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Agronomic and morphological diversity of Bambara groundnut (*Vigna subterranea* (L.) Verdc.) accessions in North-Central Namibia

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Abstract

Bambara groundnut (*Vigna subterranea* (L) Verdc.) is an orphan, underutilised and less exploited crop in Africa and beyond, yet it is an essential traditional crop for subsistence farmers in sub-Saharan Africa. Currently, in Namibia, neither a pre-breeding nor a breeding programme exists for Bambara groundnut. Twenty-five Bambara groundnut accessions acquired locally and outside Namibia were characterised for descriptor state, including possible character diversity on the quantitative descriptors. Square lattice design with three replications was used. Data were analysed using analysis of variance (ANOVA), Pearson correlation moment, Principal Component Analysis (PCA), and cluster analysis. ANOVA indicated significant differences ($P < 0.05$) among accessions for most of the characters measured, and highly significant differences ($P < 0.01$) for the number of pods per plant, pod yield, seed yield, plant height, and dry biomass. The dendrogram sub-criterion indicated three clusters, confirming the results of the PCA, which grouped accessions with common descriptors in the same quadrants. PCA biplot showed that the first two components explained 59.55% of the variation. Overall results suggest that the Bambara groundnut accessions evaluated in this study showed high variability, thus can be used as a source of pre-breeding materials to initiate a national breeding programme.

Keywords: Crop improvement, genetic diversity, pre-breeding, orphan crop, subsistence farming.

1. Introduction

Bambara groundnut (*Vigna subterranea* (L.) Verdc.) is an orphan, underutilised and less exploited crop in Africa and beyond. It is an edible grain legume crop indigenous to sub-Saharan Africa that plays socio-economic roles in semi-arid regions of the sub-continent (Massawe, Mwale, Azam-Ali, & Roberts, 2005; Juliet, Vincenzo, Cathrine, & Anita, 2017). Although Bambara groundnut is also grown in Asia, this crop originated in West Africa (Hillocks, Bennett, & Mponda, 2012). In Africa, Bambara groundnut is ranked as the third most important legume after cowpea and groundnut (Ntundu, Inga, Christiansen, & Andersen, 2004). The major world producers are mainly West African countries such as Burkina Faso, Cameroon, Mali and Niger (FAO, 2015). Bambara groundnut is adapted to high temperatures and can tolerate drought (Atoyebi, Oyatomi, Osilesi, Adebawo, & Abberton, 2017), and fix nitrogen in the soil (Mabhaudhi et al., 2013). It contains 65% carbohydrate, 18% protein and 6.5% fat, making it a valuable food for poor households who cannot afford expensive animal protein (Zerihun, 2009; Ndiang et al., 2014). Besides serving as human food, the crop is also used as a source of medicines (Hepper, 1963), livestock fodder (Okpuzor, Ogbunugafor, Okafor, & Sofidiya 2010) and cash income for the subsistence farmers, especially rural women

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who sell Bambara groundnut to generate money for household use (Mubaiwa, Fogliano, Chidewe, & Annita, 2018). In sub-Saharan Africa, agricultural production is limited by water scarcity, lack of improved crop varieties and loss of genetic diversity (Massawe et al., 2002; Pauline, Tafadzwanashe, Albert, & Paramu, 2015), increasing dependence on a few crops for food. Bambara groundnut needs improvement for genetic conservation and full utilisation. Currently, research on this crop is quite limited as compared to cereals (pearl millet, sorghum, and maize) and other pulses (peanuts and cowpeas) amongst others (Ouedraogo et al., 2008; Ibrahim et al., 2018).

Namibia is a semi-arid country in southwestern Africa, where Bambara groundnut is grown by 82% of the subsistence farming households (Fleissner, 2006). The crop is mainly grown in northern regions of Omusati, Oshana, Oshikoto, Ohangwena, Kavango West, and Kavango East, where it is ranked as the second most important legume after cowpea. Although its grain yield level on research stations measured 400 to 600 kg/ha (Fleissner, 2006), the on-farm yield level is currently unknown and expected to be much lower. Various researchers had attempted at pre-breeding activities of Bambara groundnut, but such efforts were not sustained. Flesseiner (2006) evaluated the genetic diversity of Bambara groundnut using agro-morphological markers; the results indicated high diversity among the accessions. Also, Mukakalisa et al. (2016) assessed the genetic diversity on six Bambara groundnut accessions using the molecular marker, Random Amplified DNAs (RAPD) and microsatellite. Despite these efforts, no lasting Bambara groundnut breeding work exists in Namibia. Bambara groundnut genotypes exist merely as landraces, which are informally classified and named according to areas of production and market. As a result, a single accession may be produced under different names or vice versa, resulting in some farmers cultivating materials of inferior genetic qualities with consequent persistently low yield. There is, therefore, a need to scientifically determine the genetic diversity of the local landraces to help improve production and maximise the income of the local subsistence farmers (Massawe et al., 2005). Since drought regularly strikes Namibia, high yielding and drought-tolerant Bambara groundnut varieties should be the breeding target of the national programme. Therefore, agro-morphological characteristics concerning these traits are worth evaluating.

