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Participatory Selection of Bambara Groundnut Landraces in Burkina Faso: Effects of Gender and Participant Diversity

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Abstract

The centre of origin of Bambara groundnut (BGN; *Vigna subterranea* L.) is Western Sub-Saharan Africa. Due to its high nutritional value and tolerance to biotic and abiotic stresses, this neglected and underutilised species has recently gained significant attention. However, BGN production faces several challenges, including a lack of quality varieties. This study describes a selected *core* collection based on phenotypic traits, investigates relevant selection criteria and identifies a set of landraces according to participants' preferences. A *core* collection of landraces was generated, described, and then subjected to participatory varietal selection. Through individual semi-structured interviews, key selection criteria were identified. Focus group discussions were organised to explore group criteria and to support and validate information from personal interviews. The varietal selection involved choosing three landraces per participant. The results highlighted that seed colour, seed size, cultural value, market value, seed taste, storage, and seed cooking duration were the main selection criteria; however, specific trait preferences varied by gender and participants. Two of 14 selected BGN landraces were considered by the panel of evaluators to be most suitable for recommendation to growers and breeders. They can be disseminated in BGN production regions and used for plant breeding.

Keywords: breeding; food security; NUS; smart agriculture; SUSTLIVES

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1. Introduction

Bambara groundnut [BGN, *Vigna subterranea* (L.) Verdc], also known as Bambara bean or Bambara nut, belongs to the family of *Fabaceae* [1–4]. It is one of the oldest legume crops that originated in Africa. BGN is a neglected and underutilised species (NUS), mostly produced by females for subsistence purposes [5], and regarded negatively as a poor's crop, women's crop, elders' crop, or widows' crop. It is mainly cultivated on a small scale in pure culture [6] or in association with other crops [7]. The total global

BGN production was estimated at 246,511.3 tonnes in 2022 [8]. West Africa accounts for more than half (167,031.28 tonnes) of the global BGN production [8]. BGN production faces several constraints, such as a lack of resources, including access to quality seeds and cultivars, adapted agronomic techniques, capital and extension services, land, and storage facilities [9]. BGN marketing is limited to local markets, and there are no data on cross-border trade [10].

Recently, Bambara groundnut gained great attention due to its high nutritional value, tolerance to drought and poor soils, and resistance to diseases and pests [11,12]. As a legume, BGN can contribute to improving soil physicochemical properties by fixing atmospheric nitrogen through the nodulation process [12]. The BGN grain is a good source of complete and balanced food. It contains up to 26–27% of protein, 55–56% of carbohydrates, 5–7% of fat, fibre, calcium, iron, and potassium [13]. It is consumed in many ways and at different stages of maturity [14]. BGN can be an alternative solution to animal protein deficiency in rural areas [5]. BGN does not require major agricultural inputs and can be cultivated in rainfall-limited conditions. Therefore, BGN is a climate-smart crop for resilience under climate change. Due to its food and nutritional potentials, BGN has been recently regarded as a crop for the new millennium [6] and a possible weapon in fighting against malnutrition in arid and sub-arid areas [15].

Niger leads the BGN top producers (61,753.42 tonnes in 2022), followed by Burkina Faso (57,208.53 tonnes in 2022). The crop yield is very low due to a lack of quality seeds. Despite the low yields, BGN is a legume of interest to communities due to its high agri-food, nutritional, and socio-cultural value, especially in low-income rural areas where access to animal proteins is limited [5]. The yield of BGN is generally higher in Burkina Faso compared to the other top producers. For example, in 2022, the crop yield was estimated at 1052.2 kg/ha in Burkina Faso, while only 599.8 kg/ha was reported in Niger [8]. BGN is the third most important legume crop after cowpea (*Vigna unguiculata* L.) and groundnut (*Arachis hypogaea* L.) in Burkina Faso.

Despite varietal improvement efforts, the lack of varieties adapted to the needs of value chain participants remains a major challenge to BGN production. Indeed, because of the lack of available funds, BGN varietal improvement was neglected by researchers [16]. Plant breeding has been mostly unsuccessful with BGN because of the lack of reliable scientific knowledge on its floral biology [17]. Therefore, most of the cultivated Bambara groundnut genotypes are local landraces [16]. A large number of BGN landraces were observed throughout Africa, especially in West Africa. To date, the genetic diversity of the crop remains largely unexploited [16].

Due to the unavailability of improved varieties, farmers cultivate the existing local landraces. Traditional landraces have the disadvantage of having low yields and undesirable varietal characteristics, and do not always meet the needs of value chain participants. However, they have the advantage of being phenotypically and genotypically more diverse and adapted to various local farming conditions than improved varieties. Landraces are “varieties with a high capacity to tolerate biotic and abiotic stress, resulting in high yield stability and an intermediate yield level under a low input agricultural system” [18]. Therefore, they constitute a strategic source of genes of interest and offer the possibility of selecting varieties adapted to local environmental conditions and to the needs of value chain participants.

Understanding the relevant varietal selection criteria and identifying a set of landraces according to the BGN value chain participants’ preferences would be a significant step towards varietal improvement and can contribute to the development of the BGN sector in Burkina Faso, Niger, and other sub-Saharan countries. This requires a participatory approach in defining selection criteria and selecting landraces according to the needs of BGN value chain participants. Participatory varietal selection may increase breeding efficiency and the rate of adoption of new cultivars by growers and, thereby, make it possible to overcome the constraints faced by the value chain participants [19]. Indeed, differing expertise in varietal selection was often observed across the diversity of participants. For example, some women are known for their ability to finely distinguish varieties suited to particular agricultural contexts [20].

Through a participatory approach, the present study aims at (i) describing the agro-morphological characteristics of a selected *core* collection of BGN, (ii) identifying relevant selection criteria according to BGN value chain participants' preferences, and (iii) identifying a set of landraces according to BGN value chain participants' preferences in Burkina Faso.

2. Materials and Methods

2.1. Identification of Landraces to Be Used for Participatory Selection

2.1.1. Plant Materials and Experimental Site

BGN belongs to the family of *Fabaceae*. The scientific names include *Arachis africana* Burm. f., *Glycine subterranea* L., *Voandzeia subterranea* (L.) Thouars, and *Voandzeia subterranea* (L.) DC. [5]. BGN is a geocarpic plant (Figure 1) that matures its pods in the ground, similar to peanuts [5].

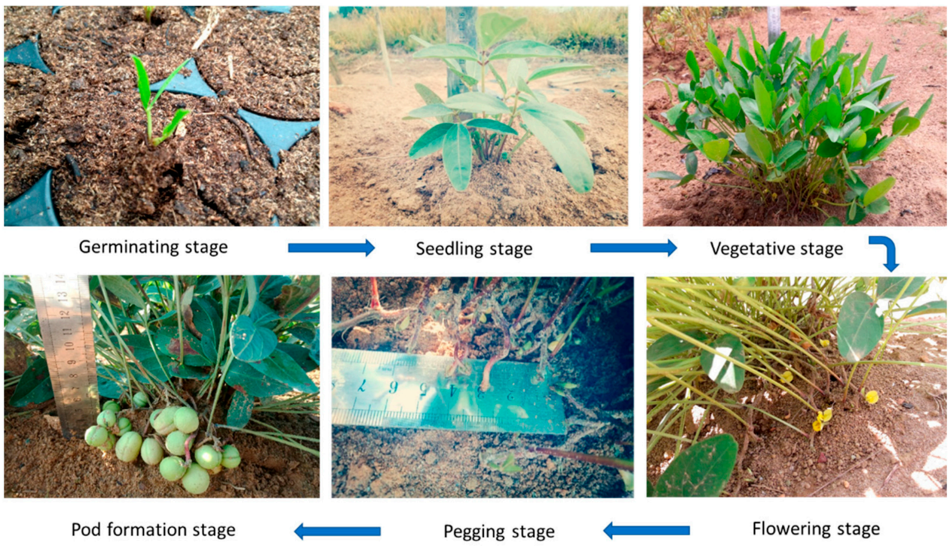


Figure 1. Growth and development stages of Bambara groundnut [21].

