1719.43	758.12	662.91	1284.84	556.37	919.62	1863.64	1947.78	1274.01
BISS1	1176.89	628.01	1813.45	740.34	597.04	1086.19	925.92	705.01	1566.23	1507.05	899.05
SLEO1	1174.31	1131.41	1915.15	768.36	656.37	1008.10	2107.78	1051.22	1264.14	1509.67	849.27
BISM1	1161.58	804.23	1610.2	762.35	716.26	944.51	810.38	636.30	1364.31	1403.19	1193.40
BISK1	1150.73	847.05	1527.75	730.05	543.77	1025.78	713.26	614.51	905.38	1270.24	790.92
KNED1	1069.42	1006.20	1473.01	907.89	1012.15	1124.21	620.37	1160.73	1436.49	1722.15	939.58
BISP3	1030.01	1145.25	2476.01	841.54	448.12	710.89	920.75	1383.56	995.14	1378.75	770.45
BISP1	985.12	1224.14	1048.30	932.67	450.72	961.58	796.89	681.09	1229.88	1389.06	602.68
BISR2	983.72	1096.23	1482.15	962.06	609.34	879.78	639.71	475.34	1001.90	1069.71	508.07
KNED3	948.43	937.56	1598.01	737.38	693.81	1340.45	960.23	706.45	1049.85	1391.12	1190.79
BPLE1	943.05	1026.76	1650.01	878.62	1488.01	736.36	853.25	898.30	1091.08	1881.92	824.94
KLAY24	–	809.76	1556.54	1233.1	644.11	913.76	542.58	452.72	1300.48	1493.41	878.14
Min.	943.05	628.01	1048.30	643.83	448.12	710.89	536.89	452.72	905.38	1069.71	508.07
Max.	1506.67	1224.14	2476.01	1233.1	1488.01	1340.45	2107.78	1383.56	1863.64	1947.78	1274.01
Land.					5.82×10^{-4}**						
Sites.					$<2.2 \times 10^{-16}$**						
Land. × sites					4.43×10^{-5}**						

Min, minimum; Max, maximum; $p \geq 0.05$ = not significant (ns); $p \leq 0.01$ = significant (**); Land., landraces; Gam., Gampela; Gound., Goundrin; Loum., Loumbila; Kol., Kolgondiesse.

seed width, it did not vary significantly according to the genotypes ($p = 0.18$), and no significant interaction was recorded between seed width and the locations ($p = 0.98$). However, a significant variation was observed according to the locations ($p < 0.014$). Seed length ranged from 7.45 mm to 14.06 mm, while seed width varied from 6.01 to 12.08 mm.

On the experimental station, seed length and width ranged from 9.89 to 12.08 mm, and from 8.89 to 10.27 mm, respectively. On-farm, they varied, respectively, from 7.45 mm to 14.06 mm, and from 6.01 to 12.08 mm. For seed weight per plant, like the other variables, the differences were significant both for genotypes ($p < 0.44 \times 10^{-3}$) and locations ($p < 2.2 \times 10^{-16}$), with an interaction between genotypes and environments ($p < 5.351 \times 10^{-5}$).

3.2.3 Variation of traits related to the plant cycle across the genotypes and the locations

The number of days to 50% flowering ranged from 21 days (in Godin) to 52 days (in Pella), while the number of days to 50% maturity varied from 78 days (Godin) to 111 days (Goundrin). The variation of both the number of days to 50% flowering and number of days to 50% maturity was significant according to study locations ($<2.2 \times 10^{-16}$ and $<2.2 \times 10^{-16}$, respectively) and genotypes ($<2.2 \times 10^{-16}$ and 2.03×10^{-7}, respectively). For these two variables, significant interactions were exhibited between locations and genotypes ($<2.2 \times 10^{-16}$, respectively). The genotypes completed their cycle earlier in Godin and Kolgondiesse (78–86 days) than in the other locations (up to 111 days). On the research station, Gampela, the cycle was intermediate (from 88 to 95 days according to the genotypes).

3.3 Yield stability and specific adaptation

The GGE "ranking" biplot showed stable genotypes according to locations (Figure 3). The genotypes with the shortest perpendicular mark on the axis are the most stable, while the genotypes with longer perpendicular mark to the axis are less stable. Thus, the most stable genotypes were BISR1, BPLE1, KNED1 and BISS1. The genotypes BISP3, SLEO1 and BIKZ1 recorded high performances counterbalanced by a low stability.

