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Phenological, Morphological and Agronomic Characterization of Bambara Groundnut Genotypes on Plinthite Soil in East-centre Area, Burkina Faso

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Authors' contributions

This work was carried out in collaboration among all authors. The concept, design and methods of the paper were constructed by authors HN, KFZ and DJK. Data collection was carried out by authors BYI, HN and KFZ. Statistical analysis software and interpretation were undertaken by authors HN, KFZ and DJK. Writing original draft preparation of the manuscript was carried out by author HN. Review and editing by authors ASK, HMO, AO, MNK and ERT. Supervision by author MO. All authors read and approved the final manuscript.

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ABSTRACT

Bambara groundnut has long been a neglected and understudied crop. Thanks to the new orientations for the développement of agriculture and achievement of food security in Burkina Faso, in recent years, studies on Bambara groundnut have experienced renewed interest. Despites nutritional, agronomic and socio-economic importance and some studies carried out on this crop. The diversity within Bambara groundnut cultivated remains poorly understood. The objective of this study was to assess phenological morphological and agronomic characterization of 20 Bambara groundnut accessions from National Institute for the Environment and Agricultural Research (INERA) genebank. The experimental device used was a completely randomized Fisher blocks with four replications on the site of University Centre of Tenkodogo. These accessions were evaluated on 23 morphological characters including four qualitative characters and 19 quantitative characters. Qualitative traits showed high proportion of oval terminal leaflet shape (70%), cream coloured seeds (45%) and 80% presence of eyes of various shapes and colours. The analysis of quantitative characters showed all the characters are discriminating except the plant spread (PlS) at the 5% treshold with regard to morphological, physiological and agronomic traits and low coefficient of variation (CV) values for the different phenological characters, except for the number of days from sowing to 50% plantlet emergence (EMG50). Pearson correlation matrix indicated positive and negative correlation. Most of the negative correlation was observed between phenological and agronomic traits The dendrogram showed organization of the variability in three different groups on the basis of the physiological, phenological and agronomic traits. The variability expressed among INERA gene bank genotypes showed important variability, which can be exploited in Bambara groundnut breeding programs using the clustering and associations of characters.

Keywords: Bambara nut; Burkina Faso; characterization; morphological; phonological; variability.

1. INTRODUCTION

Bambara groundnut (*Vigna subterranea* [L.] Verdc.) is indigenous to sub-Saharan Africa, where it is widely cultivated. The centre of origin is most likely Northern Cameroon and North-eastern Nigeria in Africa. In Southern Africa, Zimbabwe is the centre of production. Bambara groundnut is an annual, creeping legume with glabrous, trifoliate leaves. Flowers are presented as papilionaceous racemes. Bambara groundnut flowering is comprised between 32 and 42 days after sowing [1], 28 and 39 DAS [2]. Fruits are one or 2-seeded pods, with various size with diameter between 8 to 14 mm [3] and seeds are round, smooth and very hard when dry. Average yields range from 350 to 800 $kg.ha^{-1}$ in the regions where the soil is poor and rainfalls low [4]. Yields can reach 3000 $kg.ha^{-1}$ under controlled conditions with the use of fertilizers [5]. Bambara groundnut adapts easily to difficult climatic condition and poor soils [6]. It is cultivated primarily for its seeds, which are used as human food. In many traditional cropping systems, it is intercropped with other root and cereal crops [6]. Bambara groundnut play a role in addressing food insecurity, malnutrition [7] as protein supplement within rural populations. Seeds are highly calorific (387 kcal/100 g), The chemical composition of the seeds consists of 64.4% carbohydrate, 23.6% protein, 6.5% fat, and 5.5% fiber [8-10]. Besides the nutritional significance of Bambara groundnut could be used for the medicinal purpose [11].

