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Genetic Diversity of African Bambara Groundnut [*Vigna subterranean* (L) Verdc] Landraces for Yield Traits in Southwestern Agro-environments of Nigeria.

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Abstract

Assessment of genetic diversity is crucial in crop improvement programs. This study aimed at assessing genetic diversity in nineteen Bambara groundnut landraces for identification of promising genotypes for yield improvement. Experiment was carried out on the field in 2019 and 2020 cropping seasons at two locations in southwestern agro-environments of Nigeria. Data were collected on seed yield/ha (SY), days to first and 50% flowering (DFF, D50F), pods/plant (POPP), pod length (PODL), maturity (MAT), seeds/pod (SPPO), pod yield/plant (PYPP), seed yield/plant (SYPP), 100-seed weight. The data were subjected to analysis of variance, principal component (PC) and cluster analyses. Genotype (G) was significant for all of the traits at $p \leq 0.01$. Also, location (L), year (Y) and their interactions (GxL, YxG, YxL, YxGxL) were significant for most of the traits. Accessions evaluated in Kishi had a higher seed yield/ha than those in Ile-Ife by 14.59% with seed yield of 1443.78 kg/ha across locations. The first four PCs accounted for75.82%, where PC1 and PC 2 responsible for 55.38% of the total variation. The PC1 was associated with SY, PYPP, SYPP. PC 2 was mainly associated with DFF, D50F, MAT. Phenotypic distance estimates ranged from 0.001 to 0.99 with a mean of 0.32, based on Euclidean-distance. This indicates low level of genetic diversity among bamabara groundnut evaluated, which could be improved through mutation breeding, recombination or hybridization, and introduction. Nineteen accessions were delineated into five clusters. However, nine accessions (47.36%) were homogenous and found in Cluster IV. The members in this cluster had the lowest seed yield and also in other yield contributing traits. Therefore, accessions in clusters II and III had the best yield attributes, which could be selected for release to farmers after further trials.

Keywords: Bambara groundnut, Cluster analysis, Phenotypic distance, Principal component, Seed yield

Introduction

There is an increase in world population from 1.7 billion in 1900 to about 7.2 billion in 2013, with an expectation of increasing to 9.6 billion in 2050 and with over 2 billion people currently faced with protein deficiency, especially among children due to poverty (ISAAA, 2014). This can be linked to over dependence on few crops despite the rich diversity of crop species in Africa(FAO, 2019). The use of some underutilized or orphan crops especially Bambara groundnut is gradually being explored to mitigate the effect of climate change as well as supporting sustainable diets and food systems (Bvenura and Afolayan, 2015). Efficient utilization of these crop species may offer 'new' opportunities in the advent of climate change as they are uniquely suited to local harsh environments, provide nutritional diversity, and enhance agro-biodiversity within farmer fields and home gardens (Mabhaudhi *et al.*, 2019; Popoola et al., 2019).

Bambara groundnut (*Vigna subterranea* (L.) Verdc) is a legume indigenous to Africa and is cultivated across the semi-arid sub-Saharan Africa region (Hillocks et al., 2012). It has different local names by various tribes in Nigeria; for instance, it is known as Epi roro by Yoruba people, Guijiya and Gujuya by Hausa tribe, and Okpa otuanya by Igbo tribe (NRC, 1996). There has been an increasing awareness of its economic importance due to its nutritional potential to alleviate malnutrition and adaptation to low-input production (Alake and Porbeni, 2009; Alake *et al.,* 2015). It is richer in crudeprotein than cowpea, chickpea, and mungbean (Massawe et al., 2002).

However, despite the nutritional potential of Bambara groundnut, it is still classified as underutilized legume due to itslow yield, anti-nutritional factors, difficulty in dehulling (Popoola *et al.*, 2019)as well as hard seed coat, and long cooking time with extra-cost (Ikhajiagbe et al., 2021). For example, in Africa, the seed yield of Bambara groundnut varied between 500-3000 kg/ha with an average yield of 850 kg/ha on farmers' fields (Hillocks *et al.* 2012; Nedumaran *et al.* 2015).The average yield of Bambara groundnut in West Africa was reported to be 703.3 kg/ha by FAO (2017) and between 588.98 to 2991.77 kg/ha by Khan et al. (2021). The low yield could be justly attributed to the fact that there is no well-integrated and collaborative breeding effort among National Agricultural Research Institutes in sub-Saharan Africa (SSA) for its yield improvement, aimed towards its adaptation to various agro-ecologies in SSA, especially in Nigeria. Thus, it is being cultivated as a landrace to date. In order to prevent genetic erosion, it is imperative to evaluate the genetic diversity among available African Bambara groundnut landraces through assessment and characterization for yield improvement.

Although, there was little or no emphasis in the past on conservation of geneticresources, this may have resulted in a significant loss of important genes (also known as genetic erosion) in crop species. As a result, there is increasing awareness on the importance of assessment of genetic diversity in crops (Onwubiko, 2021). Assessment of genetic diversity using isozymes, seed protein electrophoresis, and molecular markers are some of the modern approaches that are readily available for characterization and exploitation of thegenetic diversityof crops in targeted breeding (Pinheiro *et al.* 2010; Lahoz *et al.* 2011). Many studies havebeen carried out on genetic diversity in cultivated Bambara groundnut genotypes using different molecular markers like AFLP, RAPD, SSR markers, diversity arrays technique (DArT) markersetc(Mukakalisa *et al.* 2013; Odongo*et al.* 2015; Han et al., 2020; Uba et al., 2021).