Regarding all the locations, the confidence index (Wi) revealed that KNED1 (1,134 kg/ha), BIKZ1 (1,190 kg/ha), BISR1 (1,148 kg/ha), BISM1 (1,037 kg/ha), KNED3 (1,049 kg/ha), BISS1 (1,059 kg/ha) and SLEO1 (1,221 kg/ha) were the most adaptable and stable genotypes (Table 6). Genotypes BPLE1 and BISB1 were also stable and adaptable. Environmental indices showed that the research station, Gampela, with an environmental index (EI) of 92, Goundrin (with EI of 1,675), Pella (with EI of 1,447), and Pelbilin (with EI of 1,276) were the most favorable locations, while the others were unfavorable.

For the favorable locations, the overall crop yield ranged from 1,148 kg/ha (in Gampela) to 1,675 kg/ha (in Goundrin), with environmental indices varying from 92 to 618, respectively. The other favorable locations recorded an overall crop yield of 1,276 kg/ha (in Pelbilin) and 1,447 kg/ha (in Pella) with environmental indices of 219 and 391, respectively.

For the unfavorable locations, overall crop yield ranged from 766 kg/ha (in Loumbila) to 1,005 kg/ha (in Menega) while the environmental indices ranged from −290–−51.7, respectively.

Considering the four favorable environments, BIKZ1 was the most performing and the most adaptable landrace (Table 9). It was

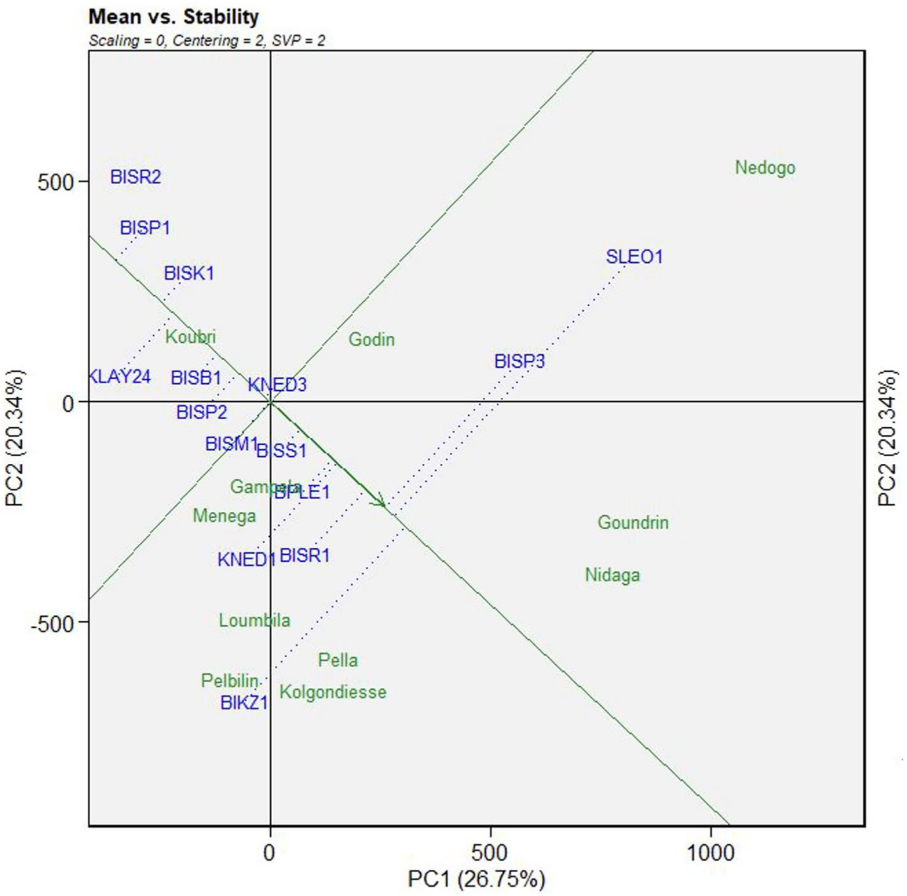

FIGURE 3
Ranking plot showing stable and specific adaptation of the genotypes.

followed by BISS1, SLEO1, BISM1, and KLAY24, which also exhibited the best adaptability and stability for seed yield. Coming to unfavorable locations, genotypes KNED1, KNED3, BISR1, BPLE1, and SLEO1 showed the greatest adaptability and stability.

