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Morphological Diversity of Some Nigerian Accessions of Bambara Groundnut (*Vigna subterranea*)

Opeyemi T. Osundare[1,2,*], Benjamin O. Akinyele[3], Alexander C. Odiyi[3], Olaniyi A. Oyatomi[2], Rajneesh Paliwal[2], Michael T. Abberton[2]

[1]Department of Crop Science and Horticulture, Federal University Oye-Ekiti, Ekiti State, Nigeria
[2]Genetic Resources Center, International Institute of Tropical Agriculture, Ibadan, Nigeria
[3]Department of Crop, Soil and Pest management, Federal University of Technology, Akure, Nigeria

Abstract Increasing effort in the selection of genotypes with superior and desired traits is important for crop improvement, to achieve food and nutritional security in the increasing world population. Hence, this study evaluated the morphological diversity of some Nigerian accessions of Bamabara groundnut. Field experiments were conducted in Nigeria for three years in two locations to assess phenotypic variation of Bambara groundnut accessions based on morphological traits in 2017. Randomized complete block design (RCBD) was used in the evaluation of the selected accessions for three years. Twenty-eight quantitative and ten qualitative traits were observed and subjected to statistical analysis using SAS, version 9.4 software. Twenty-three out of the twenty-eight quantitative morphological traits showed significant differences. TVSu-589 and TVSu-670 had the highest plant height, TVSu-572, TVSu-271 and TVSu-336 had the highest 100-seed weight. Qualitative traits analysis also showed variation. Principal component analysis (PCA) showed PC1 constituting 23.36% and PC2 constituting 15.76% of total variation, while the first eight PCs with eigen values ≥ 1 revealed 77.28% of the total variation. Cluster analysis grouped the selection into four groups. Based on yield data in this study, accessions TVSu-594, TVSu-350, TVSu-336, TVSu-1242, TVSu-129, TVSu-14, TVSu-179, TVSu-2100, TVSu-261, and TVSu-589 were the best for yield and are recommended for further evaluation to improve yield. This study showed that wide range of diversity exists in Bambara groundnut of Nigerian origin that could be useful for further utilization of genetic resources and improvement.

Keywords Cluster analysis, Nigerian accessions, Bambara groundnut, *Vigna subterranea*

1. Introduction

Bambara groundnut has the potential to improve nutrition, boost food security, foster rural development and support sustainable land use. Bambara groundnut is indigenous to sub-Sahara Africa where it is widely cultivated. The centre of origin is North-Eastern Nigeria, in West Africa [1,2]. This plant is referred to as a 'groundnut' because of the way it sets its pods, which is similar to groundnut (*Arachis hypogea)*. The seeds of Bambara groundnut are consumed in several ways and at different stages of maturation, as snack or vegetable. The young fresh seeds may be boiled and eaten as a snack in a manner similar to boiled peanut, and are made into a pudding (or steamed-paste) called Moi-Moi or Okpa (bean porridge) in some parts of Nigeria [3]. In Zambia, Bambara groundnut is used for bread making [4], and to produce legume milk [5]. Dried seeds can be roasted and eaten as confectionery. For centuries, Bambara groundnut germplasm has been maintained as landraces, which are often phenotypically and genetically diverse [6]. All cultivated Bambara groundnut genotypes are from farmers' mass selection from landraces that have evolved directly from their wild relatives, and which have adapted to the natural environments [7]. Osundare et al. [8] reported that domesticated Bambara groundnut (*Vigna subterranean* var. *subterranea*) originated from its wild relative (*V. subterranea* var. *spontanea*) through a series of gradual natural and artificial selections that are still taking place. One example of such selection is a change from a spreading / trailing to a bunching growth habit, and reductions in leaflet area, pod thickness and days to flowering as a result of domestication. Adaptation to harsh environmental conditions and yield stability are characteristics that made landraces of Bambara groundnut farmers-friendly [9]. The Bambara groundnut landraces can be systematically exploited in breeding programmes through a dedicated pre-breeding programme. Selection for genotypes will continue in mitigating the effects of climate change and enhancing the responsiveness of the crop to drought. Rex Bernardo [9] also reported that selection of good parents is a key to success in plant breeding. This study provided more

* Corresponding author:
opeyemi.osundare@fuoye.edu.ng (Opeyemi T. Osundare)
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estimation of morphological diversity as well as traits that are more diverse and considerable for further evaluation to improve the crop. Hence, this research assessed agronomic variability of 100 Nigerian bambara groundnut accessions by means of 28 quantitative and 10 qualitative agro-morphological traits. The study of the agronomic variability of these accessions could be interesting as a first step toward bambara breeding programme establishment in Nigeria.

2. Materials and Methods

2.1. Plant Material and Experimental Location

The study was carried out at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria and its research station, located at the Institute of Agricultural Research and Training (IAR&T) Ikenne, Nigeria for three years (2017/2018, 2018/2019 and 2019/2020). Ibadan is located on coordinate's 7.38°N and 3.94°E and it is situated at 181 meters above sea level. The average annual temperature is 26.5℃ and about 1311 mm of precipitation falls annually with 81% mean relative humidity. Ikenne is on coordinate's 6.87°N and 3.71°E and 235.2 meters above sea level, has an annual rainfall of 1200 mm, 65% mean relative humidity and 21.4℃ mean temperature respectively. Seeds of one hundred accessions of Bambara groundnut (Table 1) were collected from the list of Genetic Resources Center (GRC), of IITA in 2017 and used for the field experiments. The accessions were previously reported in Osundare et al. [10]. The accessions were selected to guide future research in the selection of genetic resources with thoroughly catalogued agronomic and genomic traits linked to genebank accessions, and to make data publicly available. The selection was also made to identify which of the thousands of the accessions in a database is high yielding, as a critical step in food security.

2.2. Experimental Design and Field Management

The experiments were laid out in a Randomized Complete Block Design (RCBD) with three replications. Total block size was (21 m × 50 m) and each plot was 1 m × 2.5 m. Inter and intra row spacing was 1.00 m and 0.25 m. One seed was hand sown per hole, seed germination count was carried out and supply was done two weeks after planting. Systemic and pre-emergence herbicide (Metaforce with active ingredient (a.i.) Metolachlor E.C) and contact herbicide (Paraeforce a.i. paraquat) were used to control weed at the rate of 200 milligram per 20 liters.

Table 1. List of the 100 Bambara groundnut accessions used for the experiment

S/N	Accessions	S/N	Accessions	S/N	Accessions	S/N	Accessions
1	TVSu--336	26	TVSu--570	51	TVSu--2101	76	TVSu--650
2	TVSu--644	27	TVSu--334	52	TVSu--2106	77	TVSu--579
3	TVSu--355	28	TVSu--670	53	TVSu--277	78	TVSu--590
4	TVSu--2093	29	TVSu--651	54	TVSu--330	79	TVSu--356
5	TVSu--589	30	TVSu--2094	55	TVSu--2090	80	TVSu--2102
6	TVSu--267	31	TVSu--357	56	TVSu--2105	81	TVSu--275
7	TVSu--127	32	TVSu--656	57	TVSu--576	82	TVSu--2108
8	TVSu--2104	33	TVSu--647	58	TVSu--2095	83	TVSu--361
9	TVSu--1241	34	TVSu--1239	59	TVSu--640	84	TVSu--261
10	TVSu--119	35	TVSu--256	60	TVSu--675	85	TVSu--34
11	TVSu--349	36	TVSu--359	61	TVSu--662	86	TVSu--262
12	TVSu--844	37	TVSu--331	62	TVSu--2099	87	TVSu--12
13	TVSu--278	38	TVSu--577	63	TVSu--2109	88	TVSu--586
14	TVSu--2110	39	TVSu--838	64	TVSu--179	89	TVSu--1252
15	TVSu--348	40	TVSu--366	65	TVSu--367	90	TVSu--351
16	TVSu--1222	41	TVSu--633	66	TVSu--365	91	TVSu--268
17	TVSu--1242	42	TVSu--269	67	TVSu--83	92	TVSu--347
18	TVSu--602	43	TVSu--572	68	TVSu--627	93	TVSu--2100
19	TVSu--82	44	TVSu--181	69	TVSu--346	94	TVSu--368
20	TVSu--2112	45	TVSu--287	70	TVSu--81	95	TVSu--1245
21	TVSu--173	46	TVSu--178	71	TVSu--350	96	TVSu--363
22	TVSu--263	47	TVSu--271	72	TVSu--639	97	TVSu--1246
23	TVSu--659	48	TVSu--273	73	TVSu--280	98	TVSu--2103
24	TVSu--667	49	TVSu--285	74	TVSu--129	99	TVSu--585
25	TVSu--14	50	TVSu--340	75	TVSu--333	100	TVSu--594

2.3. Data Collection

Twenty eight quantitative traits were collected using the descriptor for Bambara groundnut [11] (Table 2). The experimental unit consisted of 10 plants per replicate. Data on the traits from the replicated trials were generated using five tagged plants (at the middle of the row). Ten qualitative traits were collected as follows; terminal leaflet colour, terminal leaflet shape, petiole colour, pod shape, dry pod colour, seed shape, growth habit, open flower colour, seed hilum colour, and eye pattern as guided by the descriptor for Bambara groundnut [11].