Bambara groundnut is predominantly self-pollinating and thus expected to exist as non-identical inbred-lines, although in the past lack of co-dominant markers prevented the assessment of heterozygosity (Massawe et al., 2005). Since Bambara groundnut is marginalised, this crop is persistently threatened by genetic erosion (Pauline, Tafadzwanashe, Albert, & Paramu, 2015). Genetic diversity within accessions and populations is vital for breeding and germplasm conservation (Zhang, Jia, Meng, Ti, & Wang, 2015; Aliyu et al., 2016). Plant breeders need materials with minimum polymorphism to develop new genotypes (Ndiang et al., 2014). Therefore, collection, characterisation, evaluation, and storage of Bambara groundnut germplasms are significant steps toward establishing a crop improvement programme that would supply suitable parent materials. This study assessed the agronomic and morphological variations among Bambara groundnut accessions from Namibia and other Southern African countries for future crop improvement.

2. Materials and Methods

The field experiment was carried out at the University of Namibia-Ogongo Campus located approximately at a latitude of 17°40′37.6″ S, longitude 15°17′43.0″ E, and an altitude of 1109 m above sea level, in Omusati Region during the 2017/2018 cropping season. The area has an average annual rainfall of 400-500 mm and average annual temperature of more than 23 °C; the soil type is sandy loam. A total of 25 Bambara groundnut accessions, 10 from Namibia Botanical Research Institute (NBRI), 10 from Omahenene Research Station, Namibia; two from Kitwe, Zambia; and three from Chitedze Research Station, Malawi were assessed for genetic diversity including preferred cultivars from local farmers as controls (Table 1). The design of the experiment was a square lattice with twenty-five accessions in three replications and fifteen blocks totalling 75 experimental units. Individual plot area was 8.1 m^2 (3.6 m long × 2.25 m wide) with the intra-row spacing of 45 cm and inter-row spacing of 75 cm, giving three rows per plot. Each row comprised 10 hills, totalling a population of 30 plants per plot. The estimated total plant population for the experiment was 2,250 plants. The experimental area was 1,018 m^2 (68 m long × 15 m wide).

Quantitative data were collected according to the Bambara groundnut descriptors (IPGRI, 2000). The growth traits included days to emergence, days to 50% flowering, plant height, terminal leaflet width, terminal leaflet length, number of leaves per plant, and number of branches per plant. The yield characters entailed the number of pods per plant, number of pods with two or more seeds, seed width, seed length, fresh pod weight, dry pod weight, 100 pod weight, 100 seed weight, seed weight per plant, fresh biomass, dry biomass, shelling percentage, harvest index, pod yield per hectare and seed yield per hectare.

Bambara groundnut agro-morphological data were analysed using analysis of variance (ANOVA). Descriptive statistics were determined as indicators of agro-morphological variability. The simple correlation coefficient was calculated using the Pearson correlation coefficient to determine the relationships between the studied agro-morphological variables. Multivariate analysis of agro-morphological data by Principal Component Analysis (PCA) was used to discriminate genetic diversity among the accessions of Bambara groundnut. Genetic similarity between pairs was calculated using the agglomeration method, the unweighted pair-group method with the arithmetic averages (UPGMA).

Table 1: Bambara groundnut accessions used in the study

Serial No.	Accession ID	Country of origin	Source
1	NAM 3900	Namibia	OMRS
2	AHM 968	Namibia	OMRS
3	NAM 1754/3	Namibia	NBRI
4	NAM BLACK	Namibia	OMRS
5	LR6	Namibia	OMRS
6	NAM 3804	Namibia	NBRI
7	NAM 1195/2	Namibia	NBRI
8	MW 791	Malawi	CRS
9	ZAM 02	Zambia	Kitwe
10	NAMFA	Namibia	Farmers
11	NAM 1762/2	Namibia	NBRI
12	UNISWA RED	Swaziland	OMRS
13	NAM 1866	Namibia	NBRI
14	NAM 1758/3	Namibia	NBRI
15	NYAKC	Swaziland	OMRS
16	MW 2875	Malawi	CRS
17	ZAM 01	Zambia	Kitwe
18	NAM RED	Namibia	OMRS
19	NAM 1084/3	Namibia	NBRI
20	DIPC	Botswana	OMRS
21	KFBN	Namibia	OMRS
22	NAM 1156/3	Namibia	NBRI
23	NAM 959/4	Namibia	NBRI
24	LR4	Namibia	OMRs
25	MW 266	Malawi	CRS