Considering the "Which won where" biplot (Figure 4), around 46% of the total variation of the crop yield was explained by the first two principal components. A crossover between genotypes and locations was observed for the crop yield. Overall, four mega-environments were determined:

- Mega-environment 1: Godin, Goundrin, Nedogo, and Nidaga.
- Mega-environment 2: Pella, Pelbilin, Loumbila, Kolgondiesse, Menega, and Gampela.
- Mega-environment 3: Koubri.
- Mega-environment 4: without location. Only one genotype was recorded for this mega-environment (BISP2).

On-station, Gampela, most of the landraces showed high yields, with yields higher than 1,000 kg/ha for more than 73% of genotypes, namely BISP2, BISR1, BISB1, BIKZ1, BISS1, SLEO1, BISM1, BISK1, KNED1, and BISP3. In Nedogo and Koubri, crop yield was low except for SLEO1 with 2,107.78 kg/ha and KLAY24 with 1233.0915 kg/ha, respectively. In Goundrin, almost all the genotypes performed well, with a yield higher than 1,000 kg/ha. The three highest yielding genotypes in Goungrin were BISP3, BISR1, and SLEO1, while in Nidaga, the higher yields were observed for BISP3, KNED1, BISR1, and SLEO1. BIKZ1 was identified as the best-performing genotype in Pelbilin, Pella, and Kolguindiesse. The second best-yielding genotype in Kolguindiesse was BISM1. In Pella, in addition to genotype BIKZ1, all the other genotypes yielded very well, more than 1,069 kg/ha.

The genotypes BISP1, BISR1, BISP3, SLEO1, BISR2, BPLE1, and KNED1 were the most productive in terms of seed yield in Godin, while those recorded with the highest yield in Loumbila were BPLE1, BISR1, and KNED1. In Menega, the best performing genotypes, namely KNED3, BIKZ1, KNED1, BISP2, BISS1, BISR1, BISK1, SLEO1, recorded more than 1,000 kg/ha.

4 Discussion

By combining several approaches–including on-station and on-farm evaluation of agronomic performance, participatory selection in farming conditions, and yield stability analysis across environments—this study provides more accurate results and firmer recommendations to growers and agronomists. The applied multilocation trials are important in plant breeding and agronomy (Herawati et al., 2021). A combination of agronomy and plant breeding can improve plant characteristics and stability testing before releasing new varieties (Herawati et al., 2021).

By involving growers from different production areas in all the steps of the study, this study made it possible to take into account

TABLE 9 Classification of adaptability and stability according to Annicchiarico's method, considering mean and Wi for Bambara groundnut seed yield.

Landraces	Favorable locations			Unfavorable locations			Overall		
	Yield	Wi	Rank	Yield	Wi	Rank	Yield	Wi	Rank
BIKZ1	1844	112	1	907	86	6	1,190	93.3	2
BISB1	1,493	82.5	12	801	80.6	9	1,039	83.5	9
BISK1	1,234	76	13	752	79.7	10	920	79.9	11
BISM1	1,459	95.7	4	838	84.6	7	1,037	88.3	4
BISP1	1,222	71.6	15	807	76.2	12	937	75.6	14
BISP2	1,435	83.8	10	758	70.6	13	1,011	77.1	12
BISP3	1,621	83	11	889	77.5	11	1,101	80.2	10
BISR1	1,471	86.4	8	973	92	3	1,148	92.2	3
BISR2	1,185	75.4	14	739	68.8	15	883	71	15
BISS1	1,629	105	2	797	80.9	8	1,059	87.3	6
BPLE1	1,541	89	7	958	87	4	1,116	85.6	8
KLAY24	1,450	95.2	5	782	69.9	14	982	75.9	13
KNED1	1,544	95.1	6	967	97	1	1,134	95.4	1
KNED3	1,342	85.8	9	938	93.6	2	1,049	88	5
SLEO1	1,563	101	3	1,082	86.1	5	1,221	86.5	7

