

Performance of Bambara groundnut (*Vigna subterranea* [L.] Verdcourt) genotypes cropped on plinthite soil in the semi arid zone, Burkina Faso

ABSTRACT

Bambara groundnut is grown mainly as a food crop in Burkina Faso. The crop has been neglected although it is highly nutritious. This study was undertaken to find out the effects of genotypes on the physiological traits, yield and yield related traits of Bambara groundnut and to identify the most productive genotypes. Field experiments were conducted at the Tenkodogo University Centre site, during the 2021 rainy season. The experiments were laid out in randomized complete block design with four replications and eight genotype from INERA germplasm bank. Data collected concerned number of days to 50% field emergence, number of days from sowing to 50% flowering, number of leaves per plant, plant height, plant spread, number of pods per plant, number of one seed per pod, number of two seeds per pod, weight of seeds per plant seed length, seed width, 100-seed weight and yield. The data were subjected to the analysis of variance, and means were separated through Duncan's test at 95% confidence. The Pearson's correlation coefficients between characters were computed using SPSS 2.0. Significant and extreme significant variations were observed for almost studied characters, except plant spread and number of one seed per pod. The results showed numerous positive correlations between the characters. Most of the negative correlation was observed between physiologic and agronomic traits. The result showed that the genotypes KVS97-2 (33.75 days; 1578.12 kg.ha⁻¹); KVS360 (34.75 days; 1181 kg.ha⁻¹) and KVS235 (34.5 days; 1167.19 kg.ha⁻¹) performed than the others in yield parameters and the shorter flowering cycle.

Keywords : *Bambara groundnut, neglected crop, genotype, performance, yield, Burkina Faso*

1. INTRODUCTION

In the low income countries, there is an urgent need for new food plants or new sources to meet the nutritional needs of growing populations. It would be essential to use efficiently all the species cultivated which have an interesting agronomic potential in the arid and semi-arid areas. To sustainably agricultural productivity in the difficult climatic conditions and soil poverty, it is necessary to find out endogenous solutions. Thus, identification and evaluation of resilient crops is a challenge for ensuring food security. Bambara groundnut (*Vigna subterranea* [L.] Verdc.) is one of the important leguminous crops in Burkina Faso; but it is neglected and underutilized. Valorization of some minor/neglected crops is very crucial. Bambara groundnut is the third most important food legume in Sub-saharan after cowpea (*Vigna unguiculata* [L.] Walp.) and groundnut (*Arachis hypogaeae* L.) [1,2]. It is particularly interesting because it supports significant water deficit and has enormous agronomic potentials, and can improve soil nutrient status, especially nitrogen status, as a result of its nodulation process which traps nitrogen from atmosphere [3,4]. It can fix 100 kg N.ha⁻¹ [5]. Bambara groundnut is a species that could be used to promote sustainable agriculture in a context emphasis by poor soils and insufficient rainfall. That could empower farmer's resilience to climate change. This species has an ability to resist pest and diseases and can thrive in poor soils [6]. The dryness-tolerance genes traced in Bambara groundnut could be applied to others crop species that are susceptible to dryness through marker-assisted selection [2]. Bambara groundnut is rich in nutrients which contribute to alleviate carence within rural populations as protein supplement. It is highly calorific (387 kcal/100 g), rich in vitamins, mineral elements, essential amino acids such as lysine, methionine and proteins [7,8,9,10]. Bambara groundnut contains ~64.4% carbohydrate, 23.6% protein, 6.5% fat, and 5.5% fiber and is rich in minerals [11,12]. Besides the nutritional significance of Bambara groundnut, it also has different medicinal benefits [13,14]. Bambara groundnut is mostly grown by women and used as a cash crop. Despite all these importances, it remains a neglected crop. Research institutes and researchers have paid little attention in Burkina Faso. Consequently, there is no improved varieties and lack of improve agronomical suitable practices which limit the productivity of this crop in the farming environment. Thus, the promotion and intensification of Bambara groundnut are resilient choices and a strategic challenge to overcome hunger and malnutrition within the rural population in Burkina Faso. Therefore, it is essential to find out appropriate genotypes enable to adapt to various environments as order to include them in selection program for their agronomic performances. The objective of this study is to assess the agronomic performances and degree of adaptability of eight genotypes in the semi-arid zone of Burkina Faso.