Presently in Nigeria there is no known varieties of underutilized legumes like Bambara groundnut, mung bean, winged bean, sword bean, kidney bean, etc. that have been registered and released. As a result, potential farmers did not have access to quality or improved seed varieties. Although, morphological traits are majorly influenced by the local environment and developmental stages of the plant (Fufa *et al.* 2005; Dey *et al.* 2006). Butit offers considerable opportunities for breeders to utilize genetic resources in developing high yielding genotypes that are tolerant/resistant to biotic and abiotic stresses, thereby alleviating malnutrition and fostering food security in the face of climate change. However, there are few reports on the assessment of genetic diversity using phenotypic or morphological markers in Bambara groundnut (Massawe et al., 2003; Molosiwa et al., 2013; Han et al., 2020). Thus, there is need to evaluate the suitability and adaptability of Bambara groundnut in various agro-ecologies in Nigeria. Therefore, genetic diversity among nineteen Bambara groundnut landraces previously collected from eight countries in Africa was studied using principal component analysis (PCA) and cluster analysis with the ultimate aim of identifying promising Bambara groundnut landraces for yield improvement in Southwestern agro-environments of Nigeria.

Materials and Methods

Experimental site

The research work was carried out at two locations in southwestern agro-ecologies of Nigeria; namely; Ile-Ifein Osun State (Rainforest, latitude 7.55'N, longitude4.56'E, 280 m above sea level) and Kishi in Oyo State(Southern Guinea Savanna agro-ecology; 8.98°N, 3.94°E, 380m above sea level). According to the Food and Agriculture Organization classification system, the dominant soil type in Kishi and Ile-Ife are Ferric luxisols and Ferric lixisols, respectively (Sonneveld 2006). Nigeria has a tropical climate, where mean annual rainfall received in years 2019 and 2020 at the two locations were: 95.50 mm and 75.08 mm in Ile-Ife as well as 77.25 mm and 46.83 mm in Kish. Also, the two locations experienced a mean annual temperature of approximately 27^{0}C in 2019 and 20^{0}C in 2020 (Akinyosoye *et al.,* 2021).

Genetic materials

The Passport data of nineteen accessions of Bambara groundnut obtained from the Genetic Resource Center of International Institute of Tropical Agriculture (IITA), Ibadan, Nigeriaare presented in Table 1.

Table 1: Passport data of accessions of Bambara groundnut obtained from the Genetic Resource Center of IITA, Ibadan, Nigeria

SN	Accession number	Country of origin	Digital object Identifier	Biological status
1	TVSu-368	Nigeria	10.18730/FRSN	Cultivated
2	TVSu-329	Nigeria	10.18730/FQJK	Cultivated
3	TVSu-401	Cameroon	10.18730/FSRF	Cultivated
4	TVSu-424	Cameroon	10.18730/FTDU	Cultivated
5	TVSu-465	Cameroon	10.18730/FVN2	Cultivated
6	TVSu-534	Cameroon	10.18730/FXS~	Cultivated
7	TVSu-689	Zambia	10.18730/G2F=	Cultivated
8	TVSu-200	Benin	10.18730/FM0G	Cultivated
9	TVSu-216	Ghana	10.18730/FMBV	Cultivated
10	TVSu-283	Nigeria	10.18730/FP8E	Cultivated
11	TVSu-1606	Togo	10.18730/GWDE	Cultivated
12	TVSu-1626	Togo	10.18730/GX1$	Cultivated
13	TVSu-1698	Togo	10.18730/GYVJ	Cultivated
14	TVSu-2059	Unknown	10.18730/SS1N*	Cultivated
15	TVSu-1939	Zimbabwe	10.18730/H4JG	Cultivated
16	TVSu-1929	Malawi	10.18730/H486	Cultivated
17	TVSu-1914	Unknown	10.18730/H3SW	Cultivated
18	TVSu-1825	Cameroon	10.18730/H1Z7	Cultivated
19	TVSu-1797	Malawi	10.18730/H1BR	Cultivated

Experimental design and crop management

The trial fields were ploughed and harrowed to provide good soil tilth, obtain good seedling emergence and establishment. Nineteen Bambara groundnut accessions were sown in May and June in Ile-Ife and Kishi, respectively, when the rain had stabilized in 2019 and 2020 during the cropping seasons. Three seeds were sown per hole and later thinned to two, after two weeks. Manual weeding was done and the plot size used for each accession was 2 m by 1.5 m with the spacing of 0.5 m by 0.5 m between and within the rows, respectively. The experiment was laid out in a randomized complete block design with three replications. Weeds were manually removed asat when due,while insect pest was controlled using insecticide, Magic force(R) (Lambda-cyhalothrin 15% + Dimethoate 300 g/L) at 1.5 ml/litrewas used for the control of field insect pests at both vegetative and reproductive stages as recommended by the manufacturer (Anhui Zhongshan Chemical Industries Co. Ltd, China).

Agronomic data collection

Data were carefully collected based on Bambara groundnut descriptors (IPGRI, IITA, BAMNET, 2000) as follows: Days to first flowering(calculated by counting the number of days from planting to when flower was first noticed in a plot), days to 50% flowering(calculated bycounting the number of days from planting towhen 50% of the plants have begun to flower), days to maturity (determined when allthe plants in a plot reached maturity after planting), the number of seeds per pod (counted by randomly selecting ten pods, where number of seeds in each pod were recorded), pod length (measured by randomly selecting ten pods among the harvested pods and measured in cm), number of pods per plant (counted by randomly selecting ten plants and average was recorded), pod yield per plant (calculated by dividing total pods weight in a plot by number of plants at harvest in a plot and measured in gramme), seed yield per plant(calculated by dividing total seeds weight in a plot by number of plants at harvest in a plot and measured in gramme), 100-seed weight (measured by randomly selecting ten pods after harvesting and threshed. Three samples of 100 seeds at 12% moisture content were weighed on electronic balance to obtain average 100-seed weight and measured in gramme), and seed yield/ha (calculated by firstly determining the total number of plants stand per hectare (ha) as: [land area in ha (10,000 m^2) multiplied by number of plants per hole) and divided by spacing]. The seed yield per ha was then calculated as seed yield per plant in kg multiplied by number of plants per ha and measured in kg/ha.