Table 2. Quantitative traits observed on Bambara groundnut accessions

SN	Traits	Measurement	Unit
1	Peduncle length	Length of peduncle using meter rule	cm
2	Petiole length	Length of petiole from ground level to leaf stalk using meter rule	mm
3	Number of flowers per peduncle	Number of flower present on each peduncle	Visual assessment
4	Number of trifoliate leaves	Counting of trifoliate leaves present on each selected plant	Visual assessment
5	Banner length	Length of flag or banner of flower using meter rule	mm
6	Plant height	Distance from the ground level to longest terminal leaf using meter rule	cm
7	Internode length	Length of nodes from point to point using meter rule	mm
8	Plant spread	Taken as the widest ends of the plant using meter rule	cm
9	Terminal leaflet length	Measured as the distance from the leaf tip to the leaf stalk using meter rule	mm
10	Terminal leaflet width	Widest ends across the leaf blade using meter rule	mm
11	Number of days to 50% flowering	Counting of days to flowering of 5 plants	Visual assessment
12	Number of days to first flowering	Counting of days to first flower emergence	Visual assessment
13	Days to maturity	Number of days maturity senescence shown	Visual assessment
14	Yield /ha	Weight of pods harvested /ha using weighing balance	kg
15	Yield/plant	Weight of pods harvested / plant using weighing balance	g
16	Number of seeds per pod	Number of seed(s) present in a pod	Visual assessment
17	Number of pods/area(Plot)	Number of pods harvested per plot	Visual assessment
18	Pod length	Length of pod in perpendicular position using Digital Vernier Caliper	mm
19	Pod width	Length of pod across ends traverse position using Digital Vernier Caliper	mm
20	Seed length	Length of pod in perpendicular position using Digital Vernier Caliper	mm
21	Seed width	Length of pod across ends traverse position using Digital Vernier Caliper	mm
22	Shell thickness	Measurement of shell thickness using Digital Vernier Caliper	mm
23	100-seed weight	Weight of 100 seeds using weighing balance	g
24	Chaff weight	Weight of shell removed using weighing balance	g
25	Seed weight per plant	Weight of seeds harvested per plant using weighing balance	g
26	Seed weight per plot	Weight of seeds harvested per plot using weighing balance	g
27	Shelling percentage	Weight of seeds/weight of harvested pods x 100	%
28	Shelled harvest	Shelling% / Total pod weight x 100	%

2.4. Data Analysis

Data collected in the three replications of the two locations and in the three years across locations were averaged and computed for all accessions, then subjected to analysis of variance (ANOVA) using the PROC GLM procedure on statistical analytical system (SAS, version 9.4) [12]. Treatment means were compared using Duncan multiple range test (DRMT) at 5% and 1% to separate the significant differences. Mean squares were used to estimate the varying component for each characteristic. Principal Component Analysis (PCA) was carried out using the PROC PRINCOMP procedure on SAS to determine the contribution of each trait to the total variation observed on the accessions used. Cluster analysis was carried out using PROC CLUSTER procedure (Ward hierarchical clustering method) to show the distribution of the accessions into their different groups. Descriptive statistics was also employed to analyze qualitative data using frequencies and percentages. Pearson correlation was used to determine the relationships among the traits using PROC CORR in the SAS program.

3. Results

3.1. Quantitative Traits

The analysis of variance revealed highly significant ($P \leq 0.01$) differences for most of the quantitative traits studied (Table 3) in the three years for twenty-three traits, out of the twenty-eight quantitative traits evaluated. Such traits that varied significantly among accessions in the three years include; plant height, terminal leaflet length (mm),

terminal leaflet width (mm), number of trifoliate leaves, petiole length, 100-seed weight, plant spread, internode length, banner length, peduncle length, number of days to first flowering, number of days to 50% flowering, number of flower per peduncle, yield per plant, number of pods per plot, yield per plot, yield per hectare, number of seed per pod, pod length, pod width, seed length, seed width, shell thickness. The mean value of the accessions studied revealed that Plant height (PH, cm) varied significantly from 28.85 to 18.27, while accessions TVSu-589, TVSu-670, TVSu-2109, TVSu-2106, TVSu-285 had the highest plant height and accessions TVSu-1239, TVSu-662 and TVSu-647 had significantly short plant height. Terminal leaflet length (TLL, mm) varied significantly from 84.14 to 45.33, accessions TVSu-589, TVSu-2109, TVSu-2106, TVSu-2105, TVSu-285 had longest terminal leaflet length while accessions TVSu-662, TVSu-838, TVSu-275 and TVSu-1252 had shortest terminal leaflet length. Terminal leaflet width (TLW, mm) varied significantly from 44.97 to 19.79, accessions TVSu-2109, TVSu-589, TVSu-2105, TVSu-2106 had widest terminal leaflet width while accessions TVSu-586, TVSu-647, TVSu-14 and TVSu-365 had significantly narrow terminal leaflet width. Petiole length (PetL, mm) varied significantly from 205.88 to 116.88, accessions TVSu-670, TVSu-589, TVSu-2109, TVSu-2100, TVSu-331had longest petiole length while accessions TVSu-1239, TVSu-662, TVSu-2112, TVSu-647 had shortest petiole length. Number of trifoliate leaves (NTLs) varied significantly from 95.04 to 49.97, accessions TVSu-333, TVSu-838, TVSu-1242, TVSu-1245, TVSu-633 had the highest number of trifoliate leaves while accession TVSu-269, TVSu-627, TVSu-127, TVSu-675, TVSu-173 had lowest number of trifoliate leaves. Plant spread (PlanSpr, cm) varied significantly from 45.71 to 28.85, accessions TVSu-271, TVSu-2109, TVSu-2105, TVSu-331, TVSu-2099 covered the widest area of land while accessions TVSu-365, TVSu-647, TVSu-348, TVSu-1222 covered narrow area of land. Internodes length (IL, mm) varied significantly from 22.96 to 10.45, accessions TVSu-129, TVSu-589, TVSu-2106, TVSu-2109, TVSu-572 had the longest internodes length while accessions TVSu-173, TVSu-650, TVSu-577, TVSu-261 had shortest inter nodes length. Banner length (BL, mm) varied significantly from 5.98 to 5.25, accessions TVSu-590, TVSu-346, TVSu-2104, TVSu-348, TVSu-585 had the longest banner length while accessions TVSu-1252, TVSu-662, TVSu-334 and TVSu-576 had shortest banner length. Peduncle length (PdclL, mm) ranged from 6.58 to 3.98, accessions TVSu-670, TVSu-1241, TVSu-2112, TVSu-589, TVSu-647 had the longest peduncle length while accessions TVSu-662, TVSu-2102, TVSu-656, TVSu-271 and TVSu-178 had shortest peduncle length. Number of days to first flowering observed among the selected accessions was 34-41 days and number of days to maturity was 116-131 days. Pod length (PdL, mm) ranged from 24.68 to 14.96, accessions TVSu-2105, TVSu-589, TVSu-2109, TVSu-336, TVSu-2100 had the longest pod length while accessions TVSu-639, TVSu-640, TVSu-662 and TVSu-269 had shortest pod length. Pod width (PdW, mm) ranged from 15.79 to 10.43, accessions TVSu-572, TVSu-368, TVSu-2099, TVSu-366, TVSu-271 had the widest pod width while accessions TVSu-365, TVSu-662, TVSu-269 and TVSu-659 had narrow pod width. Grain yield per hectare (GYpHa, Kg) ranged from 1091.80 to 416.20, accessions TVSu-594, TVSu-261, TVSu-336, TVSu-350, TVSu-1242 had the highest yield per hectare while accessions TVSu-285, TVSu-659, TVSu-359, TVSu-268 had lowest grain yield per hectare. Hundred seed weight (100-sdwt, g) ranged from 121.52 to 40.18, accessions TVSu-572, TVSu-271, TVSu-336, TVSu-368, TVSu-83 had the highest 100-seed weight while accessions TVSu-287, TVSu-263, TVSu-178, TVSu-586, TVSu-662 had lowest 100-sdwt. Exceptional accessions with high yielding characteristics above 800kg per hectare in the locations and years include (TVSu-594 (1091.80), TVSu-261 (966.20), TVSu-336 (917.80), TVSu-350 (903.30), TVSu-1242 (877.30), TVSu-2100 (855.40), TVSu-179 (848.20), TVSu-14 (834.30), TVSu-589 (820.70), TVSu-129 (819.30) (Table 4).

Table 3. Mean squares of ANOVA for quantitative traits of Bambara groundnut in two locations for three years

Sources of Var.	df	PH (cm)	TLL (mm)	TLW (mm)	NTLvs	Pet L (mm)	Hsdwt g
Accession	99	77.77**	733.46**	371.51**	0.07**	4862.19**	4182.53**
Replicate	2	8.10ns	238.06ns	19.46ns	0.41**	1565.04ns	1491.11**
Year	2	6508.88**	7587.20**	3284.90**	12.20**	593357.29**	4286.78**
Location	1	618.31**	514.93ns	1272.94**	0.04ns	157654.84**	4339.82**
Accession x Replicate	198	6.98ns	36.24ns	10.60ns	0.03**	625.87ns	433.05**
Accession x Year	198	10.91**	88.95**	38.69**	0.04**	999.15**	335.02**
Accession x Location	99	7.61ns	69.93**	26.61**	0.03**	736.44ns	21.66ns
Accession x Location x year	200	25.84**	94.90**	19.81**	0.14**	3123.26**	33.14ns
Mean Square Error		6.48	39.61	9.41	0.01	610.28	50.55
Mean		22.38	62.96	27.59	67.39	151.27	67.68
StD		2.07	6.39	4.54	9.92	16.47	15.27

Legend: PHcm=Plant height(cm), TLL(mm)=Terminal leaflet length, TLW(mm)=Terminal leaflet width, NTLvs=Number of Trifoliate Leaves, Pet L(mm)= Petiole length (mm), Hsdwt g=100 seed weight g
*Significant at 5% level of probability; **Significant at 1% level of probability; ns = Not significant

Table 3. cont'd Mean squares of ANOVA for quantitative traits of Bambara groundnut in two locations for three years

Sources of Var.	df	PlanSpr cm	IntL (mm)	BL (mm)	PdclL (mm)	NDtoFF	NDto50%F
Accession	99	238.88**	96.03**	0.52**	4.52**	0.00**	0.00**
Replicate	2	40.44ns	30.85**	11.78**	6.53**	8.46ns	0.00ns
Year	2	30459.72**	7264.09**	0.65**	14.78**	1004.42**	0.74**
Location	1	18008.51**	602.27**	18.22**	14.23**	0.00ns	0.00ns
Accession x Replicate	198	29.73**	2.15ns	0.57**	3.78**	0.92ns	0.00ns
Accession x Year	198	153.36**	7264.09**	0.02ns	0.28ns	2.15**	0.00**
Accession x Location	99	43.76**	10.87**	0.03ns	0.35ns	0.00ns	0.00ns
Accession x Location x year	200	193.34**	10.25**	0.05**	0.83ns	0.00ns	0.00ns
Mean Square Error		19.37	2.90	0.02	0.69	0.00	0.00
Mean		37.43	13.63	5.63	5.17	37.11	39.11
StD		3.69	2.30	0.17	0.50	1.49	1.49