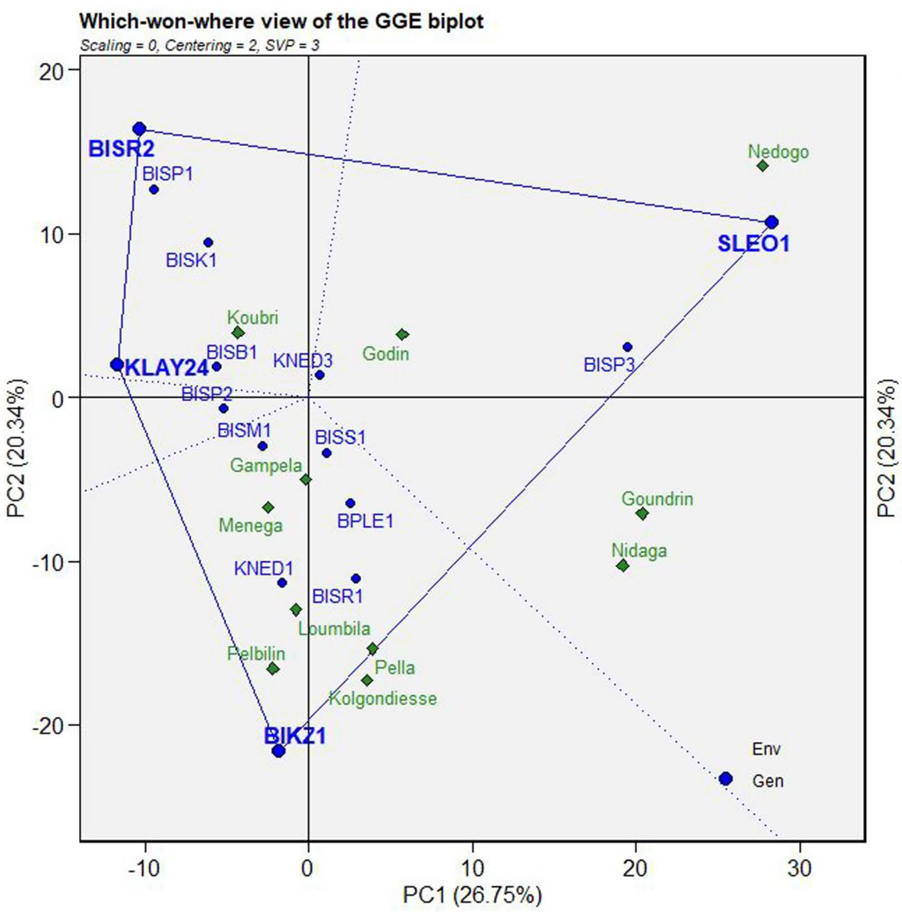

FIGURE 4
"Which won where" biplot showing mega-environments and the distribution of the genotypes for crop yield.

the socioecological factors across the BGN production areas and individual expertise in varietal selection that could influence the adoption of new varieties. The study revealed that BGN growers involved in the participatory evaluation and selection in Goundrin, Pella, and Pelbilin seem to be more aware of the suitable genotypes for their production areas than those involved in the other localities. In fact, there is a differing expertise in varietal selection according to the local context (Kiebre et al., 2025; Zerbo et al., 2026). This could probably be explained by the more rural nature of these villages, located far from urban centers. This result could reveal how environmental pressures and local agricultural practices differently shape the expertise and adaptive capacities of farmers.

The significant difference across gender and the predominance of women among the participants, up to 64.5%, highlights once more the key role of women in the management of NUS in general and Bambara groundnut in particular (Naino Jika et al., 2023; El Bilali et al., 2024a; Kiebre et al., 2025). Women in rural communities are often the primary custodians of knowledge related to the management of local plants used in the agri-food system. This is in accordance with a previous study that reported that BGN contributes to the empowerment of women who are primarily responsible for cultivating, selling, and processing (El Bilali et al., 2024a). It is worth noting that all age groups from several localities were involved in the study, thus enabling intergenerational and intercultural dialog, especially during the focus group discussions. As for results from the focus group discussions, it emerged that Pella, Pelbilin, Goundrin, Kolgondiesse, and Songpelce would be locations of high production of Bambara groundnut in Boulkiemde, Bazega, and Oubritenga provinces. In addition, it is reported that the preferences in certain genotypes (e.g., BISK1) were guided by sociocultural practices associated with them; thus confirming results from other authors (Temegne et al., 2018). If the sociocultural anchoring of Bambara groundnut constitutes a lever for its promotion in Burkina Faso, it, unfortunately, contrasts with negative taboos, beliefs, and prohibitions reported during the focus group discussions. A supposed variability of the nutritional value according to landraces was noted and must be addressed in order to give confident information to breeders, agronomists, and final users of Bambara groundnut.