Data analysis

Data obtained were subjected to combined analyses of variance across two locationsusing the Statistical Tool for Agricultural Research (Version: 2.0.1). Principal component (PC) analysis was carried out and components, where Eigen values >1.0 and PC>0.6 were considered as the major contributors to the total variation and were selected (Matus *et al.* 1999). Phenotypic distance between pairs of the Bambara groundnut accessions was calculated using IBM SPSS (Version 23.0, 2015) based on Euclidean distance. Cluster analysis based on Euclidean distance coefficient was obtained with the unweighted pair-group method based on the arithmetic mean (UPGMA) to generate the dendrogram using Palaeontological Statistics (PAST v2.17) software (Hammer *et al.* 2001). The goodness of fit of the dendrogram was confirmed by cophenetic correlation.

Results and Discussion

Analysis of variances, mean performance and coefficients of variation for yield and yield contributing traits of Bambara groundnut accessions at two locations

The combined analysis of variance (ANOVA) for yield and yield contributing traits of the nineteen Bambara groundnut accessions evaluated in 2019 and 2020 at two locations are presented in Table 2. Genotype (G) was significant for all of the traits measured such as seed yield, days to first and 50% flowering, number of pods per plant, pod length, maturity, number of seed per pod, pod and seed weights per plant, as well as 100-seed weight at $p \leq 0.01$. Also, location (L) had significant effects on days to 50% flowering, number of pods per plant, pod length, and 100-seed weight. Year exhibited significant differences in allof the traits measured, except pod length, and 100-seed weight. In addition, G X L, Y x G, Y x L and Y x G x L were significant for most of the traits measured in this study (Table 2).Ntundu *et al*. (2006) reported significant differences among quantitative traits of Bambara groundnut. Significant genotypic variations for the yield contributing traits examined in this study suggest variations in the genetic makeup of the traits and diverse environmental conditions at the experimental locations, which can support genetic improvement. The coefficients of variation (CV) revealed significant variation in Bambara groundnut accessions, with the highest CV (>50%) reported among Bambara groundnut for seed yield/ha, number of pods per plant, pod, and seed yields per plant in this study, across locations (Table 2). The CV, on the other hand, ranged from 1.0% (days to 50% flowering) in Kishi to 90.49% (seed yield per plant) in Ile-Ife (Tables 3, 4), indicating that these traits could aid in effective selection in yield improvement. Others researchers had previously reported the presence of some significant variation as shown by coefficients of variation (CV) in Bambara groundnut (Ntundu et al., 2006; Bonny et al., 2019; Khan et al., 2021).

Mean performance of the accessions of Bambara groundnut for yield and yield contributing traits revealed that Kishi had higher seed yield/ha than those in Ile-Ife by 14.59%. Accessions in Kishi reached days to first and 50% flowering as well as maturity earlier than those in Ile-Ife. Similarly, accessions in Kishi had a higher mean performance for other yield contributing traits in this study (Tables3, 4). Across locations, accessions had an overall mean seed yield/ha of 1443.78 kg/ha and reached first flowering, 50% flowering, and maturity in 45 days after sowing (DAS), 47 DAS, and 126 DAS, respectively (Table 5). Higher seed yield/ha recorded in Kishi than those in Ile-Ife by 14.59%, could due to favourable weather conditions and soil type (Ferric luxisols) predominantly in Kishi (Savanna agroecology). Accessions evaluated in Kishi reached days to first and 50% flowering as well as maturity earlier than those in Ile-Ife. This could be attributed to the indeterminate nature of flower-bearing makes it a vital issue for adjustment mechanism to an environment (Ndiang et al., 2012). Several climatic issues, photoperiod, temperature, altitude, and soil structure, as well as genotypic nature, is responsible to bearing flower in Bambara groundnut (Shegro et al., 2013). The average yield (1443.78 kg/ha) of Bambara groundnut recorded in this study is higher than the estimated average yield for Africa (Hillocks et al., 2012; Nedumaran et al., 2015; FAOSTAT, 2017). The range and mean of days to 50% flowering and maturity obtained in this study were similar to the report of Alake and Alake (2016) who obtained a range of 40-57 DAS with a mean of 47 DAS in 50% flowering and 105-131 DAS with mean of 119 DAS in maturity among forty African Bambara groundnut landraces. Genotypic differences were recorded among the accessions of Bambara groudnut evaluated across locations in this study. Three of the accessions of Bambara groundnut (TVSu1698, TVSu1825 and TVSu1797) had highest seed yield (3118.33- 5206.11 kg/ha) in Ile-Ife. Similarly, three of the accessions of Bambara groundnut (TVSu1825, TVSu1626 and TVSu1698) recorded the highest seed yield (3254.95- 3376.23 kg/ha) in Kishi(Tables 3, 4). Genotypic differences were also obtained among the accessions of Bambara groundnut across locations, where three accessions (TVSu1698, TVSu1825 and TVSu1626) had the highest seed yield (3142.3- 4230.53 kg/ha) (Table 5).Akinyosoye *et al.* (2018, 2021) suggested that any identified promising genotype(s) possessed favourable genes for high yield and their genes are not adversely affected by environmental variables. They may be chosen for an multilocation trials and on-farm evaluation before being released to farmers. The effect of year on seed yield showed that higher seed yield was recorded in 2019 (1789.34 kg/ha) than 2020 (1098.22 kg/ha). Similarly, most of the other yield contributing traits measured had better performance in 2019 than 2020 (Table 6), this could due to higher amount of rainfall received in 2019 than 2020 during evaluation.