Legend: PlanSpr cm=Plant Spread (cm), IntL mm=Internode Length (mm), BL mm=Banner Length, PdclL mm=Peduncle length, NDtoFF=Number of Days to first flowering, NDto50%F=Number of days to 50%flowering
*Significant at 5% level of probability; **Significant at 1% level of probability; ns = Not significant

Table 3. cont'd Mean squares of ANOVA for quantitative traits of Bambara groundnut in two locations for three years

Sources of Var.	df	NFpP	Y/Plant g	NPpP	YpP g	YkgpHa	Nsdpd	PdL mm
Accession	99	0.00**	367.31**	0.26**	15824.06**	275889.50**	0.01**	66.23**
Replicate	2	0.01**	765.82ns	0.31ns	44822.04ns	1044455.60ns	0.00ns	4.19ns
Year	2	0.01ns	288957.06**	161.91**	9915396.44**	158265005.90**	0.08**	962.86**
Location	1	0.00ns	29072.27**	21.21**	329430.77**	4573157.20**	0.05ns	807.37**
Accession x Replicate	198	0.00**	247.50**	0.09ns	7962.10ns	164021.30ns	0.00**	19.05**
Accession x Year	198	0.00ns	375.39**	0.17**	13304.21**	268399.40**	0.00ns	16.77**
Accession x Location	99	0.00ns	118.26ns	0.11**	5812.72ns	117024.20ns	0.00**	13.45**
Accession x Location x year	200	0.00**	190.01ns	0.12**	37611.56**	667334.80**	0.00ns	18.55**
Mean Square Error		0.00	152.17	0.06	5717.8	132100.9	0.00	3.76
Mean		1.58	20.89	118.71	159.19	641.59	1.21	18.96
StD		0.08	4.82	35.28	31.23	132.97	0.11	1.87

Legend: NFpP=Number of flower per peduncle, Y/plant g=Yield per plant in g, NpdspP=Number of pods per plot, YpP g=Yield per Plant in g YkgpHa=Yield in kilogramme per hectare, Nsdpd=Number of seed per pod, PdL mm=Pod length mm
*Significant at 5% level of probability; **Significant at 1% level of probability; ns = Not significant

Table 3. cont'd Mean squares of ANOVA for quantitative traits of Bambara groundnut in two locations for three years

Sources of Var.	df	PdW mm	SdL mm	SdW mm	Shthk mm	Sdwt/P g	Chfwt/P	Shperc	ShdhvP
Accession	99	18.23**	16.70**	7.86**	0.39**	7952.95ns	2631.08ns	557.61ns	551.37ns
Replicate	2	55.04**	21.44**	0.99ns	0.71ns	11138.41ns	1113.10ns	432.73ns	568.61ns
Year	2	1025.28**	312.76**	236.08**	7.27**	4784555.20**	680189.26**	6810.96**	6763.11**
Location	1	69.05**	103.65**	80.41**	2.56**	285570.16**	64066.80**	6821.84ns	6598.93ns
Accession x Replicate	198	4.02**	3.17**	3.97**	0.25**	3635.42ns	2128.17ns	535.47ns	535.07ns
Accession x Year	198	2.29**	1.61**	1.66**	0.10ns	6378.42ns	2522.11**	704.64**	708.75**
Accession x Location	99	1.43ns	0.56ns	0.76ns	0.03ns	7388.02ns	1795.12ns	489.26ns	492.37ns
Accession x Location x year	200	1.47ns	1.52**	1.09**	0.23**	26992.68**	4923.05**	433.35ns	432.73ns
Mean Square Error		1.04	0.67	0.72	0.11	5111.26	1680.59	469.05	472.29
Mean		13.02	11.47	9.33	0.73	111.16	43.51	37.77	62.13
StD		1.03	1.00	0.71	0.15	21.53	13.62	7.07	7.02

Legend. PdW mm=Pod width mm, SdL mm=Seed length mm, SdW mm=Seed width mm, Shthk mm=Shell thickness mm, Sdwt/P g=Seed weight per plot g, Chfwt/P=Chaff weight per plot g, Shperc=Shelling percentage, ShdhvP=Shelled harvest per plot%
*Significant at 5% level of probability; **Significant at 1% level of probability; ns = Not significant

Table 4. Mean performance of selected yield traits of 100 accessions of Bambara groundnut for three years (2017/2018, 2018/2019 and 2019/2020)

Accession	NDtoF	NDto50F	NFpP	Y/Plantg	NPpP	YpPg	YkgpHa	NSdpd	PdLmm	PdWmm
TVSu-119	37.22b-p	39.22b-p	1.48s-za	15.75i-n	126.74f-t	122.04n-v	488.10j-n	1.06vw	17.34zzo	12.87r-zh
TVSu-12	37.66a-p	39.66a-p	1.45x-za	18.71f-n	221.41ab	176.85a-u	707.40b-n	1.61a	20.24g-r	11.60zzq
TVSu-1222	39.44a-f	41.44a-f	1.43za	15.16k-n	117.35i-z	130.40j-v	521.60g-n	1.08q-w	17.77y-zm	12.15zzn
TVSu-1239	35.66h-p	37.66h-p	1.43za	17.21i-n	121.38g-x	132.28j-v	529.10f-n	1.23d-v	16.33zzq	12.03zzo
TVSu-1241	35.22l-p	37.22l-p	1.63c-n	20.55d-n	124.88f-t	158.20d-v	632.80c-n	1.26d-p	18.42t-zg	12.58y-zk
TVSu-1242	35.44j-p	37.44j-p	1.56h-y	23.27b-n	131.38f-s	219.32a-d	877.30a-e	1.24d-t	18.57r-zf	13.29k-za
TVSu-1245	35.33k-p	37.33k-p	1.59f-v	24.03b-m	162.88c-i	193.20a-m	772.80b-l	1.21e-v	18.00v-zk	11.74zzp
TVSu-1246	37.22b-p	39.22b-p	1.48r-za	19.33e-n	125.97f-t	141.86g-v	567.40e-n	1.28d-o	18.79o-ze	11.38zzq
TVSu-1252	36.66c-p	38.66c-p	1.52l-z	18.48f-n	144.09d-m	165.53b-v	662.10b-n	1.25d-r	16.49zzp	12.38zzl
TVSu-127	36.44d-p	38.44d-p	1.48s-za	13.87lmn	69.58zze	109.70uv	438.80mn	1.31c-k	20.40f-o	13.24l-zb
TVSu-129	36.11e-p	38.11e-p	1.51n-za	28.17b-h	153.17c-k	204.83a-i	819.30a-i	1.22d-v	17.83x-zm	12.03zzo
TVSu-14	37.11b-p	39.11b-p	1.54k-z	42.34a	238.67a	208.58a-g	834.30a-h	1.10p-w	16.88zzo	11.22zzq
TVSu-173	39.55a-e	41.55a-e	1.73a-d	17.23h-n	142.33d-n	162.70b-v	650.80b-n	1.11o-w	16.58zzo	11.72zzp
TVSu-178	36.88b-p	38.88b-p	1.59f-u	19.28e-n	114.63j-zb	141.19g-v	564.80e-n	1.22d-v	18.32t-zh	11.19zzr
TVSu-179	38.00a-o	40.00a-o	1.59f-v	33.15b	137.91e-q	212.05a-f	848.20a-g	1.22d-v	19.48j-x	12.86s-zh
TVSu-181	38.44a-m	40.44a-m	1.46v-za	18.64f-n	143.06d-n	144.53f-v	578.10d-n	1.11o-w	17.09zzo	11.81zzp
TVSu-2090	37.33b-p	39.33b-p	1.47t-za	18.04g-n	164.19c-g	165.97b-v	663.90b-n	1.17g-w	17.05zzo	11.73zzp
TVSu-2093	35.66h-p	37.66h-p	1.46w-za	18.76f-n	119.89g-y	157.21d-v	628.80c-n	1.31c-l	19.57h-w	13.91f-n
TVSu-2094	34.66nop	36.66nop	1.50p-za	19.72d-n	89.26r-ze	154.58d-v	618.30c-n	1.11o-w	19.75h-u	14.47c-h
TVSu-2095	35.77g-p	37.77g-p	1.46v-za	20.51d-n	97.92m-ze	161.85c-v	647.40b-n	1.13l-w	17.97v-zl	14.07f-l
TVSu-2099	37.22b-p	39.22b-p	1.70a-g	24.86b-l	86.03s-ze	166.20b-v	664.80b-n	1.11o-w	20.75e-l	15.08abc
TVSu-2100	36.88b-p	38.88b-p	1.63c-n	26.75b-i	158.53c-j	213.85a-e	855.40a-f	1.38b-e	22.78cd	13.58j-u
TVSu-2101	39.88a-d	41.88a-d	1.64b-l	24.77b-l	67.13zze	132.39j-v	529.60f-n	1.12n-w	21.76d-g	13.24l-zb
TVSu-2102	36.00f-p	38.00f-p	1.54j-z	17.94g-n	75.04x-ze	111.04tuv	444.20lmn	1.10p-w	18.11u-zj	13.18m-zc
TVSu-2103	38.00a-o	40.00a-o	1.72a-e	16.03i-n	119.11g-y	128.28l-v	513.10h-n	1.36b-f	19.40k-z	11.43zzq

Mean in a column with the same letter(s) are not significantly different according to DMRT (P = 0.05)
Legend NDtoF=Number of days to first flowering, NDto50F=Number of days to 50%flowering, NFpP=Number of flower per peduncle
Y/Plantg=Yield per plant g, NPpP=Number of pods per plot, YpP g=Yield per plot, YkgpHa=Yield per Hectare,
NSdpd=Number of seed per pod, PdL mm=Pod length, PdW mm= Pod width