2. MATERIAL AND METHODS

2.1. Plant material and site description

The plant material of our study consisted of eight Bambara groundnut genotypes provide by the Institute of Environment and Agricultural Research (*INERA: Institut de l'Environnement et de Recherches Agricoles*). These are the genotypes KVS109A, KVS141-2, KVS360, KVS314, KVS97-2, KVS311, KVS235, KVS075-1. This study was carried out at the experimental field of the Tenkodogo University Centre (11°48'37"N, 0°22'19"W) located in East-centre region of Burkina Faso. Climate of this region is Sudano-sahelian type characterized by annual rainfall between 600 and 900 mm.

Insolation is 7 - 8 h day⁻¹ with low humidity. In 2021, 52.2 mm of rainfall (May) was recorded against 249.5 mm (August); Temperature was ranged from 26°C (August) to 31°C (May) (Figure 1).

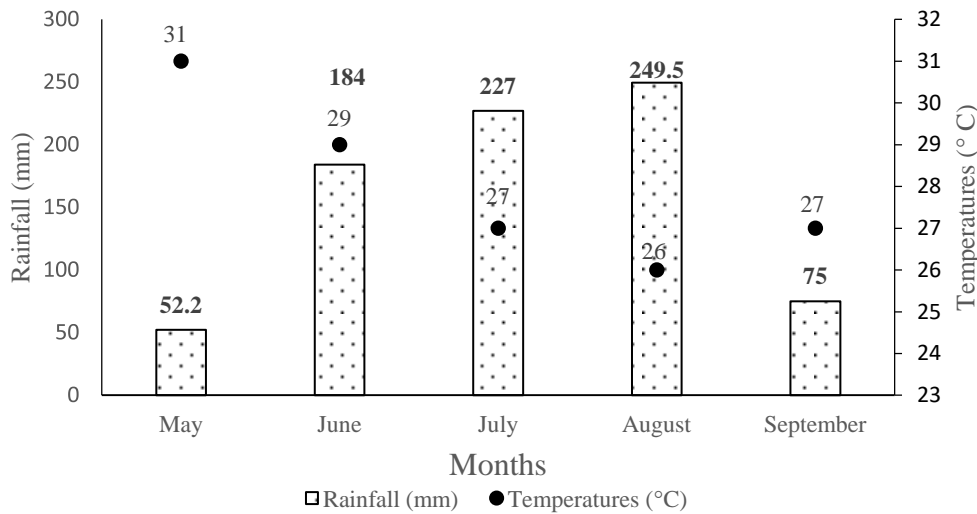


Figure 1: Average rainfall and temperature of experimental site.
(Data source: Centre-east meteorological station in 2021)

The characterization of the soil of experimental site according to [15], soil description guidelines showed that the soil has a useful depth of 0-36 cm. The 0-16 cm depth has sandy texture and the layer 16-36 cm has sandy-clay texture. Layer > 36 cm is a ferruginous shell (plinthite). The drainage is excessive to perfect and limited by the shell. This soil belongs to the ferric and manganese sesquioxides soils class and specifically to shallow leached ferruginous tropical soil according to the french classification [16]. This soil would correspond to endo petroplinthic lixisol according to the classification of [17]. The texture of soil makes it potentially suitable for Bambara groundnut cropping, because it is better drained and favors pod penetration in the soil. Well-drained, light, sandy, loamy soils with a pH of 5.0 to 6.5 are more suitable for Bambara groundnut cultivation [18].

2.2. Experimental design and field management method

Experimental device was a randomized complete blocks design with four replications separated by 1 m alley. Each replication comprised eight rows of 4 m length. Each row was randomly assigned with one genotype. The distance was 0.4 m between row and the spacing between the holes 0.2 m. A total of 21 seeds were sown on each row by genotype. Sowing was carried out on July 4, 2021 at one seed per hole, on land previously plowed flat using a tractor followed by manual shelving. Mineral fertilizer, NPK (14-23-14) was applied at a dose of 75 kg.ha⁻¹ on the sowing day. Three manual weeding were carried out on all the plots as needed. Mounding was carried out at seven weeks after sowing.