In Burkina Faso, Bambara groundnut is the second economically important grain legume [1]. The varieties with seed coat cream colour are the most appreciated. Producers, traders and consumers affirm that these varieties are aesthetically attractive with a high market value and have a reduced cooking time [12]. This perception by producers and consumers is gradually leading to the abandonment of some varieties. This resource is seriously threatened by genetic erosion in cultivated fields. Bambara groundnut is grown on small surfaces mainly by female farmers and is economically important for producers and traders. In spite of its enormous agronomic and nutritional potential it is neglected and underutilized. The literature pertaining studies in Bambara groundnut accessions is very limited in Burkina Faso. Except the studies conducted by [1,2,13] and using morphological markers and [14-16] using DNA markers, researches are limited on this specie. The valorization of any species requires knowledge and the control of its genetic diversity for its good exploitation, its improvement, as well as for its safeguard against genetic erosion. Indeed, plant genetic resources are the key to food security and sustainable agricultural development [17]. The objective of this investigation aims to characterize the level of agromorphological variability of Bambara groundnut genotypes from Burkina Faso.

2. METHODOLOGY

2.1 Plant Material and Experiment Management

This characterization study for determination of the level of the morphological and agronomic variability within Bambara groundnut collection on the experimental site of University Center of Tenkodogo. Climate is Sudano-sahelian, soil is acidic and characterized by low content of N, P, K. It has a sandy texture in the 0-16 cm depth and sandy-clay in the 16-36 cm depth, all supported by a plinthite like corresponding to an endo petroplinthic lixisol. Experiment was carried out with 20 genotypes from the gene bank of the Institute of the Environment and Agricultural Research (INERA). The different genotypes used are listed in Table 1.

The experimental device used was a completely randomized Fisher blocks with four replications. Each block consisted of 20 rows, each elementary row was randomly assigned with a genotype. Each row measured 4 m length and 21 seed were sown for each genotype per row. The spacings were 0.4 m between row and 0.2 m between the holes in the row. The blocks were separated by 1 m alley. Investigations were carried out during the rainy season 2021. Sowing was done on July 4 in a ploughed soil with one grain per hole after preparation of the soil using a tractor on July 1st. Manual weeding on demand followed by mounding on the 49th days after sowing. The device has not undergone phytosanitary treatment. In sowing, NPK (14-23-14) was applied as basal at a dose of 75 kg.ha^{-1}.

2.2 Data Collection and Analysis

A total of 23 characters (4 qualitative and 19 quantitative) were recorded (Table 2). The choice of the different traits and methods of measurement and observation were made according to the Bambara groundnut descriptor [18]. Data collection took into account the morphological, physiological and agronomic characteristics retained in this study.

Data were subjected to the descriptive statistics (mean, coefficient of variation) and analysis of variance (ANOVA) using XLSTAT 2021 4.1 software. Data analysis was performed with the average values obtained by rows and by blocks. Analysis of variance was performed to reveal the significant differences between the genotypes for each trait. The hierarchical ascending classification (HAC) was performed to group the genotypes according to morphological and agronomic parameters. The study of the relationships between quantitative traits was carried out using the Pearson correlation matrix to establish the degree of connection between the quantitative characters with the correlation coefficients.

Table 1. Name and origin of genotypes

N°	Name	Origin	N°	Name	Origin	N°	Name	Origin	N°	Name	Origin
1	KVS109A	INERA	6	KVS360	INERA	11	60GYF271	INERA	16	60GYF276	INERA
2	VARFOUR	INERA	7	KVS314	INERA	12	60GYF439	INERA	17	KVS210LR	INERA
3	KVS109B	INERA	8	KVS97-2	INERA	13	60GY301	INERA	18	10VAR360	INERA
4	KVS141-2	INERA	9	KVS311	INERA	14	60GY-F80	INERA	19	KVS075-1	INERA
5	KVS97-3	INERA	10	KVSB24P	INERA	15	KVS235	INERA	20	KVS075-2	INERA