Table 4. cont'd. Mean performance of selected yield traits of 100 accessions of Bambara groundnut for three years (2017/2018, 2018/2019 and 2019/2020)

Accession	NDtoF	NDto50F	NFpP	Y/Plantg	NPpP	YpPg	YkgpHa	NSdpd	PdLmm	PdWmm
TVSu-2104	34.88nop	36.88nop	1.54k-z	21.76c-n	115.74j-za	185.33a-p	741.30b-n	1.19g-w	18.22t-zi	13.33k-za
TVSu-2105	36.66c-p	38.66c-p	1.59f-v	24.75b-l	152.07c-k	192.52a-m	770.10b-l	1.67a	24.68a	12.97p-zg
TVSu-2106	35.55i-p	37.55i-p	1.70a-f	21.37d-n	157.43c-j	192.96a-m	771.80b-l	1.22e-v	21.73d-g	13.45j-y
TVSu-2108	37.22b-p	39.222b-p	1.57f-x	17.05i-n	84.63s-ze	149.78e-v	599.10c-n	1.15i-w	17.23zzo	13.14n-zd
TVSu-2109	37.88a-p	39.88a-p	1.77a	23.90b-m	121.79g-w	197.31a-k	789.30b-j	1.39bcd	23.25bc	12.87s-zh
TVSu-2110	34.44p	36.44p	1.56h-y	21.53c-n	66.31zze	170.88b-v	683.50b-n	1.16h-w	17.30zzo	13.24l-zb
TVSu-2112	37.33b-p	39.33b-p	1.65b-l	15.77i-n	118.83g-y	136.84i-v	547.40f-n	1.15j-w	17.92w-zl	12.69v-zh
TVSu-256	37.00b-p	39.00b-p	1.72a-e	16.63i-n	81.47t-ze	120.10o-v	480.40j-n	1.21e-v	18.90n-zd	12.86s-zh
TVSu-261	37.55b-p	39.55b-p	1.66a-j	24.30b-l	214.78ab	241.55a	966.20ab	1.15j-w	16.31zzq	12.64w-zi
TVSu-262	39.88a-d	41.88a-d	1.53l-z	16.86i-n	122.29f-v	134.17j-v	536.70f-n	1.38b-e	20.70e-l	12.77t-zh
TVSu-263	37.77a-p	39.77a-p	1.49p-za	15.60j-n	114.86j-zb	117.65p-v	470.60j-n	1.27d-p	18.67p-zf	12.21zzn
TVSu-267	37.00b-p	39.00b-p	1.45yza	13.25mn	140.61d-o	114.67q-v	458.70k-n	1.20f-v	17.74zzm	12.75t-zh
TVSu-268	37.44b-p	39.44b-p	1.66a-j	17.86g-n	76.89u-ze	104.06v	416.20n	1.24d-u	18.09u-zj	12.51zzl
TVSu-269	36.55c-p	38.55c-p	1.58f-w	16.60i-n	101.71l-ze	129.67k-v	518.70g-n	1.16h-w	14.96zzq	10.44zzr
TVSu-271	36.77c-p	38.77c-p	1.60e-t	15.99i-n	63.35zze	129.33k-v	517.30h-n	1.13m-w	21.21e-h	14.92b-e
TVSu-273	38.00a-o	40.00a-o	1.60e-s	18.74f-n	152.56c-k	127.86l-v	511.40h-n	1.19g-w	19.81h-t	12.80t-zh
TVSu-275	34.66nop	36.66nop	1.53l-z	21.95c-n	158.63c-j	187.35a-o	749.40b-m	1.45bc	19.27k-za	12.49zzl
TVSu-277	38.00a-o	40.00a-o	1.59f-v	18.18g-n	94.31p-ze	133.68j-v	534.70f-n	1.25d-t	19.58h-w	12.11zzn
TVSu-278	36.00f-p	38.00f-p	1.59f-t	17.72g-n	105.47l-ze	112.36r-v	449.50lmn	1.17h-w	17.96w-zl	12.64w-zi

Accession	NDtoF	NDto50F	NFpP	Y/Plantg	NPpP	YpPg	YkgpHa	NSdpd	PdLmm	PdWmm
TVSu-280	37.55b-p	39.55b-p	1.62d-p	23.80b-m	129.50f-s	198.50a-j	794.00b-j	1.16h-w	17.23zzo	13.06n-ze
TVSu-285	38.66a-l	40.66a-l	1.61d-q	13.17mn	113.00j-zc	109.20uv	436.80mn	1.14l-w	20.59e-m	12.82t-zh
TVSu-287	38.66a-l	40.66a-l	1.58f-w	16.45i-n	152.55c-k	139.34h-v	557.30e-n	1.27d-p	18.83o-ze	12.69v-zh
TVSu-330	38.11a-n	40.11a-n	1.61d-q	29.18b-f	98.64m-ze	179.82a-s	719.30b-n	1.12n-w	19.66h-v	14.24d-j
TVSu-331	37.22b-p	39.22b-p	1.46w-za	24.51b-l	87.06r-ze	157.00d-v	628.00c-n	1.32b-j	19.44j-y	13.73g-s
TVSu-333	40.00abc	42.00abc	1.61d-q	26.58b-j	117.82h-z	196.88a-k	787.50b-k	1.26d-p	20.33g-p	14.03f-m

Mean in a column with the same letter(s) are not significantly different according to DMRT (P = 0.05)
Legend NDtoF=Number of days to first flowering, NDto50F=Number of days to 50%flowering, NFpP=Number of flower per peduncle
Y/Plantg=Yield per plant g, NPpP=Number of pods per plot, YpP g=Yield per plot, YkgpHa=Yield per Hectare,
NSdpd=Number of seed per pod, PdL mm=Pod length, PdW mm= Pod width

Table 4. cont'd. Mean performance of selected yield traits of 100 accessions of Bambara groundnut for three years (2017/2018, 2018/2019 and 2019/2020)

Accession	NDtoF	NDto50F	NFpP	Y/Plantg	NPpP	YpPg	YkgpHa	NSdpd	PdLmm	PdWmm
TVSu-334	36.66c-p	38.66c-p	1.74abc	21.04d-n	168.06c-f	179.26a-t	717.00b-n	1.29c-n	21.07e-j	13.82g-p
TVSu-336	37.33b-p	39.33b-p	1.57g-x	33.51b	117.58h-z	229.44ab	917.80abc	1.17h-w	23.10bcd	13.57j-v
TVSu-34	37.22b-p	39.22b-p	1.56h-y	18.98f-n	82.44t-ze	144.44f-v	577.80d-n	1.30c-m	20.89e-k	14.53c-g
TVSu-340	41.00a	43.00a	1.57h-y	19.03e-n	94.83o-ze	136.86i-v	547.40f-n	1.16h-w	19.15l-zb	13.18m-zc
TVSu-346	39.88a-d	41.88a-d	1.54j-z	19.53d-n	92.57q-ze	154.73d-v	618.90c-n	1.16h-w	20.67e-l	13.75g-r
TVSu-347	40.00abc	42.00abc	1.58f-w	23.41b-n	100.94m-ze	182.50a-q	730.00b-n	1.08s-w	18.93n-zc	14.05f-m
TVSu-348	36.66c-p	38.66c-p	1.68a-i	21.11d-n	96.53n-ze	147.94e-v	591.80c-n	1.18g-w	18.45t-zg	13.49j-x
TVSu-349	36.88b-p	38.88b-p	1.49q-za	20.63d-n	69.32zze	151.96d-v	607.80c-n	1.32b-i	20.15g-s	13.43j-y
TVSu-350	35.33k-p	37.33k-p	1.72a-e	29.88b-e	184.56bcd	225.84abc	903.30a-d	1.16h-w	17.72zzn	12.92q-zg
TVSu-351	37.77a-p	39.77a-p	1.50o-za	19.48d-n	75.29w-ze	130.84j-v	523.30g-n	1.19g-w	17.96w-zl	13.18m-zc
TVSu-355	36.33e-p	38.33e-p	1.66a-k	15.90i-n	71.94zze	114.64q-v	458.60k-n	1.19g-w	19.59h-w	13.90f-o
TVSu-356	37.33b-p	39.33b-p	1.59f-u	16.65i-n	123.15f-u	136.38j-v	545.50f-n	1.10p-w	17.14zzo	12.73u-zh
TVSu-357	35.77g-p	37.77g-p	1.63c-n	21.26d-n	112.79j-zc	152.22d-v	608.90c-n	1.06uvw	17.37zzo	13.93f-n
TVSu-359	35.33k-p	37.33k-p	1.64c-n	19.64d-n	59.72zze	104.71v	418.80n	1.14k-w	17.67zzo	13.51j-w
TVSu-361	39.22a-g	41.22a-g	1.49q-za	18.94f-n	82.03t-ze	130.81j-v	523.20g-n	1.18g-w	19.41j-z	13.83g-p
TVSu-363	36.77c-p	38.77c-p	1.64b-l	20.48d-n	163.53c-i	169.66b-v	678.60b-n	1.28d-o	19.11l-zb	12.98p-zg
TVSu-365	37.88a-p	39.88a-p	1.67a-i	18.03g-n	189.12abc	161.72c-v	646.90b-n	1.47b	17.81x-zm	11.14zzr
TVSu-366	35.44j-p	37.44j-p	1.58f-x	22.19c-n	107.22k-zd	190.18a-n	760.70b-m	1.12n-w	19.30k-za	14.97b-d
TVSu-367	35.00m-p	37.00m-p	1.60d-s	19.01f-n	141.21d-o	178.54a-t	714.20b-n	1.13m-w	19.55i-w	14.46c-i
TVSu-368	34.77nop	36.77nop	1.72a-e	23.35b-n	99.93m-ze	180.70a-r	722.80b-n	1.10p-w	22.00c-f	15.39ab
TVSu-570	38.77a-k	40.77a-k	1.59e-t	22.57c-n	182.29b-e	181.10a-q	724.40b-n	1.18g-w	16.67zzo	12.18zzn
TVSu-572	34.66nop	36.66nop	1.57h-y	23.58b-n	84.69s-ze	180.93a-q	723.70b-n	1.18g-w	22.11cde	15.79a
TVSu-576	38.44a-m	40.44a-m	1.57h-y	20.38d-n	126.91f-t	152.05d-v	608.20c-n	1.02w	18.96m-zc	13.40j-yz
TVSu-577	38.88a-j	40.88a-j	1.47u-za	25.98b-k	85.69s-ze	169.97b-v	679.90b-n	1.28d-o	18.23t-zi	12.17zzn
TVSu-579	36.22e-p	38.22e-p	1.68a-h	22.07c-n	80.92t-ze	147.99e-v	592.00c-n	1.08r-w	16.24zzq	12.21zzn