Table 2: Combined analysis of variance (ANOVA) for seed yield and yield contributing traits of the nineteen accessions of Bambara groundnut evaluated across locations

	df	SY	DFF	D50F	POPP	PODL	MAT	SPPO	PYPP	SYPP	100SW
Genotype (G)	18	16181041.32**	23.84**	15.30**	4059.86**	0.14**	38.67**	0.64**	13774.36*	9972.78**	1179.52**
Location (L)	1	2941508.47	5.37	41.29**	14452.07**	0.15**	9620.00**	0.14	1881.74	2267.11	631.67*
Year (Y)	1	27226105.68**	289.69**	308.06**	42818.90*	0.01	2254.78**	1.61*	3895.08	15985.50**	621.72
REP within year	4	469964.91	4.87	4.67	4904.57**	0.03*	3.60**	0.09	1139.44	433.77	376.24*
G X L	18	3077679.07**	21.73**	15.66**	5276.91**	0	40.51**	0	2830.87**	1982.35**	180.39
Y x G	18	5877831.78**	7.53**	7.65**	1258.62	0	60.32**	0.33*	3877.34**	3738.30**	127.6
Y x L	1	33392610.96**	276.32**	289.64**	2840.33	0	2254.78**	0	32350.92**	21875.42**	38.34
Y x G x L	18	8750013.81**	7.72**	7.51**	2052.80*	0	56.27**	0	6671.17**	5400.71**	111.45
Pooled error	148	183798058.6	375.18	380.3	163864.95	1.93	950.93	16.75	148617.8	118392.73	18340.53
Mean		1443.78	44.86	47.18	64.82	0.98	133.36	1.31	44.21	36.27	63.18
CV%		75.2	3.52	3.4	50.55	11.66	1.89	25.77	70.82	76.38	17.55
SE		128.84	0.2	0.19	3.02	0.01	0.6	0.03	3.62	3.23	0.98

*, **Significant at ($P \leq 0.05$), and ($P \leq 0.01$), respectively; ns: non-significant; SE: standard error of mean; SY: seed yield/ha (kg/ha);; CV%: percentage coefficient of variation; DFF: days to first flowering; D50F: days to 50% flowering; POPP: number of pods per plant; PODL: pod length (cm); MAT: days to maturity; SPPO: number of seeds per pod; PYPP: pod yield/plant (g); SYPP: seed yield per plant (g); 100SW: 100-seed weight (g)

Table3: Mean values and coefficients of variation for yield and yield contributing traits of Bambara groundnut accessions evaluated in Ile-Ife

Accession	SY	DFF	D50F	POPP	PODL	MAT	SPPO	PYPP	SYPP	100SW
TVSu1698	5206.11	43.33	48.25	66.74	1.05	129.83	1.08	145.49	130.15	52.5
TVSu1825	3353.67	42.33	45.17	60.61	0.95	127.67	1.54	102.92	82.92	65.83
TVSu1797	3118.33	42.33	47	50.78	1.1	122.83	1.46	98.12	77.96	80.83
TVSu200	2927.34	45.67	48.42	61.51	1.04	130.33	1.38	81.79	73.19	69.17
TVSu1626	2916.67	42.83	47.83	45.28	0.94	129.83	1.25	82.25	72.92	49.83
TVSu329	2360.58	43.5	46	35.76	1.01	128	1.14	68.34	59.01	79.17
TVSu1606	1420	50	52	54.67	0.8	123	0.83	69.17	35.5	47.83
TVSu368	1270.03	43.5	45.67	35.92	0.9	128.17	1.25	39.26	31.75	53.83
TVSu689	920.03	45	47.17	78.19	1.1	121.83	1	30.71	23	75.83
TVSu1929	913.4	43.17	46.17	63.54	0.81	129.17	1.25	32.7	22.85	82.5
TVSu283	360.07	46.5	48.83	61.29	0.94	132.83	1.25	12.54	9	52.5
TVSu1914	286.69	43.5	46	56.83	0.9	129	1.12	12.68	7.17	52.5
TVSu401	150.01	43.5	45	57.38	0.94	129	1.12	4.07	2.5	75.83
TVSu465	66.71	43.33	45.83	17.17	0.9	131.33	1.62	3.77	1.25	66.83
TVSu534	2.26	48	49	58.86	0.84	122.67	1.5	0.19	0.06	67.17
TVSu1939	1.14	43.17	45.83	44.71	1.21	127.33	1.12	1.13	0.03	53.5
TVSu2059	0.36	46.33	48	91.67	0.9	122	1.75	0.09	0.01	43.83
TVSu424	0.19	47	48.67	82.58	0.87	122	1.5	0.13	0	45.17
TVSu216	0.14	52.33	53.67	56.83	0.87	123.67	1.25	0.02	0.01	54.17
Mean	1330.2	45.02	47	56.86	0.95	126.87	1.29	41.34	33.12	61.52
F test	**	**	**	*	**	**	**	**	**	**
CV%	89.92	4.38	4.65	52.25	11.96	2.79	26.28	80.13	90.49	21.99
LSD	1798.07	2.56	2.59	53.68	0.02	4.08	0.38	51.12	51.12	2.71

*' **'Significant at (P≤0.05), and (P≤ 0.01), respectively; ns: non-significant; LSD: Least significant difference at p=0.05; CV%: percentage coefficient of variation; SY: seed yield/ha (kg/ha); DFF: days to first flowering; D50F: days to 50% flowering; POPP: number of pods per plant; PODL: pod length (cm); MAT: days to maturity; SPPO: number of seeds per pod; PYPP: pod yield/plant (g); SYPP: seed yield per plant (g); 100SW: 100-seed weight (g)

Table 4: Mean values and coefficients of variation for yield and yield contributing traits of Bambara groundnut accessions evaluated in Kishi