Table 2. Bambara groundnut qualitative and quantative characters studied

Character	Code	Notation
Qualitative traits		
Terminal leaflet shape	TLS	-
Seed colour	SCO	-
Presence of eye	POE	-
Colour and appearance of eye	CAE	-
Phenological traits		
Number of days from sowing to 50% plantlet emergence	EMG50	Day
Rate of emerged plants at 21 days after sowing	RES21	%
Number of days from sowing to first flowering	FFL	Day
Number of days from sowing to 50% flowering	FLO50	Day
Vegetative traits		
Number of leaves per plant	NL/P	Number
Plant height	PlH	cm
Plant Spread	PlS	cm
Number of pods per plant	NP/P	Number
Yield related traits		
Number of of pods containing one seed	N1S	Number
Number of of pods containing two seeds	N2S	Number
Weight of pod per plant	WP/P	g
Pod length	PLen	mm
Pod width	PWid	mm
Weight of seeds per plant	WSP	g
Seed length	SLen	mm
Seed width	SWid	mm
100-seeds weight	W100S	g
Pod filling rate	PFR	%
Yield	YLD	$Kg.ha^{-1}$

3. RESULTS AND DISCUSSION

3.1 Variation of Qualitative and Quantitative Traits

All the qualitative traits studied showed the existence of several modalities (Table 3). Three modalities were recorded for the terminal leaflet shape. The oval shape was observed for 70% of the genotypes against 25% laceolate shape and 5% for elliptic shape. Except the round shape, all the different possible shapes described in the descriptor for Bambara Groundnut [18] are presented in the collection. This testifies to a good representativeness (75%) of the shape of the terminal leaflet within the collection. The result showed a high proportion of the cream-colour seeds (45%), followed by red seeds (20%) and purple seeds (15%). This high proportion of cream-colored seeds is also reported by Kambou et al. and Ouoba et al. [2,12] which explains that consumers prefer cream colour seeds for its market value and aesthetics as well as its relatively low cooking time. The colour of the seeds shows several modalities which testifies to a very great variability for this character. Kambou et al. and Issa et al. [2,19] showed that there is an important variability of the seed colour with Bambara groundnut collected from Burkina Faso and Niger respectively. The presence of the eye was observed in 80% of the genotypes. This high proportion observed within the collection is due to the producers and is taken into account for the multiplication and the valuation of their accessions according to Kambou et al. [2]. These authors also observed a high proportion (74.44%) of presence of the eye within a collection of 90 genotypes.

The results of analysis of variance for phenological and agronomic quantitative traits are recorded in the Table 4. The analysis of this table shows low coefficient of variation (CV) values for all phenological traits examined. The coefficients of variation is low (CV < 20%) and ranged between 2.57% (FFL) to 12.90% (EMG50). The yield and yield-related traits show high value of the coefficient of variation (CV > 20%) for number of pods containing two seeds (N2S = 69.67%), weight of seed per plant

(WS/P = 25.42%), yield (YLD = 24.32%) number of pods per plant (NP/P = 323.47%) and number of pods containing one seed (N1S = 22.18%). The analysis of variance carried out for Bambara groundnut genotypes from INERA genebank showed that there is a significant difference at the 5% threshold with regard to phenological, vegetative and agronomic traits. All the characters analyzed in this study were discriminant and very informative except the plant spread (PlS). This high variability corroborates those observed in similar studies by [20] with four local populations of Bambara groundnut collecte in Côte d'Ivoire. Highly significant differences were observed in the most of the traits. However, characters such as number of days from sowing to 50% plantlet emergence (EMG50), number of pods containing one seed (N1S). Pod filling rate (PFR) and pod width (PWid) have significant differences. These results show the existence of an important phenological and agronomic variability between the genotypes studied, which result from the expression of a strong genotypic heterogeneity and the influence of environmental factors [21-23]. These results corroborate those obtained by Djè et al. and Harouna et al. [24,25]. These authors testified a significant phenotypic variability between the accessions from Côte d'Ivoire and Niger respectively.