Mean in a column with the same letter(s) are not significantly different according to DMRT (P = 0.05)
Legend NDtoF=Number of days to first flowering, NDto50F=Number of days to 50%flowering, NFpP=Number of flower per peduncle
Y/Plantg=Yield per plant g, NPpP=Number of pods per plot, YpP g=Yield per plot, YkgpHa=Yield per Hectare,
NSdpd=Number of seed per pod, PdL mm=Pod length, PdW mm= Pod width

Table 4. cont'd. Mean performance of selected yield traits of 100 accessions of Bambara groundnut for three years (2017/2018, 2018/2019 and 2019/2020)

Accession	NDtoF	NDto50F	NFpP	Y/Plantg	NPpP	YpPg	YkgpHa	NSdpd	PdLmm	PdWmm
TVSu-585	36.88b-p	38.88b-p	1.55i-y	16.83i-n	75.97v-ze	125.28mv	501.10i-n	1.26d-q	20.64e-l	13.63h-t
TVSu-586	37.33b-p	39.33b-p	1.50p-za	18.54f-n	82.69t-ze	121.69o-v	486.80j-n	1.24d-u	17.33zzo	12.14zzn
TVSu-589	37.22b-p	39.22b-p	1.76ab	23.96b-m	138.76e-p	205.16a-h	820.70a-i	1.45bc	24.22ab	14.07f-l
TVSu-590	38.44a-m	40.44a-m	1.57f-x	28.59b-g	102.88l-ze	197.76a-k	791.10b-j	1.25d-s	20.34g-o	13.02o-zf
TVSu-594	39.00a-i	41.00a-i	1.46w-za	32.10bc	126.18f-t	155.30d-v	1091.80a	1.34b-g	18.33t-zh	12.89r-zh
TVSu-602	37.11b-p	39.11b-p	1.63c-o	16.52i-n	117.69h-z	150.45e-v	601.80c-n	1.16h-w	17.50zzo	13.25l-zb
TVSu-627	37.66a-p	39.66a-p	1.54j-z	21.06d-n	104.29l-ze	163.40b-v	653.60b-n	1.33b-h	20.25g-q	12.60x-zj
TVSu-633	34.55op	36.55op	1.61d-r	30.18bcd	93.78q-ze	186.30a-o	745.20b-n	1.22d-v	18.59q-zf	14.49c-g

Accession	NDtoF	NDto50F	NFpP	Y/Plantg	NPpP	YpPg	YkgpHa	NSdpd	PdLmm	PdWmm
TVSu-639	35.11m-p	37.11m-p	1.56h-y	17.60h-n	126.67f-t	161.72c-v	646.90b-n	1.15i-w	16.09zzq	12.28zzm
TVSu-640	39.11a-h	41.11a-h	1.75abc	14.20lmn	100.43m-ze	136.59i-v	546.30f-n	1.07t-w	16.06zzq	13.02o-zf
TVSu-644	36.33e-p	38.33e-p	1.64b-l	20.62d-n	92.69q-ze	144.83f-v	579.30d-n	1.19g-w	18.57s-zg	13.61i-u
TVSu-647	36.44d-p	38.44d-p	1.66a-j	17.47h-n	123.70f-t	179.87a-s	719.50b-n	1.20f-v	17.84x-zm	11.78zzp
TVSu-650	37.66a-p	39.66a-p	1.56h-y	20.29d-n	118.17g-z	158.62c-v	634.50c-n	1.24d-t	18.05v-zj	12.84t-zh
TVSu-651	34.66nop	36.66nop	1.46v-za	22.32c-n	117.35i-z	179.73a-s	718.90b-n	1.11o-w	17.29zzo	12.32zzm
TVSu-656	37.11b-p	39.11b-p	1.40za	24.29b-l	124.56f-t	196.26a-l	785.00b-k	1.18g-w	20.83e-k	14.71b-f
TVSu-659	37.55b-p	39.55b-p	1.65b-l	15.00k-n	114.15j-zb	108.02v	432.10mn	1.38b-e	18.31t-zh	10.43zzr
TVSu-662	40.33ab	42.33ab	1.55i-y	12.63n	163.88c-h	111.89s-v	447.60lmn	1.23d-v	15.04zzq	10.91zzr
TVSu-667	36.44d-p	38.44d-p	1.61d-q	19.94d-n	103.78l-ze	154.14d-v	616.60c-n	1.25d-r	18.72p-zf	13.73g-s
TVSu-670	38.77a-k	40.77a-k	1.58f-x	22.32c-n	133.50f-r	166.80b-v	667.20b-n	1.12n-w	18.43t-zg	13.32k-za
TVSu-675	37.44b-p	39.44b-p	1.64c-m	18.79f-n	122.44f-v	147.34e-v	589.30d-n	1.38b-e	21.17e-i	13.29k-za
TVSu-81	35.66h-p	37.66h-p	1.48t-za	20.76d-n	93.24q-ze	172.39b-v	689.50b-n	1.17h-w	17.79x-zm	12.83t-zh
TVSu-82	36.22e-p	38.22e-p	1.52m-za	23.25b-n	74.31y-ze	167.24b-v	669.00b-n	1.10p-w	20.53e-n	13.77g-q
TVSu-83	38.88a-j	40.88a-j	1.58f-v	20.85d-n	142.00d-n	166.06b-v	664.20b-n	1.17h-w	19.58h-w	14.13e-k
TVSu-838	35.00m-p	37.00m-p	1.70a-g	21.18d-n	151.94c-k	170.58b-v	682.30b-n	1.20f-v	18.03v-zj	12.68w-zh
TVSu-844	35.88g-p	37.88g-p	1.48s-za	23.06c-n	148.08c-l	178.83a-t	715.30b-n	1.37b-f	20.21g-s	13.11n-zd

Mean in a column with the same letter(s) are not significantly different according to DMRT (P = 0.05)
Legend NDtoF=Number of days to first flowering, NDto50F=Number of days to 50%flowering, NFpP=Number of flower per peduncle Y/Plantg=Yield per plant g, NPpP=Number of pods per plot, YpP g=Yield per plot, YkgpHa=Yield per Hectare, NSdpd=Number of seed per pod, PdL mm=Pod length, PdW mm= Pod width