2.3. Data collection and analyses

Data were recorded during plants growth and development stage and after harvest. Data collection was carried out base on the Bambara groundnut descriptor established by the International Institute of Plant Genetic Resources [19]. A total of 13 characters were recorded in this study (Table I). For each genotype, the characters were observed and measured in each replication for statistical analysis. Data were subjected to the analysis of variance (ANOVA) using Genstat 12ed software to reveal differences between genotypes for each trait, and means were separated through Duncan's test at $P = .05$. The

genetic parameters studied were estimated from the mean squares derived from the ANOVA with all the quantitative traits. The Pearson's correlation coefficients between characters were performed using SPSS 20 software.

Table I: Quantitative traits studied

Characters	Code	Notation
Number of days to 50% field emergence	EMG50	Day
Number of days from sowing to 50% flowering	FLO50	Day
Number of leaves per plant	NL/P	Number
Plant height	PIH	cm
Plant spread	PIS	cm
Number of pods per plant	NP/P	Number
Number of one seed per pod	N1S	Number
Number of two seeds per pod	N2S	Number
Weight of seeds per plant	WS/P	g
Seed length	SLen	mm
Seed width	SWid	mm
100-seed weight	W100S	g
Yield	YLD	Kg.ha ⁻¹

3. RESULTS AND DISCUSSION

3.1. Variation of studied characters

The results of analysis of variance using the mean square values are shown in table II. Significant and extreme significant variations were observed for almost studied characters, except plant spread (PIS) and number of one seed per pod (N1S). The significant variation for the most characters studied implies there is agromorphological diversity between the genotypes considered. Researches works previously carried out in Niger by [20] and in Burkina Faso showed significant variability within Bambara groundnut varieties [21,22].

Variability is considered as basis of breeding, and genetic variability could be exploited for selection and release high performant varieties. Mean squares are an estimate of the variance within population. Mean square values of genotype are highest than those of residual for all the studied characters. These results indicates that the influence of the environment does not have significant effect on the expression of the characters [23]. Furthermore, the employment of various genotypes and environments can be able to led the variable response and a number of factors have been identified as having a negative influence among vegetative traits, yield, and its attributed components [24].

Table II : Mean squares and variability of variance for physiologic and agronomic contributing 14 traits in Bambara groundnut

Source	Block	Genotype	Error	F. pr.	Significance
df	3	18	54	-	-
EMG50	0.28	2.63	0.9	0.026	*
FLO50	9.78	15.28	0.75	< 0,001	**
NL/P	495.93	1152.82	80.39	< 0.001	**
PIH	8.85	6.88	2.52	0.035	*
PIS	19.92	70	33.79	0.093	NS
NP/P	135.78	89.71	17.04	0.001	**
N1S	156.24	37.87	17.17	0.076	NS
N2S	0.64	2.98	0.8	0,009	*
WS/P	37.33	47.11	3.74	< 0.001	**
SLen	1.56	0.69	0.27	0.046	*
SWid	1.18	0.54	0.21	0,046	*
W100S	17.28	177.71	24.31	< 0,001	**
YLD	86512	496092	132318	0.009	*

EMG50: Number of days to 50% field emergence ; *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 one seed per pod ; *N2S* : Number of two seeds per pod ; *WS/P* : Weight of seeds per plant ; *SLen* : Seed length ; *SWid* : Seed width ; *W100S* : 100-seed weight ; *YLD* : Yield ; *NS* : Not significant ; * : Significant difference at 5% ; ** : Hight significant difference at 5%