OMRS: Omahenene Research Station; NBRI: Namibia Botanical Research Station; CRS: Chitedze Research Station.

3. Results

3.1 Descriptive analysis

Table 2 shows descriptive statistics of various characters of the Bambara groundnut accessions. There was high variation among accessions for yield and yield characters, with the highest coefficient of variation (CV) observed in fresh pod weight per plant (74%), number of pods with two or more seeds (72%), number of pods per plant (66%), dry pod weight plant (63%), pod yield (61%), harvest index (61%), seed yield (57%), 100 seed weight (34%), and 100 pod weight (32%). The CV values for fresh biomass, dry biomass, number of leaves and the number of branches were 52, 43, 37, and 37%, respectively.

Analysis of variance indicated significant differences among the Bambara groundnut accessions for most of the characters studied. Plant height, terminal leaflet length, terminal leaflet width, number of leaves, number of pods per plant, fresh pod weight, dry pod weight, pod yield, and grain yield were highly significant at a 1% level of probability. Whereas, the number of stems per plant, seed length, seed width, hundred seed weight, fresh biomass, and dry biomass were significant at 5% level of probability (Table 2).

Table 2: Descriptive statistics summary of the Bambara groundnut variables

Characters	Minimum	Maximum	Mean	SD	CV	*P*-value
D50F	30.00	41.00	35.57	2.04	0.06	0.266
PH (cm)	12.57	25.00	19.56	2.49	0.13	<0.001
TLW (mm)	13.33	27.00	20.04	3.03	0.15	<0.001
TLL (mm)	40.00	71.80	57.30	7.04	0.12	<0.001
NL	39.00	310.00	131.95	49.08	0.37	<0.001
NBP	13.00	103.60	44.03	16.30	0.37	0.022
NPP	2.00	46.80	16.21	10.74	0.66	<0.001
NSP	0.00	10.04	2.57	1.86	0.72	0.326
FPWP (g)	1.32	75.42	23.78	17.80	0.74	<0.001
DPWP (g)	1.00	31.13	12.14	7.65	0.63	<0.001
100PW (g)	35.41	268.14	96.36	31.32	0.32	0.13
100SD (g)	27.70	184.13	66.05	22.41	0.34	0.024
SL (mm)	9.02	17.07	13.35	1.65	0.12	0.027
SW (mm)	6.25	12.14	10.08	1.01	0.1	0.011
FB (g)	4.87	50.03	23.05	12.16	0.52	0.01
DB (g)	2.96	26.04	12.19	5.24	0.43	0.022
SP (%)	32.10	99.75	70.23	15.76	0.22	0.299
HI	0.01	1.00	0.37	0.23	0.61	0.662
PY (kg/ha)	47.62	563.57	214.77	131.59	0.61	<0.001
SY (kg/ha)	39.76	470.90	176.07	100.41	0.57	<0.001

D50F: Days to 50% flowering, PH: Plant height, TLW: Terminal leaflet width, TLL: Terminal length, NBP: Number of branches, NPP: Number of pods per plant, NSP: Number of pods with two or more seeds, SL: Seed length, SW: Seed width, FPWP: Fresh pod weight per plant, DPWP: Dry pod weight per plant,100PW: 100 Pod weight, 100SD: 100 Seed weight, FB: Fresh Biomass, DB: Dry Biomass, SP: Shelling Percentage, HI: Harvest Index, PY: Pod Yield, SY: Seed Yield.