The identification of crop yield by growers as the most important criterion is not surprising. Indeed, NUS yield, especially legume crop yield, is reported to be low in Africa (FAO, 2017; El Bilali et al., 2024a). Low yield is sometimes claimed to be one of the major constraints in BGN production (Mahmudul et al., 2021; Tyoakoso et al., 2019) and the cause of the decline in certain NUS legume production in West Africa. Interestingly, the Bambara groundnut yield observed in most of the locations in this study is higher than those previously reported for the BGN top-producers, namely Niger and Burkina Faso (FAO, 2017). This could be explained by the fact that the genotypes included in this study were previously characterized and identified as the best-producing ones.

The identification of plant cycle (short cycle), drought-resistance, and short cooking duration as relevant criteria of interest for growers is easy to understand. There are relevant choices in line with climate change resilience. Some authors underscored the climate-resilience potential of Bambara groundnut (El Bilali et al., 2024a). In fact, due to climate change, resulting in the shortening of rainy seasons, the current dynamic is toward the adoption of early varieties and those that require less gas or firewood for cooking. These choices indicate, interestingly, that farmers are increasingly aware of climate change and are trying to find adaptation mechanisms.

The market value leading the production of crops is not a new principle. BGN is increasingly an attractive NUS, especially the genotype with cream-colored seeds (Kiebre et al., 2025), because of the existence of a niche market, justifying the second rank of market value identified as a criterion of interest.

Coming to cultural value, BGN is often associated with cultural practices in Africa, explaining the identification by farmers of cultural value as of interest (Temegne et al., 2018). The significant differences in preferences and criteria of interest across locations could be explained by local sociocultural and economic specificities.

Putting the genotypes in various environments, including on-station and on-farm trials is a relevant approach for yield stability analysis. This approach offers the genotypes the possibility to express fully their genetic potential in varying conditions and makes it possible to evaluate their environmental sensitivity and adaptability. Indeed, if agriculture is to contribute significantly to climate change mitigation, the technologies to be disseminated must be assessed taking into account contextual specificities, and their contribution to climate mitigation must be quantified very precisely (Ellis and Paustian, 2024).

Overall, the choice of BISB1, BISP1, BISP2, SLEO1, and KLAY24 as the most preferred genotypes could be due to their cream-colored seeds, identified by farmers as a criterion of interest for traders (Kiebre et al., 2025). In fact, cream-colored seeds are the most demanded in local markets in Burkina Faso. According to locations, the preference in SLEO1 in Nedogo, KLAY24 in Koubri, BISP3, BISR1, and SLEO1 in Goundrin, SLEO1 in Nidaga, BIKZ1 in Menega, BIKZ1 in Pelbilin, and BISM1 in Kolgondiesse was guided by their good agronomic performance and stability as reported in this study. This is not surprising because crop yield was reported to be the most important trait for farmers across the locations. Also some authors reported this trait as of interest for farmers (Rea et al., 2017; Magaisa et al., 2022; Moussa et al., 2023).

The adaptability and stability evaluated for the crop yield made it possible to identify the most adaptable and stable landraces and the favorable and unfavorable environments. The stability of genotypes varied fairly according to GGE and Annicchiarico methods. However, landraces KNED1 and BISR1 are very stable regardless of the method used. The comparison of genotypes' performances in the on-station and in the growers' fields is a particularly interesting approach. It made it possible to better understand the reaction of genotypes to variable environmental conditions, leading to a more judicious analysis and interpretation of farmers' preferences in varieties.