3.2. Correlations between studied characters

Pearson coefficients from correlation matrix showed numerous positive associations between the characters (Table III). Number of days to 50% field emergence showed a positive correlation with number of days to 50% flowering ($r = 0.738$). In addition, number of one seed per pod is positively and strongly correlated with number of pods ($r = 0.917$, $P = .01$), weight of seed ($r = 0.907$, $P = .01$). Number of pods also showed positive correlation with 100-seed weight ($r = 0.871$, $P = .01$), seed weight ($r = 0.825$, $P = .01$), weight of seed per ($r = 0.930$, $P = .01$) and yield ($r = 0.830$, $P = .05$). Important correlation was observed between 100-seed weight and seed width ($r = 0.866$, $P = .01$), weight of seed per plant ($r = 0.857$, $P = .01$) and yield ($r = 0.825$, $P = .05$). Knowledge of the relationships between traits is an important and useful approach for identification of potential interesting agronomic traits to be taken into consideration according to breeding objectives in genetic improvement programs. In this order, [25] showed that dry pod weight, 100-seed weight, number of pods and fresh pod weight could be used as selection criteria to improve the seed yield of Bambara groundnut. The positive correlations observed between two characters imply that the characters evolve in the same direction. Even though positive correlations have been observed, there are certain negative correlations. Most of the negative correlations were observed between physiological and agronomical traits. Number of day to 50% flowering was negatively correlated with agronomic traits such as number of one seed per pod and seed width ($r = - 0.828$ and $- 0.789$ respectively, $P = .05$)

and often showed a strong correlation at $P = .01$ with number of pods per plant ($r = -0.954$), 100-seed weight ($r = -0.939$), weight of seed per plant ($r = -0.949$) and the yield ($r = -0.890$). Plant spread shown negative correlations, but non significant with all the agronomic traits. Negative correlations observed between yield and number of days to 50% flowering ($r = -0.890$, $P = .01$), plant height ($r = -0.736$, $P = .05$) and plant spread ($r = -0.648$) indicate that direct selections toward these three traits could not be interesting for the improvement of Bambara groundnut yield.

Table III. Pearson's correlation coefficient for 14 characters in Bambara nut genotypes

Characters	EMG50	FLO50	NL/P	PIH	PIS	N1S	N2S	NP/P	W100S	SLen	SWid	WS/P
FLO50	0.738*											
NL/P	-0.526	-0.519										
PIH	0.100	0.572	-0.094									
PIS	0.602	0.685	0.094	0.580								
N1S	-0.432	-0.828*	0.644	-0.729*	-0.480							
N2S	-0.556	-0.922**	0.431	-0.596	-0.545	0.752*						
NP/P	-0.734*	-0.954**	0.641	-0.638	-0.644	0.917**	0.858**					
W100S	-0.840**	-0.939**	0.562	-0.328	-0.567	0.673	0.811*	0.871**				
SLen	-0.692	-0.330	0.128	0.420	-0.284	-0.150	0.130	0.164	0.569			
SWid	-0.913**	-0.789*	0.694	-0.250	-0.540	0.643	0.538	0.825*	0.866**	0.573		
WS/P	-0.604	-0.949**	0.648	-0.531	-0.523	0.907**	0.875**	0.930**	0.857**	0.193	0.735*	
YLD	-0.504	-0.890**	0.268	-0.736*	-0.648	0.748*	0.847**	0.830*	0.825*	0.163	0.590	0.787*

*significant correlation at 0.05 level ; ** significant correlation at 0.01 level ; **EMG50** : Number of days to 50% field emergence ; **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 one seed per pod ; **N2S** : Number of two seeds per pod ; **WS/P** : Weight of seeds per plant ; **SLen** : Seed length ; **SWid** : Seed width ; **W100S** : 100-seed weight ; **YLD** : Yield

3.3. Performance analysis for assessed genotypes

There were significant differences among the genotypes concerning physiological traits, yield and yield components (Table IV). Certain genotypes shown interesting performance for the assessed characters. The flowering cycles of the genotypes were range from 33.75 to 38.50 days. High-yield genotypes ($>1000 \text{ kg.ha}^{-1}$) flowered between 33.75 and 34.75 days. Contrariwise, [26] recorded 41 to 56 days with Bambara groundnut accessions from Ivory Coast. The genotype KVS075-1 had a short flowering cycle (34.5 days) and the best yield (1650 kg.ha^{-1}). The yields were higher than those obtained (830 kg.ha^{-1}) by [21] with the similar flowering cycle. Researches undertook by [27] on 20 Bambara groundnut varieties from Zimbabwe showed that all the varieties have a very long time to flower (> 60 days) with pod yield comprised between 1 100 and 2 300 kg.ha^{-1} . The genotype KVS109A, KVS314, KVS311 and KVS141-2 took more time to flower (> 37 days) with a very low seed weight per plant, 100-seed weight and low yields. After flowering comes reproductive stage and occurring of pods in the soil. So, early flowering genotypes have pods that appear much earlier than other genotypes, and have more time for pod filling compared to late flowering genotypes. This would explain why these genotypes have interesting yield and yield components traits. To this end, improving