3.2 Principal Component Analysis (PCA)

PCA was used to infer the significance or contribution of the individual agro-morphological character to the total agro-morphological characters variability. The four principal components were selected from 20 components, which accounted for the entire 100% variability (Table 3). Eigenvalues greater than one are considered significant, and component loadings higher than ±0.3 are also regarded as significant (Kutcher, Ferguson, & Cohen, 2013). The first principal component accounted for about 45.2% of the variation, and all variables grouped under this component were mostly yielding characters. Therefore this component would be useful for yield selection as all yield components are included. The second component, representing 14.3% of the total variability, was associated with variables such as days to 50.0% flowering, plant height, terminal leaf width, terminal leaf length, hundred pod weight, hundred seed weight, seed length, and seed width. The third principal component accounted for 10.4% of total variability and was associated with vegetative characters and some yield components such as terminal leaf length, number of pods with two or more seeds, fresh biomass per plant, dry biomass per plant, pod yield per hectare and grain yield per hectare. The fourth principal component accounted only for 6.8% of the total variation, comprising days to 50.0% flowering, number of pods per plant, number of pods with two or more seeds, seed length, seed width, seed length, fresh biomass per plant, dry biomass per plant, shelling percentage and harvest index.

Table 3: Principal Component Analysis (PCA) of four components

	F1	F2	F3	F4
Eigenvalue	9.0418	2.8683	2.0884	1.3613
Variability (%)	45.2089	14.3417	10.4421	6.8065
Cumulative (%)	45.2089	59.5506	69.9928	76.7993
Variable		Eigenvector		
D50F	0.1185	0.0074	-0.3635	0.3709
PH	0.1605	0.3439	-0.3513	-0.2032
TLW (mm)	0.2740	0.0591	0.0212	-0.3061
TLL (mm)	0.2057	0.2740	-0.1963	-0.0727
NL	0.1460	-0.3541	-0.2810	-0.1777
NBP	0.1427	-0.3174	-0.1814	-0.0126
NPP	0.2571	-0.1091	0.3540	0.0631
NSP	0.1732	-0.1621	0.0513	0.5414
FPWP (g)	0.2986	-0.1004	0.2357	-0.0430
DPWP (g)	0.2987	-0.0976	0.2555	-0.0345
100PW (g)	0.2296	0.2588	-0.1404	-0.2269
100SD (g)	0.2058	0.3663	0.0322	-0.0263
SL (mm)	0.2184	0.2597	-0.0148	0.3608
SW (mm)	0.2112	0.2192	-0.1352	0.2435
FB (g)	0.2731	-0.1736	-0.1244	0.0721
DB (g)	0.2819	-0.1456	-0.1942	0.0267
SP (%)	-0.0069	0.2560	0.2799	0.3044
HI	0.1384	-0.2865	-0.2474	0.0946
PY (kg/ha)	0.2869	-0.0353	0.2464	-0.1478
SY (kg/ha)	0.2891	-0.0492	0.2282	-0.1389

D50F: Days to 50% flowering, PH: Plant height, TLW: Terminal leaflet width, TLL: Terminal length, NBP: Number of branches, NPP: Number of pods per plant, NSP: Number of pods with two or more seeds, SL: Seed length, SW: Seed width, FPWP: Fresh pod weight per plant, DPWP: Dry pod weight per plant,100PW:100 Pod weight, 100SD: 100 Seed weight, FB: Fresh Biomass, DB: Dry Biomass, SP: Shelling Percentage, HI: Harvest Index, PY: Pod Yield, SY: Seed Yield.

3.3 Principal Component Biplot

The variation observed among the Bambara groundnut accessions used in this study are depicted by the PCA biplot (Fig. 1). The accessions were divided into four quadrants produced by the PCA biplot, which presented 59.55% of the variation for the two-axis with PC1 and PC2 representing 45.21% and 14.34%, respectively. Results showed that accessions NAM 1866, NAM 959/3, NAM 1156, MW 799 and NAM 1084 were in one quadrant, of which four of them were from Namibia, and one was from Malawi. Another quadrant had LR6, NAM 1758/3, NAM 1762/2, UNISWA RED, NAM BLACK, NAM RED and DIPC. Accession UNISWA originally came from Swaziland, although it was locally sourced; DIPC was initially from Botswana; whereas the rest were from Namibia. The other quadrant comprised LR4, ZAM 01, ZAM 02, NAM3804 and NAM 1195/2 accessions from Namibia and MW 266 and MW 2875 from Malawi. The last quadrant had NAM 3900, AHM 968, KFBN, NAMFA, NYAKC, and NAM 1754/3 accessions, all from Namibia. The accessions grouped in the same component show a strong association. Fig. 1 shows characters that are associated with PC1 and PC2. In component one, the descriptors that contribute more are seed yield, the number of pods per plant and dry biomass in component two are shelling percentage, the number of leaves per plant, biomass per plant and harvest index. The positive correlation was observed between pod yield and seed yield, component one between seed length and seed width in component two.