Two hundred (200) landraces from Burkina Faso, Benin, and Niger were characterised to identify a set of landraces to be used for the participatory selection. An experiment was carried out at the SUSTLIVES project experiment station in Gampèla (12.41187 N and 1.352925 W) from July to December 2023. The soil exhibited a predominantly silty–sandy texture, a depth of 50–60 cm, and a slightly acidic pH of 5.70. During the experiment period, rainfall of 583.5 mm was recorded. August was the wettest month (253.5 mm), followed by July (158 mm), September (130 mm), and October (42 mm). The maximal temperatures varied from 33.3 to 34.6 °C, and the minimal ones from 12.5 to 23.3 °C. Before planting, the soil was ploughed and organic manure at five tonnes per hectare was applied. The site was lying fallow for many years before the current experiment was conducted.

2.1.2. Experimental Design

The study was carried out using an Alpha lattice design with three replications [22]. The distance between successive replications was one meter. In each replication, each landrace was represented by a row of five meters on which 11 hills were sown. The distances between plants and between rows were 30 cm and 50 cm, respectively. Pests and diseases were controlled with methods commonly used by growers of BGN in Burkina Faso, including biopesticides and hand weeding.

2.1.3. Phenotypic Traits Studied

Fourteen variables, including six qualitative and eight quantitative traits, were analysed. Measurements and observations were conducted according to the instructions of the BGN descriptor [23].

- Qualitative traits analysed

The qualitative traits included seed shape (round, oval, lanceolate, elliptic, other), seed size (large: seed length ≥ 11.5 mm, seed width ≥ 9.5 mm; medium: 11.5 mm ≥ seed length ≥ 10.7 mm, 9.5 mm ≥ seed width ≥ 9 mm and small: seed length ≤ 10.7 mm, seed width ≤ 9 mm), seed colour, absence/presence of eye around the seed hilum, eye colour, and eye shape. Regarding the qualitative traits, the observations were carried out on all the plants in the entire row.

- Quantitative traits analysed

The quantitative traits comprised seed length, seed width, number of pods per plant, crop yield, plant height, plant spread, number of days to 50% flowering, and number of days to 95% maturity. The last two quantitative traits were measured on the entire row, while the other quantitative traits were measured on five plants on the row. Seed size was determined using a calliper. The number of days to 50% flowering was determined by recording the number of days following sowing until 50% of the plants in a row had at least one open flower. The number of days to 95% maturity was determined by counting the number of days following sowing until the pods of 95% of the plants in a row reached maturity.

2.2. Participatory Varietal Selection

2.2.1. Identification of Relevant Selection Criteria

Thirty participants of the BGN value chain (farmers, processors, consumers, agriculture extension agents, breeders) were involved in the study. They were key informants, selected from development non-government organisations (NGOs), farmers' associations, processor enterprises, agricultural extension services, and universities and research centres. First, through individual semi-structured interviews, key selection criteria were identified and scores were assigned to them according to their importance or participants' priorities. A semi-structured individual questionnaire was employed to record data on various aspects, including gender, age, occupation, relevant selection criteria, etc. Then, focus group discussions (FGDs) were organised to explore group criteria and to support and validate the information recorded from personal interviews.

2.2.2. Selection of Landraces of Interest

The selection of landraces was carried out using seeds from the selected *core* BGN collection generated above. The individual varietal selection involved choosing three landraces per participant, to which scores were assigned according to the order of participants' preferences. The individual key selection criteria involved choosing three criteria per participant to which scores were assigned according to the order of participants' preferences:

- for the top choice (the most preferred landrace and the most important criterion), the score attributed was 7;
- for the second choice (the second most preferred landrace and the second most important criterion), the score attributed was 5;

- for the third choice (the third most preferred landrace and the third most important criterion), the score attributed was 3.

2.3. Data Analysis

The recorded agro-morphological traits were used to characterise the landraces using 18th GenStat 1.0 software [24]. Descriptive statistics were calculated for all the variables, including means, coefficients of variation and percentages. Analysis of variance was performed at $p < 0.05$ and $p < 0.01$ on quantitative agro-morphological data to investigate the significance of differences between landraces using the Newman–Keuls test. Pearson's correlation matrix was carried out to estimate the relationship between agro-morphological quantitative traits, with the significance level set at $p < 0.05$.

Then, based on the genetic diversity of landraces, a *core* collection was generated and subjected to participatory varietal selection and criteria of interest identification. The socio-demographic profile of the BGN value chain participants involved in the study was characterised using the data recorded on socio-demographics. The data recorded were related to the number of participants involved, participants' age and gender, participants' ethnical groups, and participants' domain of expertise. Descriptive statistics, including frequencies, means and percentages, were calculated using these data. The relevant selection criteria and the selected landraces were listed across *gender* and the different groups of *value chain participants* (farmers, processors, consumers, agriculture extension agents, and breeders) and their scores were calculated by adding up the individual scores attributed by each participant. Graphs were generated from these data with Excel® (Microsoft; *version* 2021). Then, in order to access the differences in participants' preferences, the scores were also used to perform a chi-square analysis across *gender* and the different groups of *value chain participants* using R software (version 4.2.2).

3. Results

3.1. Characteristics of the Selected Core Collection Used for the Participatory Selection

Based on agro-morphological diversity, a *core* collection of landraces was generated from the larger collection consisting of 200 cultivars. The selected *core* collection included 20 landraces from Burkina Faso (17 landraces), Benin (2 landraces), and Niger (1 landrace). In Burkina Faso, the 17 landraces were collected from 12 villages located in nine provinces (Table 1). The collection sites in Benin and Niger were not identified.

Table 1. Landraces selected to be included in the *core* BGN collection used for experimentation in this study.