Table 3. Variation of qualitative traits

Characters	Variant	Fréquency (%)
Terminal leaflet shape	Elliptic	5
	Oval	70
	Lanceolate	25
Seed colour	Cream	45
	Purple	20
	Cream with triangular dark eye	15
	Dark brown dots on red background	5
	Brown streaks on cream background	5
	Black	5
	Dark brown rhombic spots on a cream background on the micro pilar tip	5
Presence of eye	Present	80
	Absent	20
Colour and appearance of eye	Butterfly-shaped dark brown eye	25
	Butterfly-shaped gray eye	25
	circular brown eye	25
	Butterfly-shaped gray eye	25

Fig. 1. Different colour of Bambara groundnut seeds

Légend : A : Cream, B : Dark brown dots on light red background, C : Black, D : Dark brown rhombic spots on a cream background on the micro pilar tip, E : Brown streaks on cream background, F : Purple, G : Cream with triangular dark eye

Table 4. Analysis of variance of the 19 quantitative parameters of Bambara groundnut genotypes

Characters	CV (%)	F de Fisher	*P*-Value	Significance
Phenological traits				
EMG50	12.90	3.32	0.001	S
RES21	12.30	6.54	< 0.001	HS
FFL	2.57	9.83	< 0.001	HS
FLO50	3.16	7.01	< 0.001	HS
Vegetative traits				
NL/P	16.50	7.25	< 0.001	HS
PlH	6.75	3.45	< 0.001	HS
PlS	15.14	1.57	0.098	NS
Yield related traits				
NP/P	23.47	3.85	< 0.001	HS
N1S	22.18	2.61	< 0.003	S
N2S	69.67	3.18	< 0.001	HS
WP/P	17.93	5.03	< 0.001	HS
PLen	3.94	3.54	< 0.001	HS
PWid	4.20	2.04	0.020	S
SLen	4.10	4.56	< 0.001	HS
WS/P	25.42	2.96	< 0.001	HS
SWid	4.81	3.13	< 0.001	HS
W100S	8.12	9.34	< 0.001	HS
PFR	4.21	1.90	0.033	S
YLD	24.32	3.98	< 0.001	S

Legend: EMG50 : Number of days from sowing to 50% plantlet emergence ; RES21 : Rate of emerged plants at 21 days after sowing ; FFL : Number of days from sowing to first flowering FLO50 : Number of days from sowing to 50% flowering; NL/P : Number of leaves per plant : PlH : Plant height ; PlS : Plant Spread ; NP/P : Number of pods per plant ;N1S : Number of pods containing one seed ; N2S : Number of pods containing two seeds : WP/P : Weight of pod per plant ; WS/P : Weight of seed per plant ; PLen : Pod Lenght ; PWid : Pod width ; SLen : Seed Lenght ; SWid : Seed width ; W100S : Weight of 100 seeds ; PFR : Pod filling rate ; YLD : Yield ; F : coefficient of Fischer ; CV : coefficient of variation ; NS : Not significant ; S : Significant difference at 5% ; HS : Hight significant difference at 5%

3.2 Relationship between Characters

Pearson correlation matrix showed positive and negative correlations at the 5% threshold among quantitative characters (Table 5). The knowledge of the relationships between traits is an important and useful approach for the identification of potential agronomic traits that can be taken into consideration according to the selection objectives in genetic improvement programs. Most of the negative correlation was observed between phenological and agronomic traits. The character number of days from sowing to 50% flowering (FLO50) is negatively and significantly correlated ($- 0.70 < r < - 0.40$) with number of seed in the pod (N1S and N2S). It is also strongly and negatively correlated ($r < - 0.70$) to the number of pods per plant (NP/P), 100-seeds weight (W100S), weight of seeds per plant (WS/P), and yield (YLD). The negative correlations observed between these characters implies that the traits evolve in the opposite direction [26]. These negative correlations indicate that plants with an early semi-flowering cycle have very interesting agronomic characteristics. These results are in agreement with those obtained by Ouedraogo, Kambou [1,2]. On the other hand, [24] obtained the opposite results with accessions from Côte d'Ivoire that have very long cycles with interesting agronomic characteristics. Number of leaves per plant (NL/P) was positively and significantly correlated ($0.40 < r < 0.70$) with number of pods per plant (NP/P), weight of pods per plant (WP/P) and weight of seeds per plant (WS/P). Correlations between traits show number of leaves (NL/P) are important indices for improving Bambara groundnut productivity.