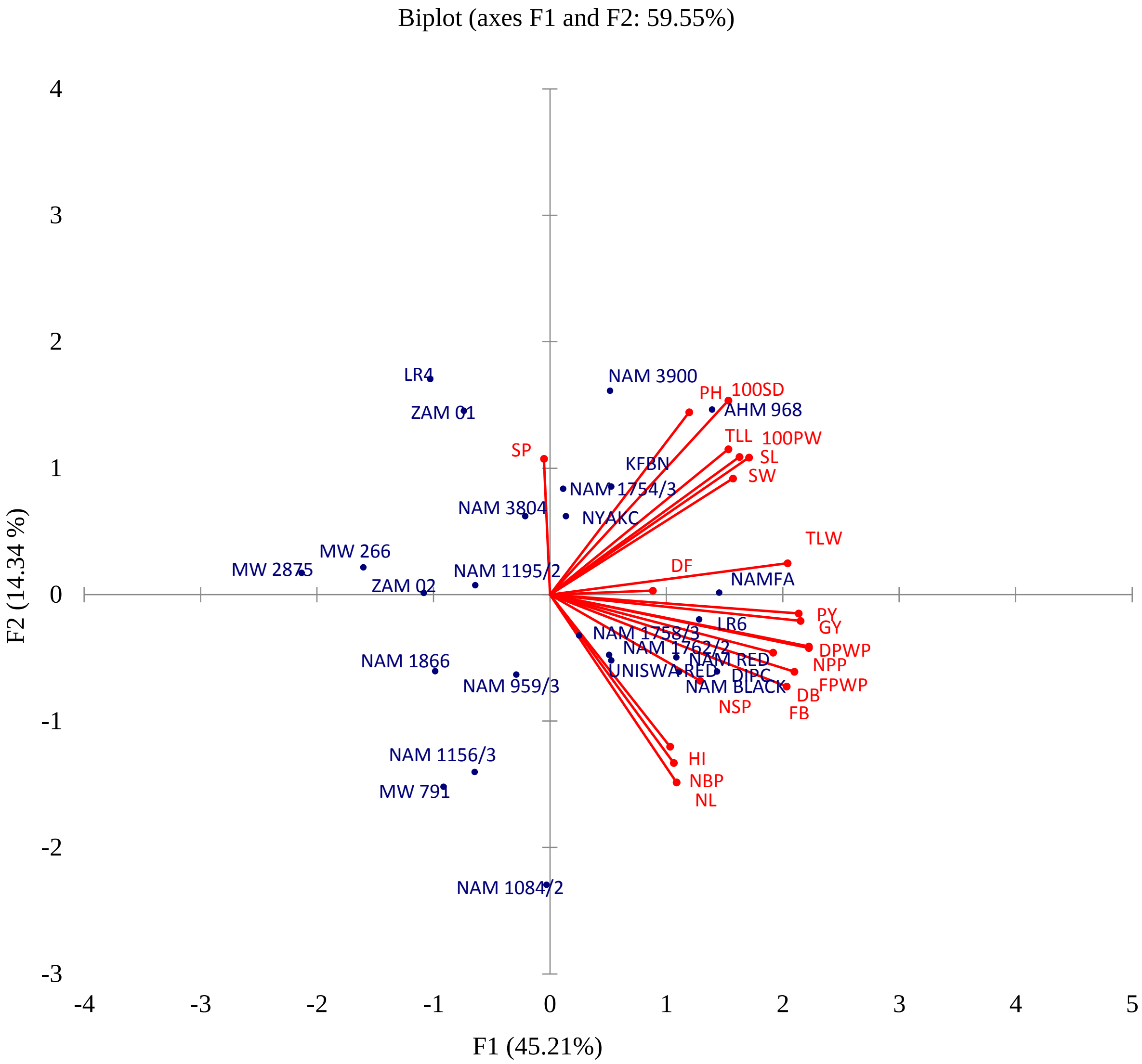

Figure 2. Configuration of the Bambara groundnut accessions under principal component axis 1 and 2. D50F: Days to 50% flowering, PH: Plant height, TLW: Terminal leaflet width, TLL: Terminal length, NBP: Number of branches, NPP: Number of pods per plant, NSP: Number of pods with two or more seeds, SL: Seed length, SW: Seed width, FPWP: Fresh pod weight per plant, DPWP: Dry pod weight per plant,100PW:100 Pod weight, 100SD: 100 Seed weight, FB: Fresh Biomass, DB: Dry Biomass, SP: Shelling Percentage, HI: Harvest Index, PY: Pod Yield ,SY: Seed Yield.