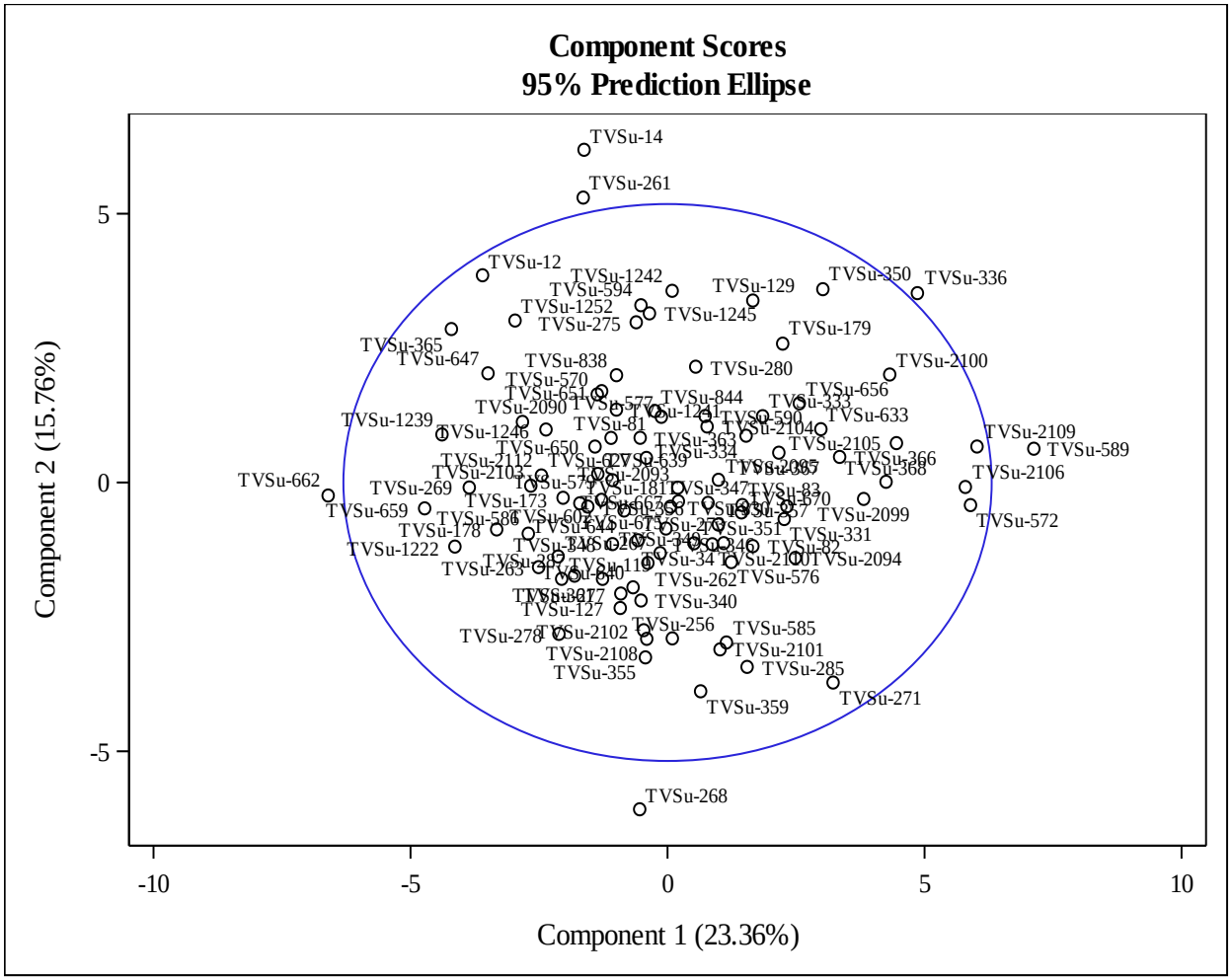

Figure 1. Contribution of PC1 and PC2 to variation

3.2. Principal Component

Comparison of the PC's contribution to diversity in the three years revealed Principal components 1-8 constitute 77.28% of the total variation, where PC 1, 2, 3, 4, 5, 6, 7 and 8 contributed (23.36%, 15.76%, 12.22%, 6.86%, 6.17%, 4.72%, 4.34% and 3.85%) respectively. Principal component analysis showed PC1 constituted 23.36% and PC2 constituted 15.76%, while the first eight PC's had eigen values ≥1 revealed 77.28% of total variation. Higher contribution to total variation was revealed by PC's 1 and 2. PC1 contributed 23.36%, containing plant height (0.28), terminal leaflet length (0.26), terminal leaflet width (0.26), petiole length (0.24), plant spread (0.25), internode length (0.19), yield per plant (0.19), yield per plot (0.19), pod length (0.28), pod width (0.29), seed length (0.30), seed width (0.24), 100-seed weight (0.28). These components contributed positively to total variation.PC2 contributed 15.76%, yield per plant (0.29), number of pods per plot (0.34), yield per plot (0.38), yield per hectare (0.38), seed weight per plot (0.40), shelled harvest per plot (0.31) while shelling percentage (-0.30) contributed negatively (Figure 1) (Table 5).

Table 5. Eigen values and contribution of first eight principal components axes to variation in 2017/2018, 2018/2019 and 2019/2020

	Contributing PC's							
	PCA 1	PCA 2	PCA 3	PCA 4	PCA 5	PCA 6	PCA 7	PCA 8
Eigen value	6.30	4.25	3.29	1.85	1.66	1.27	1.17	1.03
% Var. Exp.	23.36	15.76	12.22	6.86	6.17	4.72	4.34	3.85
Cum. Var. Exp.	23.36	39.12	51.35	58.21	64.38	69.1	73.43	77.28
PH (cm)	0.282	-0.089	0.276	-0.058	-0.048	-0.103	-0.236	-0.102
TLL (mm)	0.263	-0.124	0.264	0.037	-0.054	0.000	0.054	0.012
TLW (mm)	0.261	-0.076	0.281	0.129	-0.123	0.076	-0.034	-0.031
NTLvs	0.077	0.084	-0.192	-0.107	-0.014	0.571	-0.260	0.023
PetL (mm)	0.241	-0.066	0.242	-0.086	-0.021	-0.123	-0.322	-0.152
Plant Spr (cm)	0.253	-0.060	0.132	-0.091	-0.057	-0.028	-0.227	-0.108
IntL (mm)	0.194	0.021	0.147	0.104	-0.270	0.050	-0.075	0.160
BL (mm)	0.087	-0.041	0.021	0.323	0.066	-0.416	-0.038	-0.107
PdclL (mm)	0.062	0.102	0.196	0.248	-0.020	-0.160	0.200	0.341
NDtoFF	-0.088	-0.083	0.316	-0.223	0.528	0.036	0.068	0.061
NDto50%F	-0.088	-0.083	0.316	-0.223	0.528	0.036	0.068	0.061
NDtoM	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NFpP	0.111	-0.029	0.068	0.186	0.033	0.158	-0.024	0.740
Y/plant (g)	0.196	0.294	-0.030	0.098	0.229	0.034	-0.199	-0.149
NPdspP	-0.067	0.347	0.154	0.043	0.000	0.188	-0.041	0.124
YpP (g)	0.197	0.384	-0.045	0.082	0.140	0.032	-0.025	-0.005
Y/Ha (kg)	0.182	0.388	-0.024	0.091	0.169	0.001	-0.003	-0.044
NSdpPd	0.004	0.120	0.245	0.109	-0.208	0.305	0.526	-0.297
PdL (mm)	0.288	-0.041	0.124	-0.067	-0.007	0.195	0.424	-0.159
PdW (mm)	0.299	-0.111	-0.212	-0.122	0.076	-0.082	0.163	0.021
SdL (mm)	0.304	-0.020	-0.145	-0.234	0.045	-0.036	0.210	0.150
SdW (mm)	0.243	-0.049	-0.240	-0.206	-0.011	-0.157	0.205	0.148
Shthk (mm)	0.129	-0.148	-0.189	-0.069	0.144	0.273	-0.072	-0.108
Sdwt (g)	0.138	0.409	-0.046	0.004	0.086	-0.012	-0.052	-0.018
Chfwt (g)	0.007	0.089	-0.160	0.368	0.287	-0.176	0.175	-0.153
Shperc	0.106	-0.306	-0.109	0.404	0.184	0.209	-0.047	-0.049
Shdhv/P	-0.098	0.312	0.110	-0.389	-0.191	-0.211	0.042	0.047
100sdwt (g)	0.281	-0.029	-0.281	-0.165	0.045	-0.116	0.057	0.053

Legend PH=plant height, TLL=Terminal leaflet length, TLW=Terminal leaflet width, NTLvs=Number of trifoliate leaves, PetL=Petiole length, Plan Spr=Plant spread, IntL=Internode length, BL= Banner length, NDtoFF=Number of days to first flowering, NDto50%F PdclL=Peduncle length, NDtoM=Number of days to maturity, NFpP=Number of flowers per peduncle, Yplant=Yield per plant NPdspP=Number of pods per plot, YpP=Yield per plot, YpHa=Yield per hectare (Kg), NSdpPd=Number of seed per pod PdL=Pod length, PdW=Pod width, SdL=Seed length, SdW=Seed width, Shthk=Shell thickness, Sdwt=Seed weight per plot Chfwt=Chaff weight, Shperc=Shelling percentage, Shdhv/P=Shelled harvest per plot, 100sdwt=100 seed weight.

3.3. Qualitative Traits

Descriptive statistics on qualitative traits observed on terminal leaflet colour, growth habit and open flower colour were uniform in all the studied accessions. The analysis of Terminal leaflet shape (TLS) revealed that 55% of the selected accessions are 'lanceolate', 44% 'oval' and 1% 'elliptic'. The analysis of Petiole colour showed that 66% had 'whole green' petiole while 34% had 'base purple' petiole colour. The analysis of Pod shape revealed that 57% had 'ending in a point with nook on the other side' while 41% had 'ending in a point round on the other side' while others also exited. The analysis of Dry pod colour revealed that 82% had 'yellowish brown' dry pod colour while 13% had 'brown" dry pod colour, while others also existed. The analysis of Seed shape revealed that 89% had 'oval' seed shape while 11% had 'round' seed shape. The analysis of Seed hilum colour showed that 51% had 'white' seed hilum colour while 49% had 'chalk white' seed hilum colour. The analysis of Eye pattern showed that 'cream testa with grey butterfly-like eye' was highest with 21% while 'cream testa with brown butterfly-like eye' accounted for 16% of the selected accessions, while others also existed (Table 6). The analysis of seed colour revealed that Twenty-six percent (26%) had pale yellow colour, eleven percent (11%) had greyish yellow, nine percent (9%) had light brown, six percent (6%) had reddish brown, five percent (5%) had light orange, five percent (5%) had brownish orange, four percent (4%) had dark brown, four percent (4%) had violet brown, three percent (3%) had grayish brown, three percent (3%) had yellowish brown, two percent (2%) had light yellow, two percent (2%) had orange white, two percent (2%) had pale violet while others had less than two percent (2%) occurrence (Table 6). Plate 1 show seed colours and eye patterns of some selected accessions and plate 2 showed the layout of the experimental field.

Table 6. Classification of Bambara groundnut accessions based on qualitative traits

	Frequency	Percentage (%)	Cum. Frequency	Cum. Percentage
Terminal Leaflet Colour (TLC)				
Green	300	100	300	100
Terminal leaflet Shape (TLS)				
Oval	132	44	132	44
Lanceolate	165	55	297	99
Elliptic	3	1	300	100
Petiole Colour (Petcol)				
Whole green	198	66	198	66
Base purple	102	34	300	100
Pod shape				
Without point	6	2	6	2
Ending in a point round on the other side	123	41	129	43
Ending in a point with nook on the other side	171	57	300	100
Dry pod colour				
Yellowish brown	246	82	246	82
Brown	39	13	285	95
Reddish brown	15	5	300	100
Seed Shape				
Round	33	11	33	11
Oval	267	89	300	100
Growth habit				
Bunchy	300	100	300	100
Open flower colour				
Yellow	300	100	300	100
Seed hilum colour				
White	153	51	153	51
Chalk white	147	49	300	100

Table 6. cont'd. Classification of the selected accessions based on qualitative traits (Eye pattern)