Accession	SY	DFF	D50F	POPP	PODL	MAT	SPPO	PYPP	SYPP	100SW
TVSu1825	3376.23	44.5	46.67	115.01	1	140	1.59	104.34	84.41	72.33
TVSu1626	3367.94	44.83	46.67	115.33	0.99	139.33	1.3	95.11	84.2	61
TVSu1698	3254.95	44.83	46.83	91.04	1.1	139.67	1.13	95.2	81.37	66.58
TVSu1797	1947.11	44.5	47.17	85.5	1.16	140.33	1.51	61.64	48.68	75.83
TVSu200	1886.42	44.83	46.83	123.96	1.09	140.33	1.42	57.58	47.16	67.5
TVSu329	1700.48	44.67	46.83	128.88	1.05	140	1.19	61.93	42.51	73.17
TVSu1914	1672.5	44.67	46.67	139.88	0.95	138.83	1.18	50.11	41.81	56.67
TVSu1929	1610.29	44.5	46.8	45.55	0.86	139.67	1.3	49.71	40.26	71.67
TVSu689	1430.32	44.67	46.67	45.29	1.16	139.67	1.05	55.63	35.76	66.67
TVSu2059	1345.79	44.83	46.83	48.5	0.95	139.83	1.8	33.65	33.64	48.33
TVSu1939	1269.53	44.67	46.67	50.25	1.25	140	1.18	37.11	31.74	64
TVSu216	1222.83	44.83	46.67	66.08	0.92	140.17	1.3	30.93	30.57	57.5
TVSu368	1221.6	44.67	46.5	44.38	0.95	140	1.3	36.8	30.54	56.67
TVSu424	1132.41	44.67	46.67	51.17	0.92	140	1.55	28.59	28.31	64.17
TVSu401	840.37	44.67	46.67	60.62	0.99	140	1.18	36.54	30.38	77.5
TVSu283	837.29	44.67	46.67	25.54	0.99	139.83	1.3	22.46	20.93	61.67
TVSu465	825.1	44.83	47	49.71	0.95	140.17	1.68	20.64	20.63	67.5
TVSu534	640.48	44.83	46.83	35.92	0.92	140	1.55	16.36	16.01	68.83
TVSu1606	8.31	44.83	46.67	60.25	0.85	139.5	0.88	0.21	0.21	54.5
Mean	1557.37	44.71	46.75	72.78	1	132.52	1.34	47.08	39.43	64.85
F test	**	Ns	Ns	**	**	**	**	**	**	**
CV%	61.81	1.14	1	48.87	11.36	0.34	25.29	62.42	64.01	12.22
LSD	1798.07	2.56	2.59	53.68	0.02	7.41	0.38	51.12	51.12	2.91

*' **'Significant at (P≤0.05), and (P≤ 0.01), respectively; ns: non-significant; LSD: Least significant difference at p=0.05; CV%: percentage coefficient of variation SY: seed yield/ha (kg/ha); DFF: days to first flowering; D50F: days to 50% flowering; POPP: number of pods per plant; PODL: pod length (cm); MAT: days to maturity; SPPO: number of seeds per pod; PYPP: pod yield/plant (g); SYPP: seed yield per plant (g); 100SW: 100-seed weight (g)

Table 5: Mean values and coefficients of variation for yield and yield contributing traits of Bambara groundnut accessions evaluated acrosslocations

Accession	SY	DFF	D50F	POPP	PODL	MAT	SPPO	PYPP	SYPP	100SW
TVSu1698	4230.53	44.08	47.54	78.89	1.08	134.75	1.11	120.34	105.76	59.54
TVSu1825	3364.95	43.42	45.92	87.81	0.98	133.83	1.57	103.63	83.67	69.08
TVSu1626	3142.3	43.83	47.25	80.31	0.96	134.58	1.27	88.68	78.56	55.42
TVSu1797	2532.72	43.42	47.08	68.14	1.13	131.58	1.48	79.88	63.32	78.33
TVSu200	2406.88	45.25	47.62	92.73	1.07	135.33	1.4	69.69	60.17	68.33
TVSu329	2030.53	44.08	46.42	82.32	1.03	134	1.16	65.14	50.76	76.17
TVSu1929	1261.84	43.83	46.45	54.55	0.84	134.42	1.27	41.2	31.55	77.08
TVSu368	1245.81	44.08	46.08	40.15	0.93	134.08	1.27	38.03	31.15	55.25
TVSu689	1175.18	44.83	46.92	61.74	1.13	130.75	1.02	43.17	29.38	71.25
TVSu1914	979.6	44.08	46.33	98.35	0.93	133.92	1.15	31.39	24.49	54.58
TVSu1606	714.16	47.42	49.33	57.46	0.83	131.25	0.86	34.69	17.85	51.17
TVSu2059	673.08	45.58	47.42	70.08	0.93	130.92	1.77	16.87	16.83	46.08
TVSu1939	635.34	43.92	46.25	47.48	1.23	133.67	1.15	19.12	15.89	58.75
TVSu216	611.49	48.58	50.17	61.46	0.9	131.92	1.27	15.47	15.29	55.83
TVSu283	598.68	45.58	47.75	43.42	0.96	136.33	1.27	17.5	14.97	57.08
TVSu424	566.3	45.83	47.67	66.88	0.9	131	1.52	14.36	14.16	54.67
TVSu401	495.19	44.08	45.83	59	0.96	134.5	1.15	20.31	16.44	76.67
TVSu465	445.9	44.08	46.42	33.44	0.93	135.75	1.65	12.2	10.94	67.17
TVSu534	321.37	46.42	47.92	47.39	0.88	131.33	1.52	8.28	8.03	68
Mean	1443.78	44.86	47.18	64.82	0.98	133.36	1.31	44.21	36.27	63.18
F test	**	**	**	**	**	**	**	**	**	**
CV%	75.2	3.52	3.4	50.55	11.66	1.89	25.77	70.82	76.38	17.55
LSD	1820.04	0.69	0.71	10.97	0.01	2.54	0.28	51.85	46	2.4

*, **, Significant at (P≤0.05), and (P≤ 0.01), respectively; ns: non-significant; LSD: Least significant difference at p=0.05; CV%: percentage coefficient of variation SY: seed yield/ha (kg/ha); DFF: days to first flowering; D50F: days to 50% flowering; POPP: number of pods per plant; PODL: pod length (cm); MAT: days to maturity; SPPO: number of seeds per pod; PYPP: pod yield/plant (g); SYPP: seed yield per plant (g); 100SW: 100-seed weight (g)