N	Landraces	Countries	Regions	Provinces	Villages
1	BPbi3		Centre-Ouest	Boulkiemdé	Pelbilin
2	SDyr8		Centre-Ouest	Sanguié	Dydir
3	SLeo1		Centre-Ouest	Sissili	Léo
4	GMog6		Centre-Est	Ganzourgou	Mogtédo
5	KKou8		Centre-Est	Kouritenga	Koupèla
6	ZMag2		Centre-Sud	Zoundwéogo	Manga
7	ZMag3		Centre-Sud	Zoundwéogo	Manga
8	KNed2	Burkina Faso	Centre	Kadiogo	Nedogo
9	KLay2		Plateau Central	Kourwéogo	Laye
10	KLay3		Plateau Central	Kourwéogo	Laye
11	KLay5		Plateau Central	Kourwéogo	Laye
12	KLay67		Plateau Central	Kourwéogo	Laye

Table 1. *Cont.*

N	Landraces	Countries	Regions	Provinces	Villages
13	KTog3		Plateau Central	Kourwéogo	Toeghin
14	KSag11		Plateau Central	Kourwéogo	Sagla
15	ODap2		Plateau Central	Oubritenga	Dapélogo
16	ODap3		Plateau Central	Oubritenga	Dapélogo
17	OKog2		Plateau Central	Oubritenga	Kolgondiéssé
18	BENV3	Benin	-	-	-
19	BENV7		-	-	-
20	NIGV9	Niger	-	-	-

3.2. Description of the Selected Core Collection Using Qualitative Traits

The *core* collection represents the maximum phenotypic diversity of 200 varieties characterised. The six qualitative traits recorded on the *core* collection showed variation for all traits (Table 2). A great diversity was observed for all the qualitative traits. Out of all the traits, seed colour was the most variable, while the seed shape was the least variable. Several modalities were observed for seed colour and eye colour, two modalities for seed shape, and three modalities for seed size.

Table 2. Seeds characteristics of the landraces selected to be included in the *core* BGN collection.

Landrace Code	Seed Shape	Seed Size	Seed Colour	+/− and Eye Colour	Eye Shape
BPbi3	Oval	Large	Grey spots on cream background	Grey eye	Butterfly
SDyr8	Oval	Small	Cream on red background	Grey eye	Butterfly
SLeo1	Oval	Large	Cream	Grey eye	Triangle
GMog6	Oval	Medium	Black on cream background	Grey eye	Butterfly
KKou8	Oval	Small	Light-red spots on cream background	Grey eye	Butterfly
ZMag2	Oval	Small	Light-brown tripes on dark-red background	Grey eye	Butterfly
ZMag3	Oval	Small	Dark-grey on cream background	Grey eye	Butterfly
KNed2	Oval	Small	Dark-violette marbling on cream background	Grey eye	Butterfly
KLay2	Oval	Large	Cream on black background	Brown eye	Butterfly
KLay3	Oval	Small	Black spots on cream background	Black eye	Butterfly
KLay5	Oval	Small	Black	No eye	-
KLay67	Oval	Large	Cream	Grey eye	Butterfly
KTog3	Round	Small	Cream	No eye	-
KSag11	Oval	Medium	Black	No eye	-
ODap2	Oval	Large	Dark-red	No eye	-
ODap3	Oval	Medium	Cream	No eye	-
OKog2	Oval	Large	Violette spots on cream background	Black eye	Butterfly
BENV3	Oval	Medium	Dark-brown spots on cream background	Dark-brown eye	Butterfly
BENV7	Oval	Large	Cream	Black eye	Butterfly
NIGV9	Round	Small	Red or light-brown	No eye	-

+/− Presence/Absence.

The majority of the landraces produced oval seeds (90%), while only 10% of them produced round seeds. Referring to seed colour, most of the landraces (60%) exhibited composite seed colour (Figure 2). Forty per cent (40%) of them showed uniform seed colour, such as cream (20%), black (10%), and red (10% of light or dark-red).

Figure 2. BGN seed and seed coat features among landraces selected to be included in the *core* BGN collection.

According to the presence or absence of an eye around the seed hilum, up to 70% of landraces produced seeds with eyes such as grey eye (45%), black eye (15%), and brown eye (10%). Only 30% of landraces produced no-eye seeds. In relation to eye shape, two types were revealed, namely triangular and butterfly-shaped. Only the landrace Sleo1 produced seeds with a hilum surrounded by triangular eyes. The other landraces showed a hilum surrounded by butterfly-shaped eyes. Related to seed size, landraces produced seeds with large size (35%), medium size (20%), and small size (45%).

3.3. Description of the Core Collection Using Quantitative Traits

The study revealed a large variation in the BGN landraces quantitative traits. The analysis of variance showed significant variation between the landraces for all the traits except plant spread (Table 3). The number of days to 50% flowering ranged from 33 to 38 days, with an average of 36 days, while the number of days to 95% maturity ranged from 90 to 101 days, with an average of 95 days. The coefficients of variation were low for the number of days to 50% flowering (4.58%) and the 95% maturity (3.68%).

Table 3. Mean values of quantitative traits and analyses of variances for landraces of the selected *core* BGN collection.

Landraces	Days to 50% Flowering	Days to 95% Maturity	Plant Height (cm)	Plant Spread (cm)	Pods Number per Plant	Yield (kg/ha)	Seed Length (mm)	Seed Width (mm)
BPbi3	36.31	93.00	24.83	36.89	22.77	1566.01	12.56	10.40
SLeo1	35.00	98.00	21.53	29.77	30.15	1230.67	12.27	10.24
KLay67	36.91	98.00	19.83	33.43	18.64	1179.34	11.18	9.82
GMog6	37.50	98.00	21.70	34.01	18.40	876.01	11.14	9.31
BENV7	36.54	97.33	24.30	29.89	11.92	682.01	12.28	9.97
KTog3	36.50	91.00	19.23	31.39	34.90	1545.34	10.32	8.77
ODap2	33.64	101.67	19.06	29.51	27.00	1321.34	11.59	9.51
ODap3	35.36	90.00	19.39	29.76	26.43	1299.34	10.78	9.09
OKog2	35.000	96.33	18.95	29.50	18.67	1246.67	11.85	10.25
KLay2	35.77	91.33	19.96	28.91	16.85	973.61	12.67	10.09
KNed2	38.64	94.33	20.53	27.99	23.18	1048.01	10.38	9.06
KLay3	36.00	90.67	18.96	29.37	23.29	1056.01	10.68	9.27
BENV3	35.83	90.00	22.09	29.27	13.08	664.01	11.01	9.44
KLay53	36.25	90.33	17.70	30.64	24.38	823.34	10.79	8.51
KSag11	36.17	101.67	17.92	27.38	25.17	1008.67	10.91	9.15
SDyr8	36.50	94.33	17.99	29.00	22.15	1020.01	10.48	8.74
ZMag3	35.00	95.67	18.12	29.65	17.92	790.67	11.10	9.27
KKou8	37.00	101.00	20.18	30.66	7.00	262.01	7.93	6.02
NIGV9	35.36	93.00	16.64	26.90	22.79	906.67	10.68	8.70
ZMag2	36.23	100.33	17.51	27.69	17.08	806.01	10.55	8.81
Min.	33.64	90	16.64	26.90	7.00	262.01	7.92	6.02
Mean	36.08	95.299	19.82	30.08	21.09	1015.29	11.06	9.22
±SE	±1.65	±3.51	±3.23	±6.58	±13.62	±9.38	±1.02	±0.80
Max.	38.64	101.67	24.83	36.89	34.90	1566.01	12.67	10.40
CV (%)	4.58	3.68	16.29	21.94	64.74	61.06	9.20	8.60
p-value	0.000	<0.001	0.000	0.059	0.001	0.000	0.000	0.000
Significance	**	**	**	ns	**	**	**	**

Min: Minimum; Max: Maximum; SE: Standard error; $p \geq 0.05$ = Not significant (ns); $p \leq 0.01$ = Significant (**); CV: Coefficient of variation.