Selection of Bambara groundnut genotypes with interesting pods parameters should be oriented towards high number of leaves. In addition, number of leaves, short flowering cycle have a direct effect on the yield and direct selection based on these characters would be favorable to improve Bambara groundnut yield. The number of pods containing one seed (N1S) is highly and positively correlated ($r < 0.70$) with the number of pods per plant (NP/P), weight of pods per plant (WP/P) and weight of seeds per plant (WS/P). The 100-seed weight (W100S) was strongly and

Table 5. Pearson's correlations matrice between the 19 quantitative variables

Variables	EMG50	RES21	FFL	FLO50	NL/P	PIH	PIS	N1S	N2S	NP/P	WP/P	W100S	PLen	PWid	SLen	SWid	PFR	WS/P
RES21	**-0.568**																	
FFL	0.413	0.121																
FLO50	0.312	0.028	**0.857**															
NL/P	**-0.471**	-0.206	**-0.650**	**-0.541**														
PIH	-0.214	0.084	0.369	**0.581**	-0.090													
PIS	0.391	-0.343	0.411	**0.526**	0.058	**0.467**												
N1S	0.026	-0.234	**-0.574**	**-0.696**	**0.592**	**-0.520**	-0.132											
N2S	-0.117	-0.213	**-0.634**	**-0.675**	0.454	**-0.588**	-0.399	**0.564**										
NP/P	-0.249	-0.098	**-0.734**	**-0.861**	**0.689**	**-0.515**	-0.286	**0.901**	**0.692**									
WP/P	-0.125	-0.356	**-0.814**	**-0.890**	**0.699**	**-0.502**	-0.223	**0.828**	**0.695**	**0.892**								
W100S	-0.334	0.113	**-0.737**	**-0.802**	**0.485**	**-0.460**	-0.434	**0.627**	**0.555**	**0.683**	**0.737**							
PLen	-0.121	-0.136	-0.105	0.178	0.060	**0.553**	0.379	-0.272	-0.298	-0.263	-0.108	0.063						
PWid	0.143	-0.326	-0.179	0.069	0.113	0.263	0.417	-0.086	-0.128	-0.133	0.058	0.127	**0.847**					
SLen	0.023	-0.080	-0.404	-0.354	-0.049	-0.119	-0.132	0.028	-0.006	0.062	0.287	**0.548**	**0.616**	**0.649**				
SWid	-0.344	-0.060	**-0.775**	**-0.733**	**0.612**	-0.435	-0.306	**0.594**	**0.529**	**0.682**	**0.780**	**0.873**	0.202	0.309	**0.594**			
PFR	**-0.456**	0.308	-0.433	-0.439	0.288	-0.240	-0.317	0.204	0.134	0.433	0.313	0.369	0.017	0.044	0.301	**0.506**		
WS/P	-0.022	-0.420	**-0.759**	**-0.845**	**0.595**	**-0.472**	-0.210	**0.757**	**0.660**	**0.783**	**0.948**	**0.652**	-0.100	0.062	0.271	**0.663**	0.057	
YLD	-0.343	0.287	**-0.668**	**-0.814**	0.404	**-0.553**	**-0.471**	**0.615**	**0.540**	**0.684**	**0.703**	**0.869**	-0.183	-0.095	0.345	**0.745**	0.328	**0.681**

Legend: EMG50: Number of days from sowing to 50% plantlet emergence; RES21: Rate of emerged plants at 21 days after sowing; FFL: Number of days from sowing to first flowering FLO50: Number of days from sowing to 50% flowering; NL/P: Number of leaves per plant : PIH: Plant height; PIS: Plant Spread; NP/P: Number of pods per plant; N1S : Number of pods containing one seed ; N2S : Number of pods containing two seeds : WP/P : Weight of pod per plant; WS/P : Weight of seed per plant; PLen : Pode Lenght; PWid : Pod width; SLen : Seed Lenght; SWid : Seed width; W100S : Weight of 100 seeds; PFR : Pod filling rate; YLD : Yield