Principal component analysis for yield and yield contributing traits of Bambara groundnut accessions

The first four principal components (PC) with Eigen values greater than 1.0, accounted for about 75.82% of the total variation. The relative discriminating power of the PCA as revealed by Eigen value was 3.02, 2.01, 1.04, and 1.0 for PC1, PC2, PC3, PC3, and PC4 respectively with corresponding contributions of 32.16%, 23.22 %, 10.32%, and 10.11%, respectively (Table7). The PC1 is associated primarily with yield characters (seed yield/ha, pod, and seed yield per plant) with positive loading. PC 2 was mainly responsible for flowering (days to first flowering, 50% flowering, and physiological maturity) with positive loading. The traits that contributed the most positive loadings to the PC 3 were 100-seed weight and number of pods per plant, while PC 4 was associated with the number of seeds per pod with positive loading. The results obtained are corroborated by the findings of Khan et al. (2021) who reported 73.48% from the first four principal components among the Bambara groundnut accessions evaluated. PC1 and PC 2 accounted for 55.38% of the variation, which was associated mainly with yield characters and flowering, respectively. This indicates that pod yield per plant, seed yield per plant, days to first flowering, days to 50 % flowering, physiological maturity, 100-seed weight, and the number of seed per pod were adjudged as major contributors to the total variation having PC values > 0.6 (Matus et al., 1999) in this study. Therefore, these identified yield contributing traits would be useful in effective selection in bamabra groundnut improvement.

Table 6: Mean values and coefficients of variation for yield and yield contributing traits of Bambara groundnut accessions evaluated in 2019 and 2020

Accession	SY		DFF		D50F		POPP		PODL	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
TVSu1606	996.98	431.33	47.5	47.33	49.5	49.17	57.46	57.46	0.83	0.82
TVSu1626	4452.38	1832.22	45	42.67	49.17	45.33	79.92	80.69	0.97	0.96
TVSu1698	6586.06	1875	45.17	43	49.25	45.83	92.03	65.75	1.08	1.07
TVSu1797	3142.67	1922.78	44.83	42	49.17	45	76.99	59.29	1.14	1.12
TVSu1825	4806.78	1923.11	44.83	42	47.33	44.5	104.3	71.28	0.98	0.97
TVSu1914	392.53	1566.67	44.83	43.33	47.33	45.33	114.5	82.17	0.94	0.92
TVSu1929	734.8	1788.89	44.83	42.83	47.5	45.2	57.21	51.88	0.84	0.83
TVSu1939	707.34	563.33	45.17	42.67	47.33	45.17	56.29	38.67	1.23	1.23
TVSu200	3083.09	1730.67	48	42.5	49.75	45.5	119.1	66.38	1.07	1.06
TVSu2059	926.02	420.13	45.5	45.67	47.33	47.5	83.5	56.67	0.94	0.92
TVSu216	758.06	464.92	48.67	48.5	50	50.33	83.5	39.42	0.9	0.89
TVSu283	529.32	668.04	47.33	43.83	49.33	46.17	45.83	41	0.97	0.96
TVSu329	2063.83	1997.22	45.83	42.33	47.67	45.17	98.65	65.99	1.04	1.02
TVSu368	1471.63	1020	45.83	42.33	47.83	44.33	59.46	20.83	0.94	0.92
TVSu401	682.05	308.33	45.83	42.33	47.33	44.33	101.5	16.5	0.97	0.96
TVSu424	710.28	422.32	45.83	45.83	47.67	47.67	80.46	53.29	0.9	0.89
TVSu465	498.27	393.54	46	42.17	47.83	45	54.04	12.83	0.94	0.92
TVSu534	341.72	301.01	46.5	46.33	48	47.83	55.51	39.26	0.88	0.88
TVSu689	1113.69	1236.67	46.33	43.33	49.17	44.67	71.65	51.83	1.14	1.12
Mean	1789.34	1098.22	45.99	43.74	48.34	46	78.52	51.12	0.98	0.97
LSD	1798.07	1798.07	2.57	2.56	2.59	2.59	53.68	53.68	0.16	0.16

Accession	MAT		SPPO		PYPP		SYPP		100SW	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
TVSu1606	131.33	131.17	0.86	0.86	37.59	31.79	24.92	10.78	52.83	49.5
TVSu1626	131.17	138	1.52	1.02	118.3	59.06	111.3	45.81	53.83	57
TVSu1698	131.33	138.17	1.19	1.02	174	66.71	164.7	46.88	60.33	58.75
TVSu1797	127.17	136	1.61	1.36	90.25	69.51	78.57	48.07	85	71.67
TVSu1825	131.17	136.5	1.44	1.69	133.1	74.15	120.2	47.16	70.83	67.33
TVSu1914	129.83	138	1.27	1.02	10.79	52	9.82	39.17	59.17	50
TVSu1929	129.83	139	1.52	1.02	19.85	62.56	18.38	44.72	73.33	80.83
TVSu1939	130	137.33	1.27	1.02	17.96	20.28	17.69	14.08	59.5	58
TVSu200	132.67	138	1.77	1.02	81.01	58.37	77.08	43.27	69.17	67.5
TVSu2059	131	130.83	1.77	1.77	23.19	10.55	23.15	10.51	49	43.17
TVSu216	132	131.83	1.27	1.27	19.18	11.77	18.95	11.62	58.33	53.33
TVSu283	132.17	140.5	1.52	1.02	14.07	20.92	13.23	16.7	57.5	56.67
TVSu329	129.67	138.33	1.3	1.02	55.66	74.61	51.6	49.93	82.33	70
TVSu368	129.67	138.5	1.52	1.02	39.69	36.37	36.79	25.5	58.17	52.33
TVSu401	128.5	140.5	1.27	1.02	15.88	24.73	15.8	17.08	79.17	74.17
TVSu424	131	131	1.52	1.52	18	10.73	17.76	10.56	50.5	58.83
TVSu465	131.17	140.33	1.27	2.02	12.15	12.26	12.04	9.84	63.83	70.5
TVSu534	131.33	131.33	1.52	1.52	8.8	7.76	8.54	7.53	70.67	65.33
TVSu689	123.17	138.33	1.02	1.02	29.03	57.32	27.84	30.92	78.33	64.17
Mean	130.22	136.51	1.39	1.22	48.34	40.08	44.65	27.9	64.83	61.53
LSD	4.08	4.08	0.3	0.21	51.12	51.12	45.64	45.63	48.61	45.1