The earliest flowering landraces were SLeo1, ODap2 and OKog2, while the latest flowering ones were KNed2, GMog6, and KKou8. In relation to maturing time, the earliest landraces were BENV3, ODap3, KLay53, KLay3, KTog3, and KLay2, while the latest maturing ones were ODap2, KSag11, KKou8, ZMag2, SLeo1, KLay67, and GMog6. It is worth noting that the landraces ODap2 and SLeo1 start flowering earlier than the other landraces but ripen later than the others due to their long cycle. The landraces ODap3, BENV3, and KLay2 start flowering and mature earlier than the other landraces due to their short cycle.

Average plant height varied from 16.64 (NIGV9) to 24.83 cm (BPbi3) with an overall average of 19.82 cm and a coefficient of variation of 16.29%. The average pod number per plant was very variable, ranging from 7 to 34 pods per plant, with an overall average of 21 pods and a larger coefficient of variation of 64.74%. In terms of average number of pods produced per plant, the landraces KTog3, SLeo1, ODap2, and ODap3 were the most productive (with 34, 30, 27, and 26 pods, respectively) while KKou8, BENV7, and BENV3 were the least productive (with 7, 11, and 13 pods, respectively).

The yield was very variable, varying from 0.26 to 1.56 tonnes per hectare. The mean yield was 1.01529 tonnes with a larger CV of 61.06%. The highest-yielding landraces were BPbi3, KTog3, ODap2, ODap3, OKog2, and SLeo1 (up to 1.23–1.56 t/ha), while the lowest yields were recorded for KKou8, BENV3, BENV7, ZMag3, and ZMag2 (0.26–0.80 t/ha). The average seed length varied from 7.92 to 12.67 mm with an overall average of 11.06 mm, while the average seed width ranged from 6.02 to 10.40 mm, with an overall average of

9.22 mm. The coefficients of variation observed for these two variables were 9.20% and 8.60%, respectively. The largest seed sizes were recorded for landraces BPbi3, SLeo1, and KLay2, while the smallest ones were observed for landraces KKou8 and KTog3.

3.4. Relationship Between Quantitative Traits

Overall, five positive correlations between traits were observed (Table 4). Positive and strong correlations were observed between plant height and plant spread (r = 0.611), pod number per plant and crop yield (r = 0.796), and seed length and seed width (r = 0.948). Two positive and moderate correlations were revealed between seed length and yield (r = 0.489) and seed width and yield (r = 0.591).

Table 4. Correlation matrix (Pearson's linear correlation) between quantitative traits among landraces of the *core* BGN collection.

Quantitative Traits	1	2	3	4	5	6	7
1. Days to 50% flowering							
2. Days to 95% maturity	−0.049						
3. Plant height (cm)	0.250	−0.033					
4. Plant spread (cm)	0.220	−0.063	0.611 *				
5. Pods number per plant	−0.237	−0.229	−0.251	−0.005			
6. Yield (kg/ha)	−0.246	−0.222	0.081	0.332	0.796 *		
7. Seed length (mm)	−0.365	−0.131	0.412	0.213	0.203	0.489 *	
8. Seed width (mm)	−0.290	−0.154	0.377	0.206	0.275	0.591 *	0.948 *

*: Significant correlation.

3.5. Participatory Varietal Selection

3.5.1. Demographic Characteristics of Participants

Participants were fairly gender-balanced (55% male and 45% female) and mostly young, with an average age of 37 years. The youngest participant was 24 years old, while the oldest was 78 years old. Seven different ethnical groups were identified. The majority of participants (44.46%) were *Moossé*, followed by *Bissa*, *Bwaba*, *Dafing*, and *Samo* (11.10%, respectively). *Fulani* (*Peuls*) and *Goin* were the least represented (5.57%, respectively). With regards to the different groups of value chain participants, breeders and consumers were the most numerous (27.77%, respectively). They were followed by producers and processors (16.67%, respectively), while agricultural extension agents were the least numerous (11.12%).

3.5.2. Key Selection Criteria

Ten selection criteria of interest—including seed colour, seed size, cultural value, market value, seed taste, seed cooking duration, easy storage, crop yield, seed appearance (smooth seed), and nutritional value—were recorded across the value chain participants (Figure 3). The most important criteria identified were seed colour, seed size, cultural value, and market value. In reference to colour, the cream-coloured seeds were more preferred (89.36% of participants) than the other seed colours (10.64% of participants). In relation to seed size, large seeds were more preferred (76.56% of participants) than medium (15.63% of participants) and small ones (7.81% of participants). All the participants preferred short cooking duration and high yield over alternative trait values.

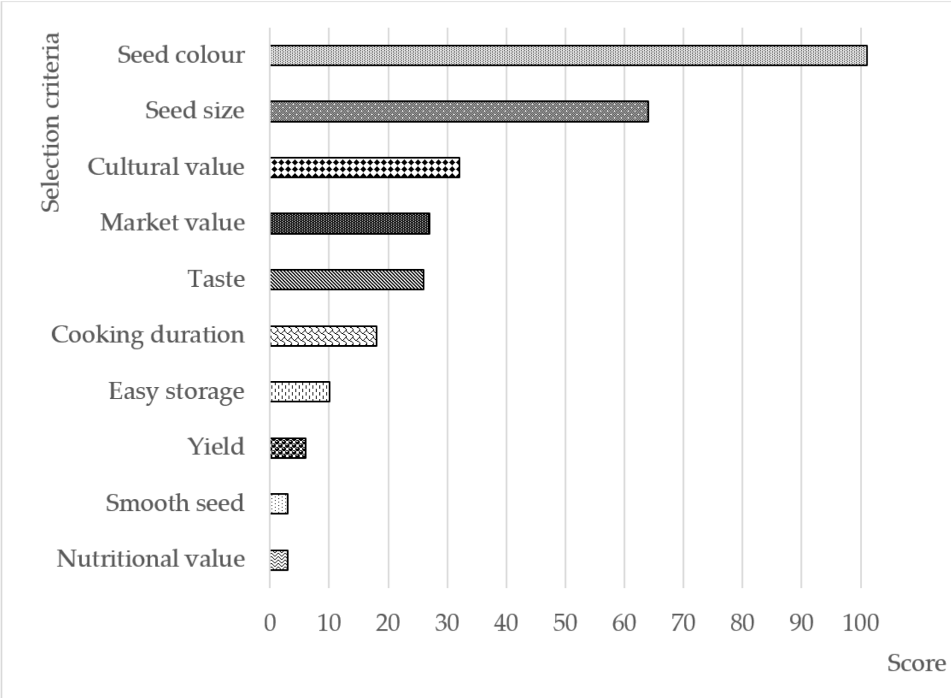


Figure 3. Key selection criteria and their importance for the BGN value chain participants.

According to *gender*, nine relevant selection criteria were recorded for men and seven criteria for women (Figure 4). Six of the criteria (seed colour, seed size, cultural value, market value, taste and cooking duration) were common to both men and women. Some differing criteria according to *gender* were exhibited. Indeed, nutritional value is a criterion of interest for women only, while seed appearance (smooth seed), crop yield and easy storage are criteria of interest for men only. For both men and women, seed colour, seed size and cultural value are the most important criteria. Referring to colour, the cream-coloured seeds were more preferred by both men (91.94% of participants) and women (87.18%) than the other colours. In reference to seed size, the large seeds were more preferred by both men and women (100% and 53.13%, respectively) than medium (31.25% for women) and small ones 15.62% for women). The chi-square test across gender indicated significant differences between women's and men's selection criteria (Table 5).