As expected, Gampela, the research station, was identified as one of the favorable environments for cultivating BGN. This is not surprising because in a research station where environmental factors are in control, genotypes were able to express better their genetic potential. The other on-farm favorable environments, namely Goundrin, Pella, and Pelbilin, correspond to villages reported during the focus group discussions to be sites of high production of Bambara groundnut in the related provinces. Most of the unfavorable locations were villages close to Ouagadougou, the capital city; therefore, obviously influenced by urbanization and industrialization. The differences observed between favorable and unfavorable locations could be explained by the pedological and climatic variability. They could also be explained by a thorough knowledge of good agricultural practices by producers in favorable villages, which enabled them to identify on-field study sites better corresponding to Bambara groundnut growth. Indeed, participatory varietal selection is a rapid and cost-effective way to identify high-yielding and suitable varieties (Moussa et al., 2023).

The significant differences observed across locations and the significant interactions between genotypes and environments underline the differential reaction of genotypes following environmental variability (Kiebre et al., 2019). This suggests that the choice of varieties to be disseminated throughout Bambara groundnut production areas may take into account their adaptability potential. For future recommendations, genotypes BIKZ1, BISP3, BISR1, and SLEO1 are the most promising in the favorable locations because of their overall stability and adaptability for yield and the growers' preferences in them. For the same reasons, genotypes SLEO1, KLAY24, BIKZ1, and BISM1 are more suitable in unfavorable locations, while SLEO1 and BIKZ1 are the most suitable for overall environments. Some of these genotypes, for example SLEO1, have been identified in previous studies as well suited to the needs of several user groups, including processors, farmers, breeders, etc. (Kiebre et al., 2025). Genotypes falling under a mega-environment without locality is common (Kachapur et al., 2023). The existence of the landrace BISP2 in the mega-environment without locality could be explained by his performances that was very different from the other genotypes; probably due to the germination issue observed with this genotype in some villages. The germination issue and the periods of drought observed in some localities could influence the performance of certain landraces.

Related to the plant cycle, in general, it was longer in favorable environments than in unfavorable locations. This could be explained by the good performance observed in the favorable environments because a long maturing time leads to good seed-filling. Large seed size reported in this study as a criterion of interest could counterbalance the climate-resilience ability of Bambara groundnut. Cooking large seeds could require more time, more gas or firewood; counterbalancing with its ability to improve soil fertility through nitrogen fixation, considered a climate-resilience trait.

5 Conclusion

The crop yield is the most important criterion for BGN growers for varietal adoption and cultivation in Burkina Faso.

This study, conducted on-station and on growers' fields, made it possible to evaluate and select high-performing, stable, and adaptable Bambara groundnut genotypes according to farmers' preferences in four regions in Burkina Faso. The genotypes' performance, adaptability, and stability, and the participants' preferences in BGN varied significantly across locations and experimental site, indicating that combining on-farm and on-station participatory evaluations and selections can be an innovative approach for firmer recommendations.

The identification of favorable locations for BGN cultivation, corresponding to more rural areas, indicates how environmental pressures and local agricultural practices differently shape the expertise and adaptive capacities of farmers.

The landraces SLEO1 and BIKZ1 are the most promising genotypes that combine high agronomic performance with strong farmer preference for potential recommendation and dissemination in Burkina Faso.

This study did not take into account all the pedological, climatic, and socio-cultural variability of Burkina Faso. A thorough participatory evaluation and selection must be done on a large scale in Burkina Faso for firmer conclusions.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

ZK: Methodology, Conceptualization, Data curation, Writing – review & editing, Validation, Resources, Formal analysis, Writing – original draft, Visualization, Software. MK: Writing – review & editing, Conceptualization, Writing – original draft, Methodology. RN: Writing – review & editing, Writing – original draft, Methodology, Validation, Supervision, Conceptualization. FT: Writing – review & editing, Writing – original draft. KT: Formal analysis, Data curation, Investigation, Methodology, Writing – review & editing, Conceptualization, Writing – original draft, Software. PB: Writing – review & editing, Investigation, Data curation, Writing – original draft. V-MR: Writing – review & editing, Writing – original draft. HB: Writing – original draft, Funding acquisition, Project administration, Validation, Writing – review & editing. FA: Funding acquisition, Writing – original draft, Supervision, Project administration, Writing – review & editing. JN: Writing – review & editing, Writing – original draft, Project administration, Funding acquisition.

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Conflict of interest

FA was employed by Italian Agency for Development Cooperation (AICS).

The remaining author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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