LSD: Least significant difference at p=0.05;SY: seed yield/ha (kg/ha); DFF: days to first flowering; D50F: days to 50% flowering; POPP: number of pods per plant; PODL: pod length (cm); MAT: days to maturity; SPPO: number of seeds per pod; PYPP: pod yield/plant (g); SYPP: seed yield per plant (g); 100SW: 100-seed weight (g)

Clustering of Bambara groundnut accessions

Phenotypic distance (PD) estimates based on Euclidean distance of Bambara groundnut accessions ranged from 0.001 (TVSu-1939 and TVSu-216; TVSu-1939 and TVSu-283; TVSu-216 and TVSu-283; TVSu-1929 and TVSu-368) to 0.99 (TVSu-1698 and TVSu-534) with a mean of 0.32 (Table 8). This connotes that some of the accessions obtained from Nigeria, Ghana, Malawi, and Zimbabwe were morphologically closely related to other countries, whereas there was wide morphological variation in some of the accessions from Togo and Cameroon. The low level of genetic diversity obtained in this study, could due to the fact that most of the subsistence resource-limited farmers in Africa generally tend to exchange seeds frequently. This assertion is supported by findings of

Abu and Buah (2011) who reported a high frequency of Bambara groundnut seed exchange by farmers over wide geographic-ethnic regions as well as the different informal names given to landraces from one region to another which may give room for genotype duplications.

Table7: Characters with respect to its principal component, Eigen values and variation of Bambara groundnut accessions evaluated across locations

Traits	PC 1	PC 2	PC 3	PC 4
Seed yield (kg/ha)	0.95*	-0.23	-0.16	0.01
Days to 1st flowering	0.27	0.86*	0.09	-0.02
Days to 50% flowering	0.43	0.83*	0.05	-0.08
Number of pods per plant	0.35	0.14	0.56*	0.05
Pod length (cm)	0.24	-0.36	0.47	-0.21
Days physiological maturity	-0.23	0.69*	-0.06	0.1
Number of seed per pod	0.05	0.18	-0.17	0.90*
Pod yield per plant(g)	0.94*	-0.25	-0.14	-0.03
Seed yield per plant (g)	0.96*	-0.23	-0.16	0.01
100-seed weight (g)	0.15	-0.24	0.62*	0.38
Eigen value	3.02	2.01	1.04	1
% of Variance	32.16	23.22	10.32	10.11
Cumulative %	32.16	55.38	65.7	75.82

*component contributors; PC: principal component

The goodness of fit of the dendrogram was based on cophenetic correlation (rcop) was 0.86. Accessions of Bambara groundnut were delineated into five clusters at a rescaled distance of 500 units (Figure 1); cluster I consisted of three accessions (TVSu-1797, TVSu-200, and TVSu-329), which were previously originated from Malawi, Benin Republic, and Nigeria. The members of this group had the moderate seed yield/ha, moderate pods per plant, moderate pod and seed yields per plant as well as moderate 100-seed weight (Figure 1, Table 9, 10). Cluster II had two accessions (TVSu-1626 and TVSu-1825) from Togo and Cameroon, respectively. The members of this cluster had second highest number of pods per plant and 100-seed weight as well as second highest seed yield/ha, pod, and seed yield per plant. Cluster III is made up of only one accession (TVSu-1698), which was initially obtained from Togo. This accession had the highest seed yield/ha, pod, and seed yield per plant as well as a high number of pods per plant and 100-seed weight. Nine accessions (TVSu-1939, TVSu-216, TVSu-283, TVSu-424, TVSu-2059, TVSu-1606, TVSu-401, TVSu-465, TVSu-534) (47.36%) out of 19 accessions, were found in cluster IV. The members of this group recordedlowest seed yield/ha, lowest pods per plant, pod and seed yield per plant, and the lowest 100-seed weight. Cluster V had four members (TVSu-1914,TVSu-1929, TVSu-368, TVSu-689) (Figure 1, Table 9, 10). The members of this group had moderate had the second lowest seed yield/ha, pods per plant, pod and seed yields per plant as well as moderate 100-seed weight. Hence, accessions from clusters II and III were heterogeneous and high-yielding. This signals the possibility of using these promising landraces as parents for hybridization in improvement programs(Booyet al., 2000). Nine (47.36%) out of 19 accessions accessions evaluated in this study were found in Cluster IV. This indicates that most of the accessions in this cluster were homogenous and could have originated from the same source, but given different local names. Also, the lowest yield obtained in cluster IV, could due to low diversity among the accessions. Akande (2007) suggested that through mutation breeding, introduction, recombination, and selection, improved varieties which are more productive than those currently grown by farmers can be developed.

Table8: Estimates of genetic distance for Bambara groundnut accessions evaluated across locations.