Table 5. Results of the chi-square test according to women's and men's selection criteria of interest.

Selection Criteria of Interest	Men	Women	Total	df	Chi^2	p-Value
Seed colour	62	39	101			
Seed size	32	32	64			
Cultural value	18	14	32			
Market value	10	17	27			
Taste	20	6	26	9	30.196	0.0004
Cooking duration	8	10	18			
Easy storage	10	0	10			
Yield	6	0	6			
Seed smooth	3	0	3			
Nutritional value	0	3	3			

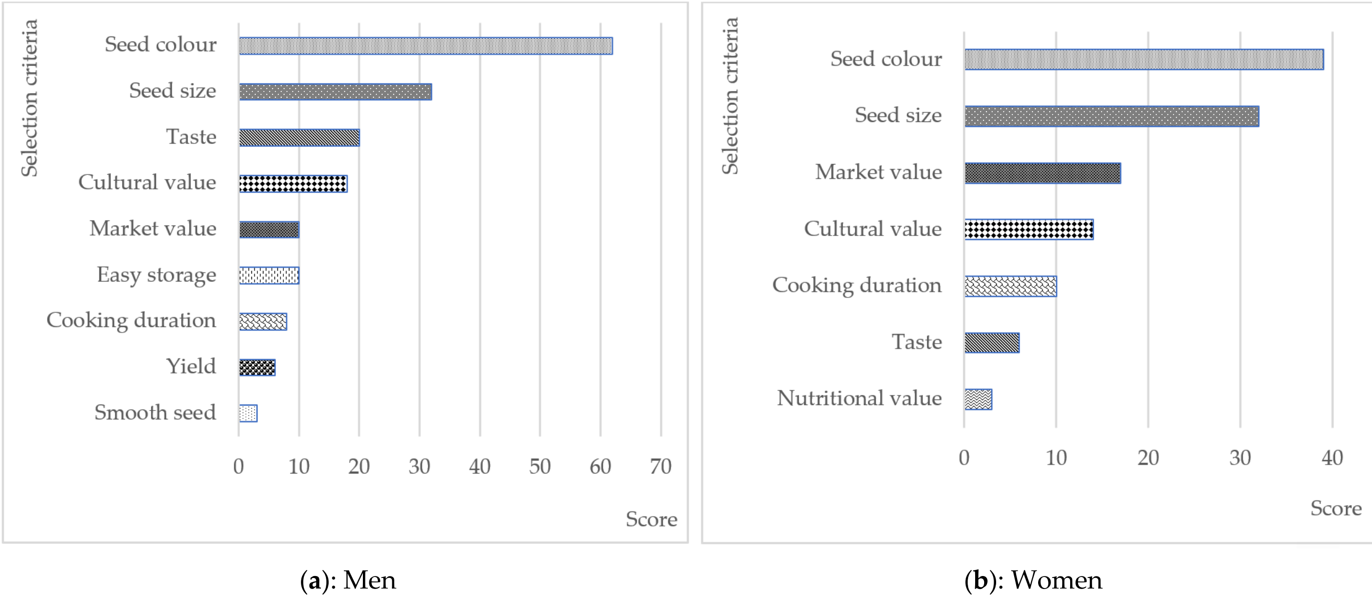


Figure 4. Key selection criteria and their importance across gender.

Regarding criteria of interest across different groups of *value chain participants*, seven criteria were listed as relevant criteria for producers and breeders, six key criteria for processors and consumers and four criteria for agricultural extension agents (Figure 5). Three criteria (seed colour, seed size, cultural value) were common to all the *value chain participants*. However, some differing criteria were also highlighted, depending on the different groups of *value chain participants*. The importance of the criteria varied according to the *participants*. For example, criteria such as seed taste, market value and seed cooking duration are of interest to breeders and consumers, while crop yield and easy storage of seeds are criteria of interest to producers only. In relation to colour, the cream-coloured seeds were preferred by all the participants. Indeed, 84.38% of consumers, 100% of producers, 100% of breeders, 66.67% of processors and 100% of agricultural extension agents preferred the cream-coloured seeds, while 15.62% of consumers and 33.33% of processors preferred the other colours. As for seed size, the large seeds were preferred by all the participants over medium and small ones. One hundred per cent (100%) of producers, processors and consumers, 58.34% of breeders and 50% of agricultural extension agents preferred large seeds. Only 20.83% of breeders preferred medium and small sizes, respectively, while 50% of agricultural extension agents preferred medium size. The chi-square test, according to value chain participants, showed significant differences between participants' selection criteria of interest (Table 6).

Table 6. Results of the chi-square test, according to the value chain participants' selection criteria.

Selection Criteria of Interest	Cons.	Prod.	Bree.	Proc.	Exte.	Total Score	Chi^2	df	p-Value
Seed colour	32	14	26	15	14	101			
Seed size	18	5	24	7	10	64			
Cultural value	7	12	3	7	3	32			
Market value	7	10	5	5	0	27			
Taste	15	0	8	0	3	26	125.41	36	8.018×10^{-12}
Cooking duration	3	5	3	7	0	18			

Table 6. *Cont.*

Selection Criteria of Interest	Cons.	Prod.	Bree.	Proc.	Exte.	Total Score	Chi^2	df	*p*-Value
Easy storage	3	7	0	0	0	10			
Yield	0	6	0	0	0	6			
Seed smooth	0	0	3	0	0	3			
Nutritional value	0	0	0	3	0	3			

Cons.: Consumers; Prod.: Producers; Bree.: Breeders; Proc.: Processors; Exte.: Agricultural extension agents.