The dendrogram from the average linkage method grouped the 25 accessions into three clusters (Fig. 2). The accessions were separated with a similarity distance from 0.99 to 0.87. The first cluster consisted of 15 accessions, namely NAM 3900, AHM 968, NAM BLACK, LR6, NAM 3804, NAM 1195/2, MW 791, ZAM 02, NAMFA, NAM 1762/2, NAM 1866, NYAKC, MW 2875, NAM 1754/3 and LR4. Furthermore, this cluster also consisted of two sub-clusters. The second cluster consisted of four accessions, namely UNISWA RED, NAM 1084/3, KFBN and MW 266 of which UNISWA RED was from Swaziland, MW 266 from Malawi and the remaining two were from Namibia. The third cluster comprised six accessions including

NAM 1758/3, ZAM 01, NAM RED, DIPC, NAM 1156/3 and NAM 959/4 whereby four of these accessions were from Namibia, one from Zambia and the other from Botswana.

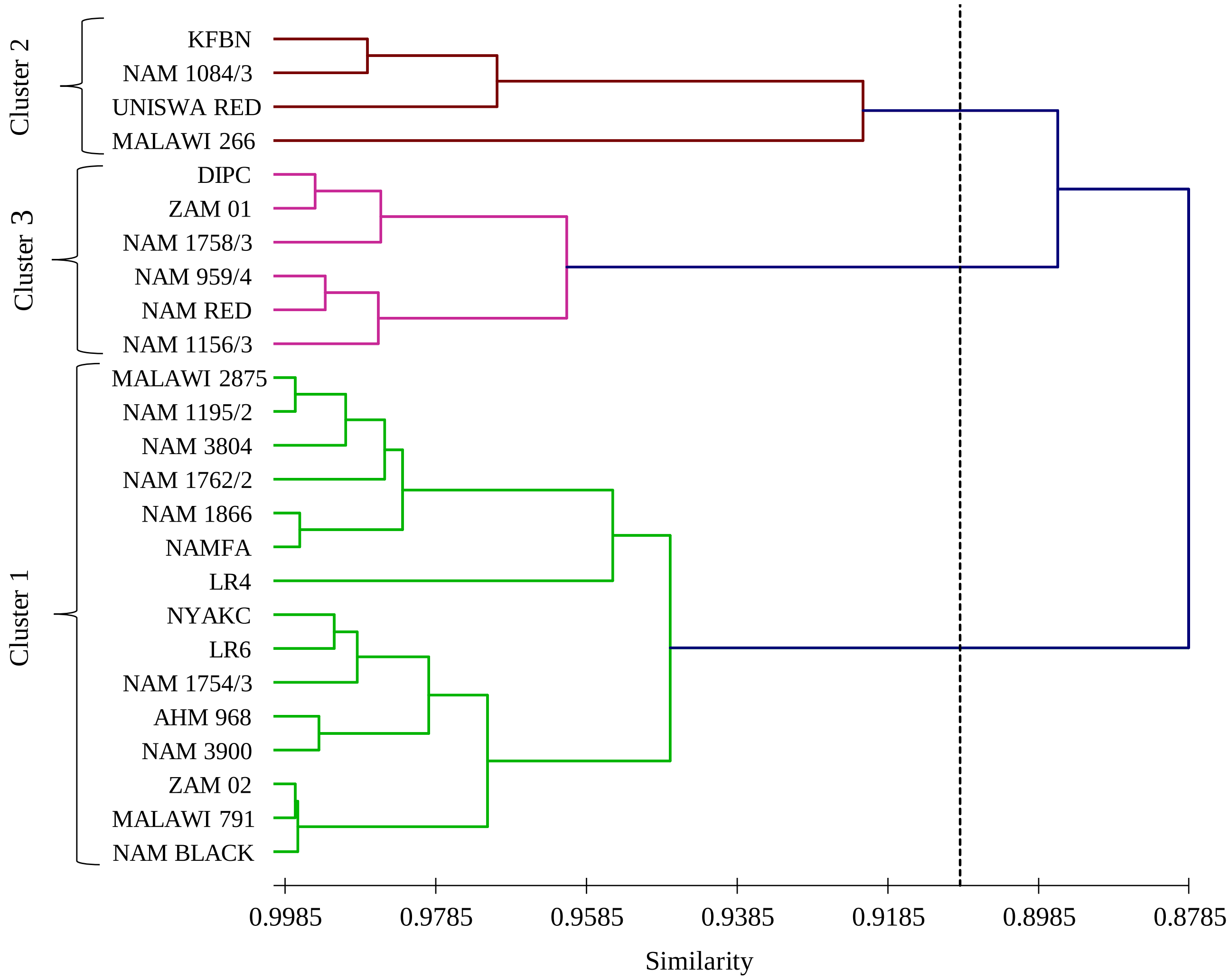

Figure 2. Dendrogram showing distinctive clusters constructed based on Bambara groundnut accessions.