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	0.62	0.9	0.46	0.68	0.06	0.14	0.02	0.43	0.01	0.02	0.02	0.33	0.13	0.05	0.03	0.06	0.1	0.11
2	1	0.27	0.15	0.05	0.55	0.48	0.64	0.18	0.63	0.65	0.65	0.28	0.48	0.68	0.66	0.69	0.72	0.5
3		1	0.43	0.22	0.83	0.76	0.92	0.46	0.91	0.93	0.93	0.56	0.76	0.96	0.94	0.97	0.99	0.78
4			1	0.21	0.39	0.32	0.48	0.03	0.47	0.49	0.49	0.12	0.33	0.52	0.5	0.53	0.56	0.34
5				1	0.61	0.54	0.7	0.24	0.69	0.7	0.71	0.34	0.54	0.73	0.71	0.75	0.78	0.56
6					1	0.07	0.08	0.36	0.07	0.09	0.09	0.27	0.06	0.12	0.1	0.13	0.16	0.05
7						1	0.16	0.29	0.15	0.16	0.17	0.19	0	0.19	0.17	0.2	0.24	0.02
8							1	0.45	0.01	0	0	0.35	0.15	0.03	0.01	0.04	0.08	0.13
9								1	0.44	0.46	0.46	0.09	0.29	0.49	0.47	0.5	0.53	0.31
10									1	0.01	0.02	0.34	0.14	0.04	0.02	0.05	0.09	0.12
11										1	0	0.36	0.16	0.03	0.01	0.04	0.07	0.14
12											1	0.36	0.16	0.02	0.01	0.03	0.07	0.14
13												1	0.2	0.39	0.37	0.4	0.43	0.21
14													1	0.19	0.17	0.2	0.23	0.01
15														1	0.01	0.01	0.04	0.17
16															1	0.03	0.06	0.15
17																1	0.03	0.18
18																	1	0.21
19																		1

1: TVSu-1606; 2: TVSu-1626; 3: TVSu-1698; 4: TVSu-1797; 5: TVSu-1825; 6: TVSu-1914; 7: TVSu-1929; 8: TVSu-1939; 9: TVSu-200; 10: TVSu-2059; 11: TVSu-216; 12: TVSu-283; 13: TVSu-329; 14: TVSu-368; 15: TVSu-401; 16: TVSu-424; 17: TVSu-465; 18: TVSu-534; 19: TVSu-689

Table9: Means characteristics of Bambara groundnut accessions evaluated across locations

Cluster	1	2	3	4	5
Member	3	2	1	9	4
Seed yield (kg/ha)	2323.38	3253.63	4230.53	562.39	1165.61
Days to 1st flowering	44.25	43.63	44.08	45.72	44.21
Days to 50% flowering	47.04	46.59	47.54	47.64	46.45
Number of pods per plant	81.06	84.06	78.89	54.07	63.7
Pod length (cm)	1.08	0.97	1.08	0.95	0.96
Days physiological maturity	133.64	134.21	134.75	132.96	133.29
Number of seed per pod	1.35	1.42	1.11	1.35	1.18
Pod yield per plant(g)	71.57	96.16	120.34	17.64	38.45
Seed yield per plant (g)	58.08	81.12	105.76	14.49	29.14
100-seed weight (g)	74.28	62.25	59.54	59.49	64.54

Table10: Sources of Bambara groundnut accessions of each of the four clusters.

Clusters	Members	Country of origin
1	TVSu-1797	Malawi
	TVSu-200	Benin Republic
	TVSu-329	Nigeria
2	TVSu-1626	Togo
	TVSu-1825	Cameroon
3	TVSu-1698	Togo
4	TVSu-2059	Unknown
	TVSu-283	Nigeria
	TVSu-1939	Zimbabwe
	TVSu-216	Ghana
	TVSu-1606	Togo
	TVSu-401, TVSu-465, TVSu-534, TVSu-424	Cameroon
5	TVSu-1914	Unknown
	TVSu-1929	Malawi
	TVSu-368	Nigeria
	TVSu-689	Zambia

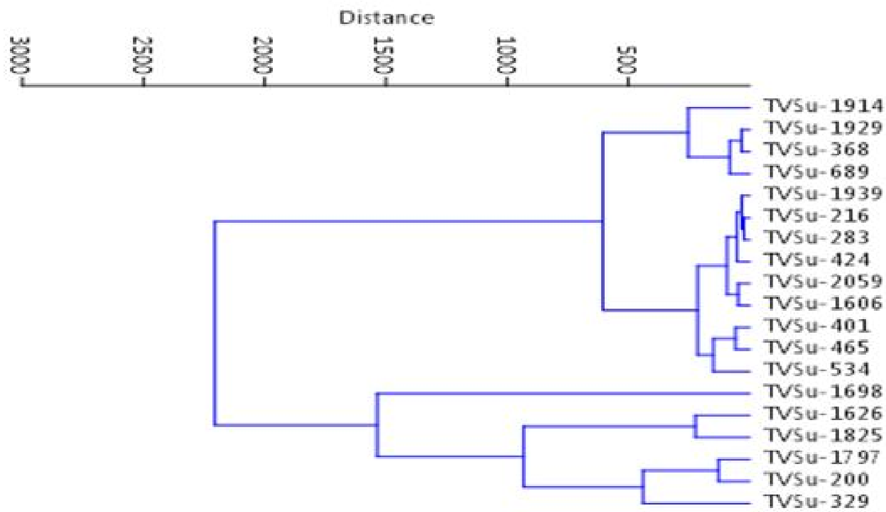

Figure1: Dendrogram of the 19 Bambara groundnut accessions evaluated across two locations based on hierarchical clustering using squared Euclidean distance showing the five clusters formed at the rescaled distance of 500 units

Conclusion

The results obtained revealed a low level of genetic diversity among African Bambara groundnut accessions evaluated. The accessions were delineated into five clusters with accessions in cluster II (TVSu-1626, TVSu-1825) and III (TVSu-1698), had the best yield attributes. Therefore, these accessions could be selected for eventual release to farmers after further trials. Also, pod yield/plant, seed yield/plant, days to first flowering and 50% flowering, maturity, 100-seed weight, and the number of seed per pod were adjudged as major contributors to total variation. Thus, identified traits could facilitate higher precision in Bambara groundnut varietal selection.

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