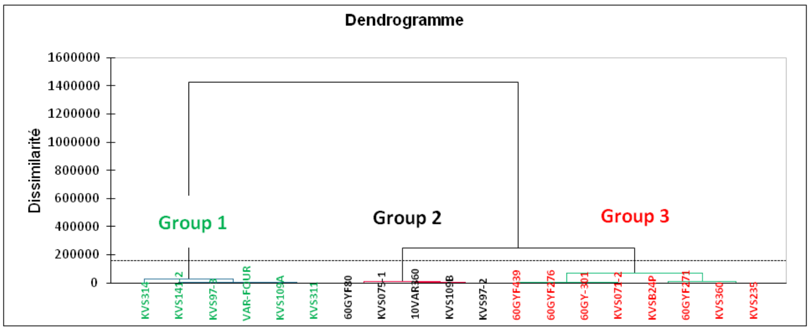

Fig. 2. Dendrogram showing the clustering pattern in Bambara groundnut genotypes

positively correlated (r > 0.70) with seed width (SWid), and yield (YLD). Weight of seed per plant (WS/P) shows a positive and significant correlation (r = 0.681) with yield (YLD). Correlations are an essential tool for breeders because they can facilitate genetic improvement in so far as when traits are positively correlated, improving one will lead to improving others [27].

3.3 Organization of the Variability and Characteristics of the Groups

The hierarchical ascending classification (HAC) carried out using Euclidean distances with the Ward method as the aggregation criterion is represented by the dendrogram in the Fig. 2. This study has allowed to obtain an organization of the genotypes in three different groups on the basis of the physiological, phenological and agronomic traits. These results could be explained by the variability of this species and testify to morphometric and agronomic diversity within the collection. The unidirectional test of mean egalities of the groups showed the gathering of the genotypes is based mainly on characters such as number of days from sowing to 50% flowering (FLO50 ; P < 0.0001), plant spread (PlS; P < 0.05), number of pods per plant (NP/P; P = 0.000), 100-seeds weight (W100S; P < 0.0001), seed width (SWid; P < 0.0001), (WS/P = 0.002) and yield (YLD; P < 0.0001). The group 1 (in green colour) is composed of six genotypes. The group 2 (in black colour) is composed of five genotypes and the group 3 (in red colour) being the most supplied group with eight genotypes. This result corroborated those of Diagara et al. [28] who obtained three groups with 30 accessions from Niger. However it is different of the findings reported by Bonny and Djè [23] who obtained four distinct groups with 101 accessions from Côte d'Ivoire, and the most relevant variables to describe the variability between these groups were internode length, pod length, plant height and cycle length. Issa et al. [29] have also obtained four groups with accessions from Niger. The four different group could be due to the high number of accessions used in their study.

The results showed that the the genotypes of the group 1 is the lesser performant. They have very low values of yield and yield components. In addition they take more time to emerged (EMG50 = 7 days) and to flower (FLO50 = 37,42 days). The group 2 contains the most productive genotypes. It is characterized by genotypes with earlier flowering (FLO50 = 34.4 days) and high values of 100-seeds weight (W100S = 59.45 g), seed width (SWid = 9.04 mm), weight of seed per plant (WS/P = 17.58 g) and yield (YLD = 1597.50 kg.ha^{-1}). Five promising accessions KVS109B, KVS97-2, 60GYF80, 10VAR360 and KVS075-1 based on their agronomic and physiological performance were identified and could be taken into account in a possible Bambara groundnut improvement program.

4. CONCLUSION

The analysis of variance indicated significant differences within the Bambara groundnut genotypes for the 19 characters studied. Correlations between variables showed that yield is correlated with most of the agromorphological parameters used in this study. The hierarchical ascending classification showed that Bambara groundnut genotypes can be classified into three distinct groups. Group 1 is one characterized by a long crop cycle and taller plants. This group is opposed to group 2 with interesting yield component and high yield. The variability expressed among INERA genebank genotypes can be exploited in Bambara groundnut breeding programs. Most of the negative correlation was observed between phenological and agronomic traits. However, several correlations are positive and many significant correlations have been observed between the characters related to yield. Selection of Bambara groundnut genotypes with interesting yield should be oriented toward 100-seeds weight, weight of seed per plant and seed width.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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