productivity of Bambara groundnut in Burkina Faso should take into account genotypes that combine high seed weight per plant (WS/P), High number of pods per plant (NP/P), high yield (YLD) and early flowering cycle (FLO50). This must be judiciously combined with appropriate cultural options depending on the production context in order to maximize the yield potential of cultivars with high productive value. The genotypes KVS141-2, KVS235, KVS360, and KVS97-2 had high number of leaves (respectively 79.25, 69.40, 65.50, 67.10). However, the genotypes KVS97-2 (33.75 days; 1578.12 kg.ha⁻¹); KVS360 (34.75 days; 1181 kg.ha⁻¹) and KVS235 (34.5 days; 1167.19 kg.ha⁻¹) performed than the others in yield parameters and the shorter flowering cycle. Late genotypes gave the lowest yields. These results are different from those obtained by [28] with Bambara groundnut from Ivory Coast. This could be explained by the fact the rains are abundant in this country. The number of pod per plant (NP/P) was between 13 (KVS314) and 25.50 (KVS360, KVS235 and KVS97-2). This result is different from that obtained by [1] range from 18.24 to 46.52 pods per plant, [29] and [22]. These genotypes recorded high weight seed per plant (WS/P).

Table II : Effects of genotypes on the physiological traits, yield and yield related components of Bambara groundnut from Burkina Faso

Génotypes	NL/P	FLO50	NP/P	W100S	WS/P	YLD
KVS109A	36.6 a	38.50 b	16.25 ab	45.00 a	8.79 a	881.25 a
KVS141-2	79.25 b	37.50 b	19.00 ab	47.50 a	13.14 abc	848.44 a
KVS360	65.50 b	34.75 a	23.50 b	56.25 b	17.66 c	1181.25 ab
KVS314	41.50 a	38.25 b	13.00 a	48.25 a	9.49 a	692.19 a
KVS235	69.40 b	34.5 a	25.50 b	56.50 b	15.82 bc	1167.19 ab
KVS97-2	67.10 b	33.75 a	25.50 b	62.25 b	17.26 c	1578.12 b
KVS311	35.30 a	37.50 b	16.75 ab	43.5 a	12.06 ab	878.12 a
KVS075-1	47.45 a	34.5 a	23.25 b	55.5 b	15.88 bc	1650 b
Mean	55.2625	36.15	20.3438	51.8438	13.7625	1109.57

NL/P : Number of leaves per plant ; *FLO50* : Number of days from sowing to 50% flowering ; *NP/P* : Number of pods per plant ; *W100S* : 100-seed weight ; *WS/P* : Weight of seeds per plant ; *YLD* : Yield

4. CONCLUSION

From the results obtained in this study, it could be concluded that the average yield obtained with all the eight Bambara groundnut genotypes from INERA germplasm were 1109.57 kg.ha⁻¹. This shows a good performance compared to the national average which is estimated at less than 500 kg.ha⁻¹. The agronomical performances of the Bambara groundnut genotypes from INERA germplasm showed that KVS 075-1, KVS97-2, KVS360 and KVS235 performed well both in physiological and in yield parameters. This testifies to a good adaptation of these genotypes to the semi-arid zone with annual rainfall comprise between 600 to 900 mm. Using performant genotypes combined with well-distributed rainfall and good soil fertility could contribute to improve Bambara groundnut production.