Eye pattern	Frequency	Percentage (%)	Cum. Frequency	Cum. Percentage
cream testa with black butterfly-like eye	12	4	12	4
cream testa with grey butterfly-like eye	63	21	75	25
cream testa with black triangular eye	12	4	87	29
cream testa with brown triangular eye	15	5	102	34
cream with grey triangular eye	12	4	114	38
cream testa with black irregular eye	6	2	120	40
cream testa with grey double thick lines on both sides of the eye	9	3	129	43
cream testa with brown circular eye	6	2	135	45
light brown testa with grey butterfly-like eye	9	3	144	48
light brownish red testa with dark brown circular or triangular eye	24	8	168	56
cream black with grey irregular eye	3	1	171	57
cream testa with light purple butterfly-like eye	6	2	177	59
dark violet testa with grey butterfly-like eye	3	1	180	60
cream testa with brown butterfly-like eye	48	16	228	76
cream testa with butterfly eye and double thick line on both side of eye	3	1	231	77
light brown testa with brown circular eye	12	4	243	81
light brown testa with dark brown butterfly eye	6	2	249	83
cream testa with tan brown speckle butterfly eye	3	1	252	84
black testa with ash or grey circular eye	9	3	261	87
yellowish brown testa with cream circular like eye	3	1	264	88
dark testa with tan brown butterfly-like eye	3	1	267	89
dark testa with cream butterfly-like eye	6	2	273	91
brown testa with black speckles tan brown eye	3	1	276	92
brownish red testa with grey circular like eye	6	2	282	94
brown testa with dark butterfly-like eye	3	1	285	95
dark brown testa with brown circular like eye	3	1	288	96
light brown testa with grey circular like eye	3	1	291	97
irregular black testa with double thick dark lines on both sides of eye	3	1	294	98
irregular brown testa with brown butterfly like eye	3	1	297	99
reddish brown testa with brown regular eye	3	1	300	100

Table 6. cont'd. Classification of the selected accessions based on qualitative traits

	(Seed Colour)			
Seed Colour	Frequency	Percentage (%)	Cum. Frequency	Cum. Percentage
Brown	6	2	6	2
Brownish Orange	6	2	12	4
Brownish biege	3	1	15	5
Brownish orange	15	5	30	10
Dark Purple	3	1	33	11
Dark brown	12	4	45	15
Dark purple	3	1	48	16
Dark ruby	3	1	51	17
Dark violet	6	2	57	19
Dull yellow	6	2	63	21
Greyish brown	9	3	72	24

	(Seed Colour)			
Seed Colour	Frequency	Percentage (%)	Cum. Frequency	Cum. Percentage
Greyish orange	6	2	78	26
Greyish yellow	33	11	111	37
Light Orange	3	1	114	38
Light brown	27	9	141	47
Light orange	15	5	156	52
Light yellow	6	2	162	54
Orange white	6	2	168	56
Pale orange	6	2	174	58
Pale violet	6	2	180	60
Pale yellow	78	26	258	86
Reddish brown	18	6	276	92
Violet brown	12	4	288	96
Yellowish brown	9	3	297	99
Yellowish grey	3	1	300	100

Plate 1. Selected Bambara groundnut accessions showing seed colour and eye pattern

Plate 2. Bambara groundnut field in one of the locations

Table 7. Combined phenotypic correlation of yield contributing traits evaluated in Ibadan and Ikenne for three years

Traits	PHcm	NoDtoF	Yplantg	NPdspar	YpPg	YKgpha	Nsdpd	PdL mm	PdW mm	SdL mm	SdW mm	Sdwtg	Chwtg	Shperc	Shdhvp
NoDtoF	0.08ns														
Yplantg	0.23*	-0.15ns													
NPdspar	-0.09ns	-0.00ns	0.28**												
YpPg	0.27**	-0.28**	0.78**	0.47**											
YKgpha	0.23*	-0.22*	0.81**	0.45**	0.93**										
Nsdpd	0.07ns	0.01ns	-0.02ns	0.24*	0.05ns	0.09ns									
Pdlthmm	0.54**	0.01ns	0.25**	-0.11ns	0.30**	0.27**	0.42**								
PdWidmm	0.35**	-0.23*	0.25**	-0.36**	0.29**	0.26**	-0.21*	0.54**							
SdLthmm	0.39**	-0.17ns	0.36**	-0.18ns	0.43**	0.37**	-0.14ns	0.63**	0.74**						
SdWidmm	0.21*	-0.27**	0.21*	-0.27**	0.26**	0.23*	-0.21*	0.34**	0.74**	0.67**					
Sdwtg	0.12ns	-0.29**	0.78**	0.45**	0.87**	0.83**	0.08ns	0.17ns	0.15ns	0.29**	0.18ns				
Chwtg	-0.12ns	-0.17ns	0.18ns	0.00ns	0.26**	0.26**	-0.07ns	-0.08ns	0.05ns	0.01ns	0.06ns	0.12ns			
Shperc	0.14ns	-0.05ns	-0.06ns	-0.45**	-0.18ns	-0.21*	-0.16ns	0.15ns	0.32**	0.09ns	0.11ns	-0.32**	0.22*		
Shdhvp	-0.12ns	0.03ns	0.08ns	0.45**	0.20*	0.23*	0.18ns	-0.14ns	-0.31**	-0.09ns	-0.11ns	0.35**	-0.21*	-0.98**	
Hdsdwtg	0.28**	-0.32**	0.30**	-0.27**	0.41**	0.34**	-0.28**	0.39**	0.78**	0.77**	0.71**	0.30**	0.19*	0.17ns	-0.16ns

* significant at P≤0.05, ** significant at P≤0.01, ns = not significant

Legend PHcm=Plant height, NoDtoF=Number of days to first flowering, Yplant g=Yield per plant, Npdspar=Number of pods per area, YpP g=Yield per plot, YKgpHa=Yield per ha, NSdpd=Number of seed per pod, PdL mm=Pod length, PdW mm=Pod width, SdL mm=Seed length, SdW mm=Seed width, Sdwt g=Seed weight per plot, Chwt g=Chaff weight per plot, Shperc=Shelling percentage, ShdhvP=Shelled harvest per plot.

Table 8. Clustering of 100 accessions of Bambara Groundnut based on Morphological markers

		Group of clusters					
S/N	Cluster 1	S/N	Cluster 2	S/N	Cluster 3	S/N	Cluster 4
1	TVSu-594	1	TVSu-590	1	TVSu-2108	1	TVSu-586
2	TVSu-261	2	TVSu-333	2	TVSu-331	2	TVSu-585
3	TVSu-14	3	TVSu-656	3	TVSu-2094	3	TVSu-256
4	TVSu-2100	4	TVSu-280	4	TVSu-675	4	TVSu-640
5	TVSu-129	5	TVSu-589	5	TVSu-602	5	TVSu-271
6	TVSu-179	6	TVSu-2109	6	TVSu-644	6	TVSu-361
7	TVSu-336	7	TVSu-2106	7	TVSu-348	7	TVSu-351
8	TVSu-350	8	TVSu-2105	8	TVSu-579	8	TVSu-340
9	TVSu-1242	9	TVSu-275	9	TVSu-34	9	TVSu-277
		10	TVSu-1245	10	TVSu-576	10	TVSu-2101
		11	TVSu-651	11	TVSu-667	11	TVSu-287
		12	TVSu-647	12	TVSu-359	12	TVSu-181
		13	TVSu-572	13	TVSu-346	13	TVSu-178
		14	TVSu-368	14	TVSu-650	14	TVSu-356
		15	TVSu-347	15	TVSu-2093	15	TVSu-1246
		16	TVSu-330	16	TVSu-1241	16	TVSu-273
		17	TVSu-633			17	TVSu-269
		18	TVSu-366			18	TVSu-262
		19	TVSu-2104			19	TVSu-2103
		20	TVSu-2110			20	TVSu-2112
		21	TVSu-81			21	TVSu-1239
		22	TVSu-577			22	TVSu-1222
		23	TVSu-82			23	TVSu-268
		24	TVSu-2099			24	TVSu-359
		25	TVSu-2095			25	TVSu-355
		26	TVSu-670			26	TVSu-2102
		27	TVSu-365			27	TVSu-127
		28	TVSu-83			28	TVSu-662
		29	TVSu-838			29	TVSu-285
		30	TVSu-263			30	TVSu-659
		31	TVSu-2090			31	TVSu-278
		32	TVSu-627			32	TVSu-263
		33	TVSu-639			33	TVSu-267
		34	TVSu-173			34	TVSu-119
		35	TVSu-1252				
		36	TVSu-570				
		37	TVSu-367				
		38	TVSu-844				
		39	TVSu-334				
		40	TVSu-12				
		41	TVSu-349				