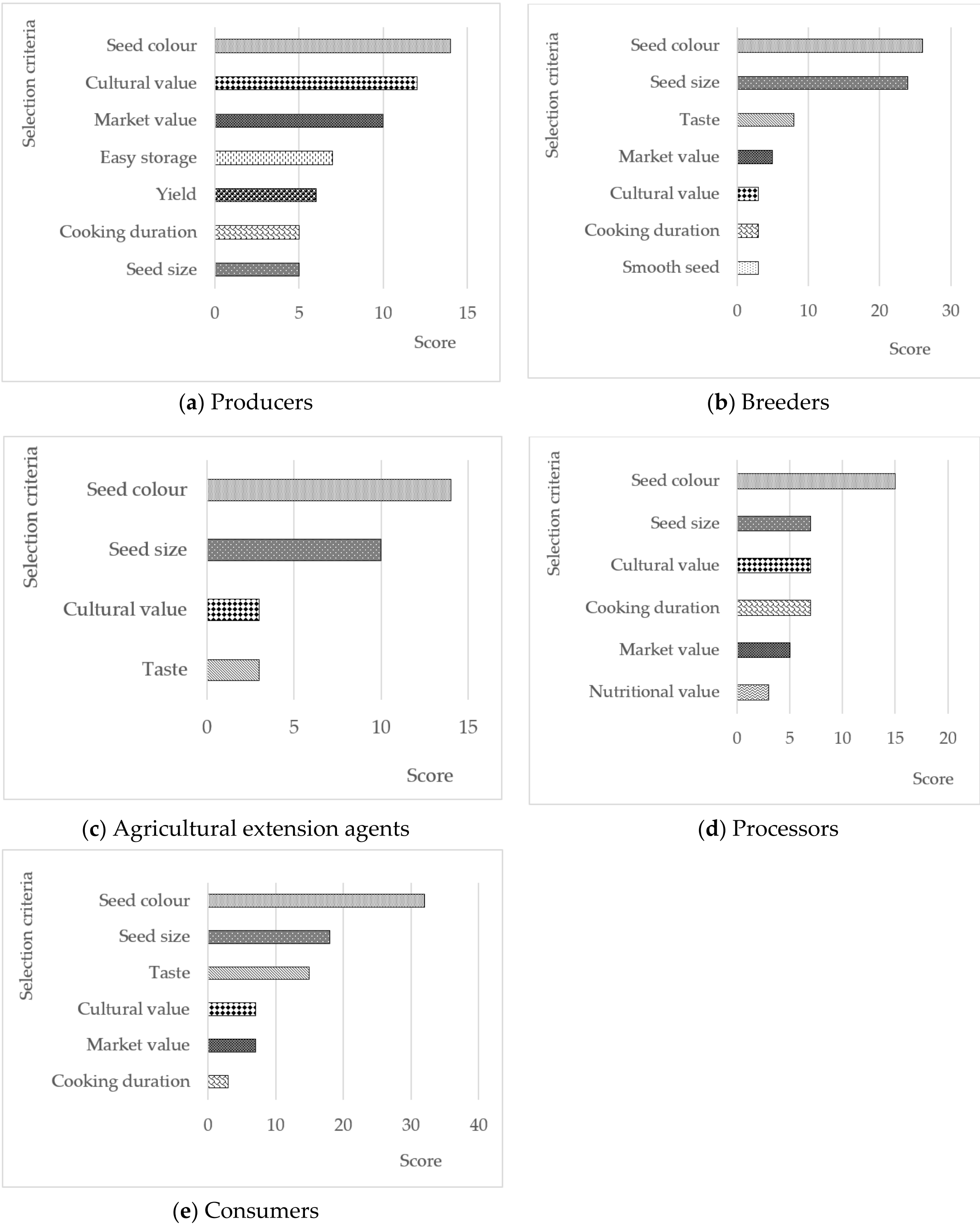


Figure 5. Key selection criteria and their importance across different groups of BGN value chain participants.

3.5.3. Landraces of Interest for the Value Chain Participants

Out of the 20 landraces used for the participatory varietal selection, the BGN *value chain participants* selected a total of 14 landraces (Figure 6), of which ODap3 (total score: 71) and SLeo1 (total score: 57) were the most preferred (Table 7). These two landraces share common features such as oval seed shape and cream-coloured seeds. However, there are some differences between them. For example, SLeo1 is characterised by a large seed size and the presence of a grey triangle-shaped eye around the hilum, while ODap3 is characterised by a small seed size without an eye around the hilum. The four most preferred landraces are shown in Figure 7.

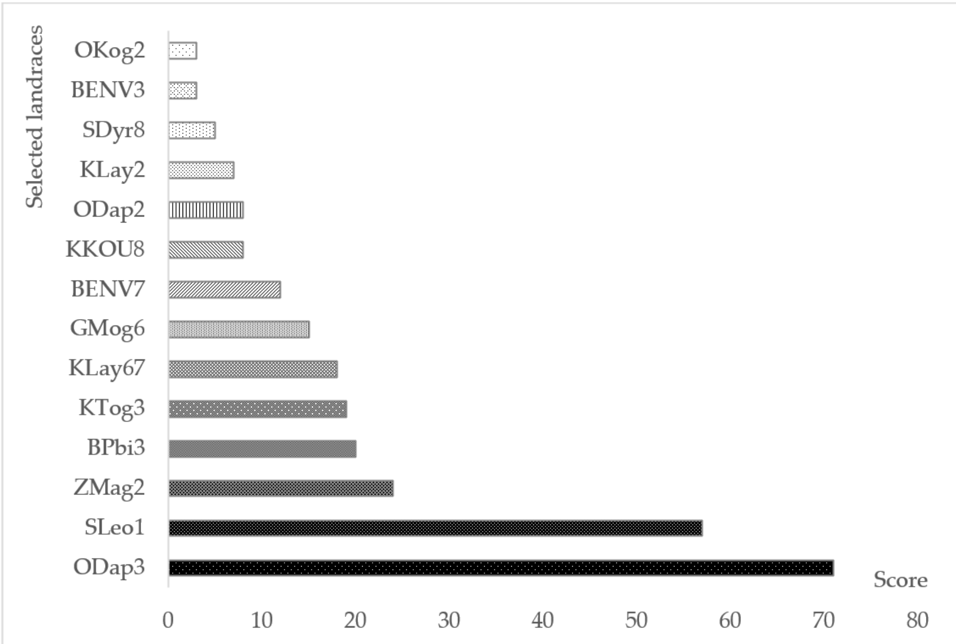


Figure 6. Selected landraces and their importance for the BGN value chain participants.

Table 7. Results of the chi-square test according to women's and men's landraces of interest.

Landraces	Women	Men	Total	df	Chi^2	p-Value
ODap3	39	32	71			
SLeo1	23	34	57			
ZMag2	19	5	24			
BPbi3	0	20	20			
KTog3	12	7	19			
KLay67	5	13	18			
GMog6	3	12	15	57.967	13	1.21×10^{-7}
BENV7	5	7	12			
KKOU8	3	5	8			
ODap2	3	5	8			
KLay2	0	7	7			
SDyr8	5	0	5			
BENV3	0	3	3			
OKog2	3	0	3			