REFERENCES

1. Toure Y, Koné M, Silué S, Kouadio YJ. Prospection, collecte et caractérisation agro-morphologique des morphotypes de voandzou (*Vigna subterranea* (L.) Verdc) de la zone savanicole en Côte d'Ivoire. *European scientific journal*. 2013;9: 308-325. French.
2. Khan MMH, Rafii MY, Ramlee SI, Jusoh M, Al-Mamun M. Bambara Groundnut (*Vigna subterranea* L. Verdc): A Crop for the New Millennium, Its Genetic Diversity, and Improvements to Mitigate Future Food and Nutritional Challenges. *Sustainability*. 2021;3, 5530. <https://doi.org/10.3390/su13105530>.
3. Mabhaudhi T, Modi AT, Beletse YG. Growth, phenological and yield responses of a Bambara groundnut (*Vigna subterranea* L. Verdc) landrace to imposed water stress: II. Rain shelter conditions. *Afr. Crop Sci. J.* 2013; 39:191-198.
4. Ndiang Z, Semboung LF, Ngo NL, Wafo FD, Tchinda NL, Bell J. M., 2022. Nodulation Potential of Bambara Groundnut (*Vigna subterranea* L.) in Yaounde (Centre Region of Cameroon). *American Journal of Food and Nutrition*. 2022;10(1):34-39.
5. Musa M, Massawe F, Mayes S, Alshareef I, Singh A. Nitrogen fixation and N-Balance studies on Bambara groundnut (*Vigna subterranea* L. Verdc.) Landraces grown on tropical acidic soils of Malaysia. *Commun Soil Sci Plant Anal*. 2016;47(4):533-542.
6. Obidiebube EA, Eruotor PG, Akparobi SO, Okolie H, Obasi CC. Assessment of Bambara Groundnut (*Vigna Subterranea* (L) Verdc) Varieties for Adaptation to Rainforest Agro-Ecological Zone of Anambra State of Nigeria. *Canadian Journal of Agriculture and Crops*. 2020;5(1):1-6.
7. Minka, SR, Bruneteau M. Partial Chemical Composition of Bambara Pea (*Vigna subterranean* L. Verde). *Food Chemistry*. 2000;68 :273-276. [http://dx.doi.org/10.1016/S0308-8146\(99\)00186-7](http://dx.doi.org/10.1016/S0308-8146(99)00186-7)
8. Amarteifio O, Tibe O, Njogu RM. The mineral composition of Bambara groundnut (*Vigna subterranea* [L] Verdc) grown in Southern Africa. *African Journal of Biotechnology*. 2006;5(23):2408-2411.
9. Onwubiko NIC, Odum OB, Utazi CO, Poly-Mbah PC. Studies on the Adaptation of Bambara Groundnut [*Vigna Subterranea* (L.) Verdc] in Owerri southeastern Nigeria. *Agricultural Journal*. 2010;6(2):60-65.
10. Sévérin B, Yao D. Variabilité morphologique et agronomique des variétés traditionnelles de voandzou (*Vigna subterranea* L. Verdc,) de Côte d'Ivoire. *Journal of Applied Biosciences*. 2011;41:2820-2835. French.
11. Azman HR, Barkla BJ, Mayes S, King GJ. The potential of the underutilized pulse bambara groundnut (*Vigna subterranea* (L.) Verdc.) for nutritional food security. *J. Food Compos Anal*. 2019;77:47-59.