3.5 Correlation analysis

Pearson's correlation coefficients showed different interrelationships among the measured variables (Table 4). The yield and its yield components displayed highly significant positive correlations. Grain yield was significantly positively correlated with pod yield (r = 0.98), fresh pod weight (r = 0.71), dry pod weight (r = 0.81), number of pods per plant (r = 0.68), terminal leaf width (r = 0.61), terminal leaf length (r = 0.40), fresh biomass (r = 0.48) and dry biomass (r = 0.46). Plant height showed significantly positive correlation with terminal leaf length (r = 0.71) and terminal leaf width (r = 0.49). Terminal leaf length and terminal leaf width were also significantly positively correlated (r = 0.53; $P \leq 0.001$). The number of branches per plant and the number of leaves per plant was positively correlated (r = 0.74). A positive correlation was also observed between fresh biomass and dry biomass (r = 0.91). Seed length and seed width showed a significantly positive correlation (r = 0.81). The dry pod weight per plant was positively correlated with pod yield (r = 0.82) and fresh pod weight per plant (r = 0.84). Moreover, fresh pod weight per plant and the number of pods per plant had a significant positive correlation (r = 0.80).

Table 4: Partial Pearson correlation coefficient matrix (upper number) and p-value (under number) of quantitative descriptors

Variables	D50F	PH	TLW(mm)	TLL(mm)	NL	NBP	NPP	NSP	FPWP	DPWP	100PW	100SD	SL(mm)	SW(mm)	FB	DB	SP%	HI	PY(kg/ha)	GY (kg/ha)
D50F	1																			
	0																			
PH	0.1513	1																		
	0.1950	0																		
TLW(mm)	0.2114	0.4866	1																	
	0.0687	< 0.0001	0																	
TLL(mm)	0.3674	0.7097	0.5346	1																
	0.0012	< 0.0001	< 0.0001	0																
NL	0.0771	0.1249	0.2493	0.1333	1															
	0.5106	0.2856	0.0310	0.2542	0															
NBP	0.0073	0.0789	0.1810	0.0595	0.7418	1														
	0.9508	0.5013	0.1203	0.6122	< 0.0001	0														
NPP	0.1859	0.0254	0.4319	0.2865	0.3143	0.4622	1													
	0.1103	0.8287	0.0001	0.0127	0.0060	< 0.0001	0													
NSP	0.1840	-0.0213	0.1542	0.0923	0.0973	0.2362	0.3860	1												
	0.1140	0.8563	0.1867	0.4310	0.4061	0.0413	0.0006	0												
FPWP	0.0765	0.1572	0.5491	0.3035	0.3566	0.4005	0.8092	0.3854	1											
	0.5140	0.1780	< 0.0001	0.0081	0.0017	0.0004	< 0.0001	0.0006	0											
DPWP	0.1307	0.1793	0.5813	0.3403	0.3911	0.4302	0.8764	0.4748	0.8448	1										
	0.2636	0.1238	< 0.0001	0.0028	0.0005	0.0001	< 0.0001	< 0.0001	< 0.0001	0										
100PW	0.1494	0.4166	0.4376	0.3225	0.2096	0.3484	0.3767	0.3017	0.4331	0.5404	1									
	0.2009	0.0002	< 0.0001	0.0048	0.0711	0.0022	0.0009	0.0085	0.0001	< 0.0001	0									
100SD	0.2453	0.3771	0.3752	0.3705	0.0954	0.2346	0.3639	0.1568	0.3041	0.4335	0.7667	1								
	0.0339	0.0009	0.0009	0.0011	0.4155	0.0428	0.0013	0.1791	0.0080	0.0001	< 0.0001	0								
SL(mm)	0.1479	0.2461	0.3575	0.2921	-0.0074	-0.0810	0.1997	0.1815	0.1702	0.2199	0.0962	0.0818	1							
	0.2054	0.0333	0.0016	0.0110	0.9495	0.4899	0.0858	0.1191	0.1444	0.0580	0.4117	0.4856	0							