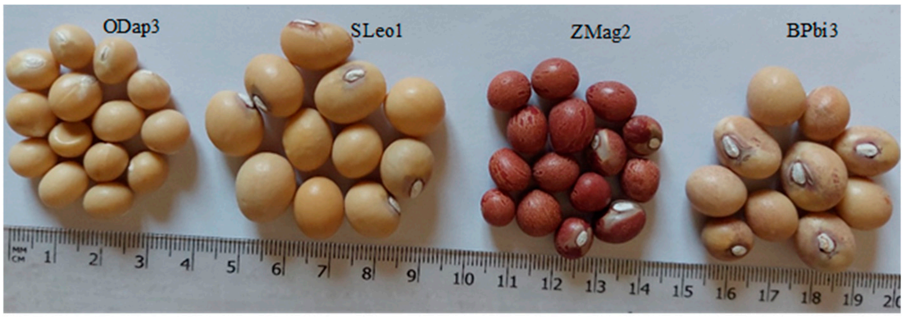
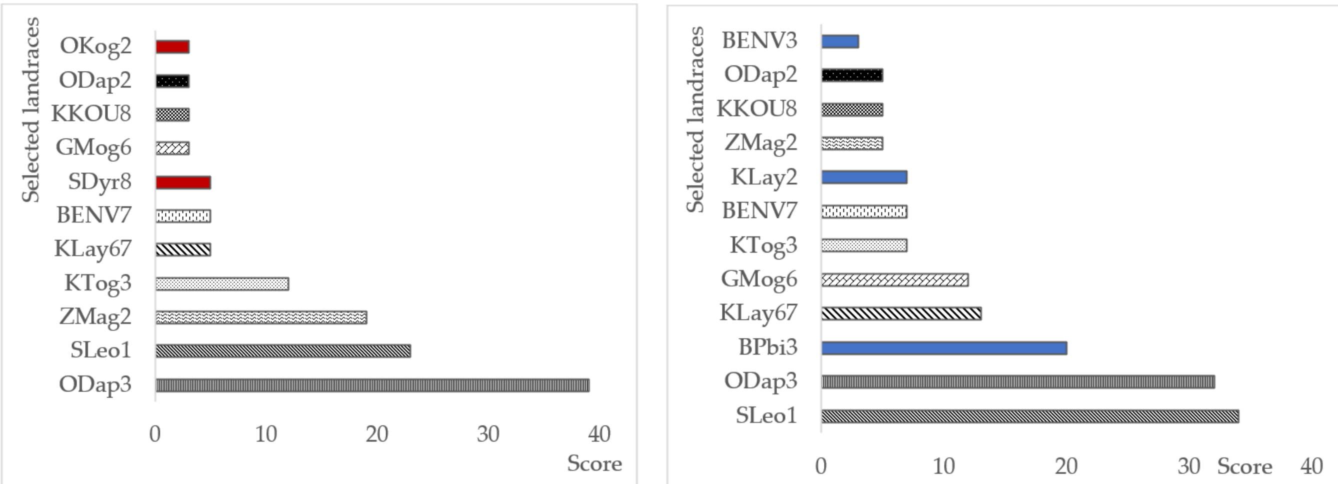


Figure 7. The four most preferred landraces according to the BGN value chain participants.

With regards to *gender* preferences among selected *core* landraces, both men and women preferred ODap3 and SLeo1 (Figure 8). However, the priority in choice varied according to men and women. Indeed, ODap3 is the women's most preferred landrace while SLeo1 is the men's most preferred landrace. In addition, there are some specific choices according to *gender*. BPbi3, KLay2, and BENV3 were selected by men only, while SDyr8 and OKog2 were selected by women only. In this respect, the chi-square test indicated significant differences in men's and women's preferences (Table 7).



(**a**) Women (**b**) Men

Figure 8. Selected landraces of interest and their importance for women and men. Landraces in red are specific to women, while those in blue are specific to men.

With regard to the different groups of value chain participants, the number of selected landraces varied notably from four to ten. Seven landraces were selected by producers and breeders, four by processors, and six by agricultural extension agents. Up to ten landraces were selected by consumers (Table 8). Concordances in the preferences of the participants for certain landraces were observed. For example, ODap3 was the most preferred landrace for all the participants except for agricultural extension agents, while SLeo1 was the second most preferred for them, except for producers.

Table 8. Scores recorded for the selected landraces and results of the chi-square test according to different groups of BGN value chain participants.

Landraces	Cons.	Prod.	Bree.	Proc.	Exte.	Total Score	Chi^2	df	*p*-Value
ODap3	22	12	25	12	0	71			
SLeo1	15	5	20	10	7	57			
ZMag2	12	0	5	0	7	24			
BPbi3	7	3	5	0	5	20			
KTog3	7	0	12	0	0	19			
KLay67	3	7	0	5	3	18			
GMog6	9	6	0	0	0	15	30.196	52	0.0004
BENV7	7	0	5	0	0	12			
KKOU8	5	0	3	0	0	8			
ODap2	0	5	0	3	0	8			
KLay2	0	7	0	0	0	7			
SDyr8	0	0	0	0	5	5			
BENV3	3	0	0	0	0	3			
OKog2	0	0	0	0	3	3			

Cons.: Consumers; Prod.: Producers; Bree.: Breeders; Proc.: Processors; Exte.: Agricultural extension agents.

Discordant preferences were also highlighted between the different groups of value chain participants. ZMag2 was selected by consumers, breeders and agricultural extension agents only, while KTog3 was preferred by consumers and breeders only. The results from the chi-square test performed across the preferences of value chain participants highlighted significant differences (Table 8).

Out of 20 landraces, six were not selected (Figure 9): KLay3, KLay5, KNed2, KSag11, NIGV9 and ZMag3. These are black, red, or cream-coloured seeds with black spots.

Figure 9. Rejected landraces.

The FGDs indicated that black and red-coloured seeds are less preferred than others due to their supposedly very long cooking time and their unattractive appearance after cooking. However, some believe that seeds of these cultivars are more nutritious than others in the selected *core* collection. According to FGDs, black-coloured seeds are said to be particularly sought after by certain consumers for specific uses.

Socio-cultural factors influencing and maintaining BGN diversity were identified by participants. For instance, landraces with light-brown tripes on dark-red background (for instance, ZMag2) are associated with several cultural practices in western Burkina Faso. However, many negative taboos and beliefs that hamper the development of the BGN value chain are also identified by participants. For example, in some regions of Burkina Faso, only widows or post-menopausal women are allowed to cultivate BGN. The landrace with cream-coloured seed (KTog3) is the most common BGN in Burkina Faso. It is the most produced, consumed, and commercialised landrace in local markets.

4. Discussion

The soil characteristics and the rainfall recorded during the experiment were in accordance with the soil and the requirements for BGN production [25]. The highly significant variation in phenotypic traits suggests that the *core* BGN collection used for the study is suitable for participatory varietal selection. This high diversity offered the BGN value chain participants the possibility of selecting landraces according to their needs. The high diversity highlighted is not surprising since the sample used is a selected *core* collection generated from 200 landraces collected in three countries in West Africa (viz., Burkina Faso, Benin, and Niger), the centre of origin of BGN. Additionally, landraces are generally more diverse than improved ones. BGN landraces are particularly known for the great variability in phenotypic traits [26].

The plant cycles are in accordance with some previous studies carried out in Niger [27] and Burkina Faso [28]. However, the landraces are earlier than those used in other studies carried out in Malaysia [29] and South Africa [30]. This suggests interestingly that the landraces used in the present study have a good potential to be more resilient to climate change, which is leading progressively to a shortening of rainy seasons in West Africa. The landraces, such as SLeo1 and Odap2, which have a long maturing time, have advantages and disadvantages. With regard to production, a long maturing time leads to good seed-filling rates, resulting in good yields. The disadvantages include the inability to complete their cycle in case of drought, generally observed at the end of rainy seasons.

Generally, the earlier landraces, like BENV3 and KLay2, have relatively low-yielding potential but are suitable for arid zones where rainy seasons are short. Interestingly, Odap3 is one of the earliest landraces and also one of the most productive ones. It is worth noting that the yields of certain landraces recorded in this study are higher than those reported in Burkina Faso, Niger, and Cameroon, the top producers of BGN in Africa [8]. This is a great opportunity for breeders to select varieties with high-yielding potential.

Out of the correlations identified, the one between pods number per plant and crop yield was, by far, the most important, suggesting that the pods number per plant is a more interesting variable than the seeds number per pod. The positive correlation between seed size and yield indicates that larger BGN seeds lead to higher crop yields.