12. Lin-Tan X, Azam-Ali S, Goh EV, Mustafa MA, Chai HH, Kuan-Ho W, Mayes S, Mabhaudhi T, Azam-Ali S, Massawe F. Bambara groundnut: An underutilized leguminous crop for global food security and nutrition. *Front. Nutr.* 2020;7, 601496. doi: [10.3389/fnut.2020.601496](https://doi.org/10.3389/fnut.2020.601496)
13. Brink M., Grubben G. J. H., Belay G. and Agrooh., 2006. Ressources végétales de l'Afrique Tropicale 1: Céréales et légumes secs. Edition M. Brink. Wageningen University, P.O. Box 341, 6700 AH Wageningen, Netherlands, 328 p. French
14. Atoyebi JO, Osilesi O, Abberton M, Adebawo O, Oyatomi O. Quantification of selected anti-nutrients and bioactive compounds in African Bambara groundnut [*Vigna subterranea* (L.) Verdc.]. *Am. J. Food Nutr.* 2018;6:88-95.
15. FAO, ISRIC (Centre International de Référence et d'Information des Sols). Directives pour la description des sols. 3ème édition (révisée), Service des sols-ressources, aménagement et conservation, Division de la mise en valeur des terres et des eaux, 1994. 78p.
16. CPCS (Commission de Pédologie et de cartographie des sols). Commission de Pédologie et de Cartographie des Sols. 1967; https://horizon.documentation.ird.fr/exl-doc/pleins_textes/divers16-03/12186.pdf.
17. WRB (World Référence Bases). Base de référence mondiale pour les ressources en sols 2014. Système international de classification des sols pour nommer les sols et élaborer des légendes de cartes pédologiques. Mise à jour 2015. 203p. Classification, corrélation and communication, 2nd éd. World Soil Resources Reports No.103, FAO, Rome. 2015;145p. French.
18. Basu S, Roberts JA, Azam-Ali SN, Mayes S. Bambara Groundnut. In: Kole C. (eds) Pulses, Sugar and Tuber Crops. Genome Mapping and Molecular Breeding in Plants, Springer, Berlin, Heidelberg. 2007;3:159-173. . https://doi.org/10.1007/978-3-540-34516-9_10.
19. IPGRI, IITA, BAMNET. Descriptors for Bambara groundnut (*Vigna subterranea*). International Plant Genetic Resources Institute, Rome Italy; International Institute of Tropical Agriculture, Ibadan, Nigeria; The International Bambara Groundnut Network, Germany. 2000;57p.
20. Harouna AI, Bakasso Y, Zoubeirou AM, Doumma A, Maiboucar I. Diagnostic participatif de la diversité de morphotypes et des connaissances locales en matière de culture du Voandzou (*Vigna Subterranea* L.) au Niger. *International Journal of Innovation and Applied Studies.* 2014;9(4):915-1925. French.
21. Ouedraogo M, Ouedraogo JT, Tignere JB, Balma D, Dabire BC and Konate G. Characterization and evaluation of accessions of bambara groundnut (*Vigna subterranean* (L.) Verdc.) from Burkina Faso. *Sciences & Nature.* 2008;5:191-197.
22. Kambou DJ, Nandkangre H, Ouoba A, Konate NM, Sawadogo N, Ouedraogo M, Sawadogo M. Agro-morphological characterization of Bambara nut accessions [*Vigna subterranea* (L) Verdcourt] from Burkina Faso. *Journal of Applied Biosciences.* 2020;153: 15727-15744.
23. Nandkangre H, Ouedraogo M, Nanema KR, Bado S, Ouedraogo N, Sawadogo S. Variability, correlations, heritability and genetic advance of rhizome yield and yield related traits in ginger

- (*Zingiber officinale* Rosc.) landraces from Burkina Faso. *Journal of Applied Environmental and Biological Science*. 2016;6(8):54-60
24. Misangu RN, Azmio A, Reuben SOWM, Kusolwa PM, Mulungu LS. Path coefficient analysis among components of yield in bambara groundnut (*Vigna subterranea* L. Verdc) landraces under screen house conditions. *J. Agron*. 2007;6(2):317-323.
 25. Khan MMH, Rafii MY., Ramlee SI, Jusoh M, Al-Mamun M. 2022. Path-coefficient and correlation analysis in Bambara groundnut (*Vigna subterranea* [L.] Verdc.) accessions over environments. *Sci Rep*. 2022;12, 245. <https://doi.org/10.1038/s41598-021-03692-z>
 26. Djè Y, Bonny BS, Zoro I A. Observations préliminaires de la variabilité entre quelques morphotypes de voandzou (*Vigna subterranea* (L.) Verdc., Fabaceae) de Côte d'Ivoire. *Biotechnologie, Agronomie, Société et Environnement*. 2005;9(4):249-258.
 27. Makanda I, Tongoona P, Madamba1 R, Icishahayo D, Derera J. Evaluation of Bambara groundnut varieties for off-season production in Zimbabwe. *African Crop Science Journal*. 2009;16(3):175-183.
 28. Bonny SB, Dje Y. Variabilité morphologique et agronomique des variétés traditionnelles de voandzou [*Vigna subterranea* (L.) verdc. (*Fabaceae*)] de Côte d'Ivoire. *Journal of Applied Biosciences*. (2011);41:2820-2835.
 29. Issa HA, Agali A, Ousmane DS, Kodo BS. Variabilité morphologique et agronomique des morphotypes de voandzou (*Vigna Subterranea* (L.) cultivés dans la zone sahélienne du Niger. *European Scientific Journal*. 2018;14:377-393.