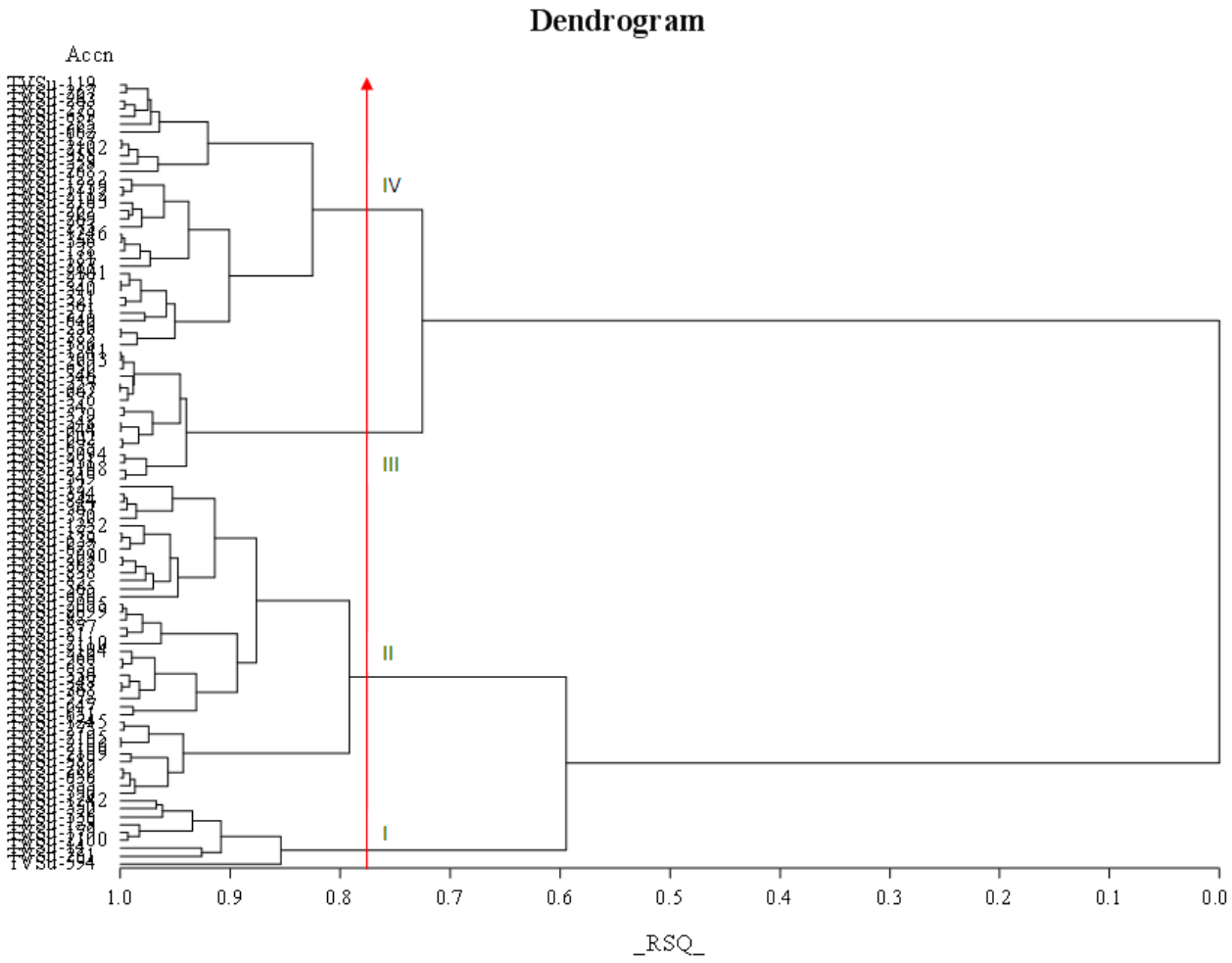

Figure 2. Cluster pattern of the 100 Bambara groundnut accessions into four groups at a 0.77 dissimilarity coefficient based on their observed morphological traits. Note**:** The tabular expression of the clustering was also presented in Table 8

3.4. Correlation Coefficients

Correlation coefficients revealed that plant height had positive and significant correlation with yield per plant, yield per plot, yield per hectare, pod length, pod width, seed length, seed width, 100-seed weight. Number of days to first flowering had negative and significant correlation with yield per plot, yield per hectare, pod width, seed width, seed weight per plot, and 100-seed weight. Yield per plant had positive and significant correlation with number of pods per plot, yield per plot, yield per hectare, pod length, pod width, seed length, seed width, seed weight per plot, and 100-seed weight. Number of pod per plot had positive and significant correlation with yield per plot, yield per hectare, number of seed per pod, seed weight per plot, shelled harvest per plot, but had negative and significant correlation with pod width, seed width, shelling percentage, and 100-seed weight. Yield per plot had positive and significant correlation with yield per hectare, pod length, pod width, seed length, seed width, seed weight per plot, chaff weight, shelled harvest per plot, and 100-seed weight. Yield per hectare had positive and significant correlation with pod length, pod width, seed length, seed width, seed weight per plot, chaff weight, shelled harvest, 100-seed weight, but had negative and significant correlation with shelling percentage. Number of seed per pod had positive and significant correlation with pod length but had negative and significant correlation with pod width, seed width, and 100-seed weight. Pod length had positive and significant correlation with pod width, seed length, seed width, and 100-seed weight. Pod width had positive and significant correlation with seed length, seed width, shelling percentage, 100-seed weight, but had negative and significant correlation with shelled harvest. Seed length had positive and significant correlation with seed width, seed weight per plot, and 100-seed weight. Seed width had positive and significant correlation with 100-seed weight. Seed weight per plot had positive and significant correlation with shelled harvest per plot, and 100-seed weight but had negative and significant correlation with shelling percentage. Chaff weight had positive and significant correlation with shelling percentage, 100-seed weight but had negative and significant correlation with shelled harvest per plot. Shelling percentage had negative and significant correlation with shelled harvest per plot.

3.5. Cluster Analysis of Quantitative Traits

Cluster analysis was used to assess the genetic differences of the observed quantitative traits, where individuals with related descriptions are grouped into the same cluster. The similarity, relatedness, and distance of the varieties are the foundation of this method, where similar accessions were grouped into the same cluster, and dissimilar accessions were grouped differently. The length between the lines (distance between two points) was calculated using standardized morphological data, and dendrogram was constructed using these values (Figure 2). The selected population was grouped into four subpopulations, cluster 1 had 9 accessions, cluster 2 had 41 accessions and cluster 3 had 16 accessions and cluster 4 had 34 accessions (Table 8) (Figure 2). Accession with the highest yield components and highest agronomic traits responses fell into cluster 2 and cluster 4 as revealed through the means.

4. Discussion

The highly significant differences observed on the quantitative traits indicated the presence of genetic variation among the accessions studied. [13, 14, 15, 16 and Odongo et al. [17] reported morphological variations of the quantitative and qualitative traits of Bambara groundnut accessions studied. Tafadzwanashe and Albert [18,19] also reported variation in plant height, number of leaves, number of days to first flowering and number of days to 50% flowering. Shegro *et al*. [15] and [20,21,22] also reported variation in number of pods per plot among the accessions studied, this could be due to the heterogeneity existing among Bambara groundnut accessions. The earliness and variation in number of days to first flowering and number of days to maturity indicated the selected accessions for this study could be selected for early maturity. Similar trend of early maturity in Bambara groundnut was also reported [15,16,21] flowering ranged from 32 to 42 days after sowing, later days to flowering had been reported [2] in Northern, Cote d'Ivoire for late maturing accessions of Bambara groundnut. Number of seed per pod revealed higher percentage of the pods was single seeded compared to double seeded pod [23]. Variation observed on the number of days to flowering, might be due to genotypic factors or influence of environmental conditions such as day length duration that prevailed during the crop growth and development. No significant difference in the number of days to maturity among the accessions, which indicated that vagaries of weather may fasten the maturity period of Bambara groundnut or might have been among the group of early maturing ones. Berchie et al. [24] observed no significant difference in the number of days to maturity. Earliness to maturity may be a veritable tool to escape drought in erratic heightening moisture stress environment and insect infestation [25,26]. Yield per plant varied significantly among the selected accessions, locations and in the years, indicating that yield of Bambara groundnut varied widely depending on accessions and environmental conditions. Similar result was reported by Khan et al. [27]. Yield per hectare also revealed significant differences among the accessions in the observed years with an average of 641.59 kg per hectare. This confirmed the report of Khan [28] that Bambara groundnut can grow and produce reasonable yield in Africa [27,37].

PC1 and PC2 had the highest contribution to variation, indicating that the component traits in PC1 and PC 2 are key factors to reveal diversity in the selected accessions. Similar results were also reported by Ntundu et al. [13,28,29] that vegetative traits had prominent loadings in principal components analysis [30]; Mohammed et al. [31] reported diversity on seed morphological features; this might be valuable to generate baseline seed morphology revealing diversity of the crop. Variation observed in yield and agronomic traits such as 100-seed weight yield per plant, plant height indicated that diversity existed in the accessions used for this study as revealed by different clusters. This also indicated that accessions within the same cluster possess similar morphological traits. The level of morphological similarity showed by accessions within the same cluster indicated that the accessions may not have common ancestry. Similar results were reported [13,14] and Mohammed et al. [21] on Bambara groundnut. The analysis of 'Locations' showed significant variations for twenty out of the twenty eight traits evaluated in the years, meaning that locations have significant effect on the traits and such traits may be more reliant on genetic expression as influenced by environmental conditions. Similar result was obtained by Esan et al. [33] reported significant differences on traits of Bambara groundnut evaluated in different regions in Cote d'Ivoire. Yield per plant varied significantly among accessions in the years from 12g/plant – 42g/plant, indicating that the yield of Bambara groundnut varied widely depending on accessions and environmental conditions. Shareef et al. [34,25,35] also reported reasonable yield of Bambara groundnut accessions with minimal input, low rainfall and poor soil fertility. Chai et al. [35,36,37] further reiterated that Bambara groundnut are drought resistant compared to other crops but that yields are highly affected by water stress and even moderate water stress can cause high yield losses. Morphological variation as revealed in the 'Years' had significant effects on observed traits. Similar result was reported by Hlanga et al. [6,33,38].

The interaction of 'Accession by location' also indicated that traits responsible for diversity in Bambara groundnut showed significant differences in the locations. This was also reported by Muhammad et al. [7]. Some of the non-significant quantitative traits are less influenced by location and may express their genetic potentials at any particular location. The interaction of 'Accession by location by year' showed that accessions of Bambara groundnut express it morphological traits differently in locations, hence, diversity among the 'accessions' is genetically and environmentally controlled.

5. Conclusions

This study concluded that morphological variability existed among Bambara groundnut in Nigeria and that such variation existed in plant height, petiole length, pod width, plant spread, yield per hectare, yield per plot, yield per plant, number of pods per plot, terminal leaflet length, number of days to first flowering and number of days to 50% flowering and are important traits that should be given attention in making effective selection for parents in Bambara groundnut breeding. This study confirmed that positive correlation existed among yield contributing traits and yield per hectare. Furthermore, the dendrogram showed that the selected population was divided into four primary clusters based on the observed quantitative traits. Accessions TVSu-594, TVSu-350, TVSu-336, TVSu-1242, TVSu-129, TVSu-14, TVSu-179, TVSu-2100, TVSu-261, and TVSu-589 had the best in terms of yield and yield components based on yield data in this study, and should be given attention in future breeding programmes in other ecological zones in Nigeria. Further studies should also make use of high throughput sequencing markers to dissect the level of diversity established in this study in the genomic constituent of Bambara groundnut.

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Conflict of Interest

The authors declare that we have no conflict of interest.

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