The participatory varietal selection, involving gender-balanced participants from different age groups and different groups of BGN value chain participants, was very interesting. Indeed, this made it possible to assess the variation in preferences based on socio-professional specificities. Many authors underlined the differing expertise in participatory varietal selection [20,31]. The significant differences according to *gender* and *value chain participants'* selection criteria of interest revealed by chi-square tests support such claims.

The number of participants across the ethnic groups and the different groups of BGN value chain *participants* is fairly balanced. It is not surprising that participants from the *mossé* ethnic group were predominantly represented since the *mossé* ethnic group is the majority in the study area. The number of selection criteria varied greatly according to *gender* and the different groups of BGN *value chain participants*. Some selection criteria overlapped, while others were specific to certain groups of *participants*. However, seed colour (cream) was, by far, the most important criterion for all the *participants*. Surprisingly, the cultural value of landraces was identified as a very important criterion that guided the participants' choice. This demonstrates that cultural practices could contribute to maintaining the genetic diversity of neglected and underutilised species such as BGN. Similar results have revealed the socio-cultural role in influencing and maintaining crop diversity [32].

The nutritional value, exhibited only by women as a relevant criterion, suggests that women are more aware of the BGN nutritional potential than men. Indeed, in Burkina Faso, some women use BGN seed flour for food supplementation, especially for infants. As a result, this underscores the important role of BGN in fighting against food insecurity and multi-deficiency malnutrition, on the one hand, and the leading role of women in promoting NUS, on the other hand.

Reducing BGN cooking duration is a major challenge that research has to address. The long cooking time is an obstacle to the widespread adoption of BGN [33,34]. In a global warming context requiring the reduction in firewood, charcoal, and gas use, the long cooking time of BGN is a disadvantage that is counterbalanced by the desirable capacity to restore degraded soils by fixing atmospheric nitrogen [12]. Also, a long cooking time with open fire or traditional cookstoves may contribute to respiratory and other diseases [35], especially of women, who usually perform this task.

Surprisingly, participants do not seem to give much importance to yield, although this is reported by several authors to be a major constraint to BGN production [29,36]. This could be explained by the fact that the BGN yield observed in Burkina Faso is higher than that reported in several West African countries [8]. This is in concordance with the high-yielding potential of some landraces identified in this study. Indeed, out of the top eight producers of BGN in Africa (viz. Niger, Burkina Faso, Cameroon, Mali, Togo, Zimbabwe, Democratic Republic of the Congo and Zambia), the highest yield was observed in Burkina Faso (1052.2 kg/ha) followed by Zambia (912.5 kg/ha), Cameroon (828.7 kg/ha), and Togo (822.6 kg/ha) in 2022 [8,37]. Although Niger is the leading BGN-producing country, the yield of BGN in Niger (599.8 kg/ha) is very low [8]. The low-yielding potential of varieties, generally mentioned as the major obstacle to the development of BGN cultivation in Burkina Faso, seems to be of second rank compared to negative perceptions, beliefs and taboos reported by participants. Investigations should be carried out in Burkina Faso to assess the link between these negative perceptions and the NUS value chain's development.

It is worth noting that disease-resistance and drought-tolerance were not listed as relevant selection criteria for participants. This could be justified by the fact that BGN is generally considered to be more resistant to diseases and pests and more tolerant to drought and poor soils than the other legumes cultivated in Burkina Faso [11,12].

The selected landraces are in line with the inventoried key selection criteria. Out of the top three selected landraces, 3/3 of those selected by men and 2/3 of those selected by women were cream-coloured seeds, confirming that colour is, by far, the most important criterion. The presence of landrace ZMag2 (light-brown tripes on dark-red background) in the top three selected by women should be explained by the economic role and cultural practices associated with this landrace. For example, in western Burkina Faso, it is prepared and marketed by women as a snack, such as popcorn.

The top three landraces selected (SLeo1, ODap3, and BPbi3 for men, ODap3, SLeo1, and ZMag2 for women) by BGN *value chain participants* have very interesting characteristics, but also disadvantages. Referring to advantages, ODap3, SLeo1, and BPbi3 are landraces with high yield potential, up to 1.56 t/ha. Therefore, they can be used by breeders for the development of high-yielding varieties. ODap3 is a very early landrace; therefore, it is suitable for the Sahelian region, where rainy seasons are short. It can be used by breeders for the development of extra early varieties for Sahelian regions. In relation to disadvantages, SLeo1 has a long cycle. ZMag2, in addition to having a long cycle, also has a low yield. Landraces BPbi3 and SLeo1 have large seeds, unfortunately resulting in a longer cooking time. The landraces from Benin and Niger were less competitive compared to those from Burkina Faso, both in terms of agronomic performances and participants' preferences. Their low agronomic performances could be explained by the fact that these exotic landraces were unable to fully express their genetic potential in a new environment.

Most of the unselected landraces are dark-coloured, rejected because of their supposedly longer cooking time, contrasting with the results from focus group discussions that indicate that the dark-coloured seeds would be potentially more nutritious than others. This is a major drawback because previous studies showed that landraces with dark-coloured seeds have the highest protein and anthocyanin contents, which are very beneficial for the human diet [38,39]. Therefore, it would be interesting to carry out investigations to establish the link between BGN landrace seed colour and their cooking duration.

5. Conclusions

This study investigated relevant criteria for BGN varietal selection in Burkina Faso. Out of the ten criteria identified, seed colour (cream), seed size (large), cultural value, market value, seed taste, and cooking duration (short) are the most important criteria for all the BGN value chain participants. Crop yield, disease resistance, and drought tolerance seem to be criteria of second rank in Burkina Faso. Common and differing criteria were identified with significant differences in preferences. Referring to *gender*, the nutritional value is a key selection criterion for women only, while seed appearance (smooth seed), yield, and easy storage are criteria of interest for men only. Criteria such as taste, market value, and cooking duration are of interest to breeders and consumers, while crop yield and easy storage of seeds are criteria of interest to producers only. The study identified a set of landraces according to the BGN value chain participants' preferences. Out of the 14 landraces selected as of interest, ODap3 and SLeo1 are the most preferred by all the participants. However, the priority in choice for these two landraces varied according to participants, with significant differences in preferences for landraces. They have high-yielding potential, up to 1.56 t/ha, and can be used for the development of high-yielding varieties. ODap3 is a very early landrace; therefore, they are suitable for the Sahelian region, where rainy seasons are short. They can also be used by breeders for the development of extra early varieties for Sahelian regions. The dark-coloured seeds were the least preferred. Socio-cultural factors seem to play a key role in influencing and maintaining BGN diversity in Burkina Faso. From now on, the identified key selection criteria should guide breeders in the development of new varieties of BGN in Burkina Faso. The top selected landraces can be used for dissemination in Bambara groundnut production regions and future varietal improvement.

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Institutional Review Board Statement: The study was conducted in accordance with the code of ethics for scientific research of Joseph KI-ZERBO University (ARRETE N 2023-001/MESRI/SG/UJKZ/P, on 10 January 2023. Prior to the participatory varietal selection, consent was obtained from the participants through their signatures. Concepts and the objectives of the study were explained to the participants. They were informed that their anonymity would be assured and that there is no risk involved in participating.

Data Availability Statement: Data are contained within the article.

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Conflicts of Interest: The authors declare no conflicts of interest.

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