SW(mm)	0.2735	0.2688	0.3973	0.2770	0.0410	-0.0374	0.1994	0.1348	0.2355	0.2224	0.1752	0.1486	0.8123	1						
	0.0176	0.0197	0.0004	0.0161	0.7272	0.7504	0.0863	0.2487	0.0419	0.0551	0.1327	0.2031	< 0.0001	0						
FB	0.1943	0.2202	0.3989	0.3716	0.3954	0.3214	0.4273	0.3415	0.4835	0.5493	0.3933	0.2691	0.1124	0.2093	1					
	0.0949	0.0577	0.0004	0.0010	0.0004	0.0049	0.0001	0.0027	< 0.0001	< 0.0001	0.0005	0.0196	0.3370	0.0715	0					
DB	0.1397	0.2850	0.4090	0.3847	0.5272	0.4291	0.4090	0.2999	0.5171	0.5520	0.4456	0.2722	0.1341	0.2289	0.9057	1				
	0.2321	0.0132	0.0003	0.0007	< 0.0001	0.0001	0.0003	0.0090	< 0.0001	< 0.0001	< 0.0001	0.0182	0.2513	0.0482	< 0.0001	0				
SP%	0.0969	-0.0593	-0.1095	0.0632	-0.2032	-0.1811	-0.0527	-0.2213	-0.1868	-0.1782	-0.3326	0.3246	-0.0757	-0.0701	-0.1622	-0.2508	1			
	0.4081	0.6131	0.3498	0.5904	0.0805	0.1199	0.6534	0.0563	0.1086	0.1261	0.0036	0.0045	0.5186	0.5502	0.1644	0.0300	0			
HI	0.1687	0.0467	0.0920	0.1742	0.1851	0.0797	0.0633	0.1496	0.0753	0.0987	-0.0515	-0.2501	0.1177	0.1782	0.5421	0.4143	-0.2203	1		
	0.1479	0.6906	0.4322	0.1349	0.1118	0.4965	0.5893	0.2002	0.5209	0.3993	0.6610	0.0305	0.3144	0.1261	< 0.0001	0.0002	0.0576	0		
PY(kg/ha)	0.1472	0.2543	0.6091	0.4176	0.3081	0.2560	0.6921	0.2641	0.6855	0.8182	0.3645	0.3054	0.2544	0.2406	0.4639	0.4479	-0.0997	0.1890	1	
	0.2076	0.0277	< 0.0001	0.0002	0.0072	0.0266	< 0.0001	0.0220	< 0.0001	< 0.0001	0.0013	0.0077	0.0276	0.0376	< 0.0001	< 0.0001	0.3946	0.1044	0	
GY (kg/ha)	0.1322	0.2608	0.6144	0.4087	0.2837	0.2484	0.6847	0.3094	0.7051	0.8142	0.3725	0.2975	0.2420	0.2353	0.4836	0.4604	-0.1178	0.2193	0.9808	1
	0.2582	0.0238	< 0.0001	0.0003	0.0137	0.0317	< 0.0001	0.0069	< 0.0001	< 0.0001	0.0010	0.0095	0.0364	0.0421	< 0.0001	< 0.0001	0.3143	0.0587	< 0.0001	0

D50F: Days to 50% flowering, **PH**: Plant height, **TLW**: Terminal leaflet width, **TLL**: Terminal length, **NBP**: Number of branches, **NPP**: Number of pods per plant, **NSP**: Number of pods with two or more seeds, **SL**: Seed length, **SW**: Seed width, **FPWP**: Fresh pod weight per plant, **DPWP**: Dry pod weight per plant,**100PW**:100 Pod weight, **100SD**: 100 Seed weight, **FB**: Fresh Biomass, **DB**: Dry Biomass, **SP**: Shelling Percentage, **HI**: Harvest Index, **PY**: Pod Yield ,**GY**: Seed Yield.

4. Discussion

4.1 Descriptive statistics

The genetic variability observed in breeding materials is an indication of desirable characters of crops that can be integrated into the breeding program (Choudhary, Payasi, & Patle, 2017). The observed significant differences in this study indicated that considerable genetic variations existed among the Bambara groundnut accessions for the characters investigated, and such variations may be ascribed to the accessions' genetic background and their source of origin. These findings are in agreement with those of Madukwe, Onuh, and Christo (2011) and Mohammed (2014) who reported highly significant differences among Bambara groundnut accessions based on selected characters.

The assessment of genetic diversity in agro-morphological variability and characterisation is the first step in plant breeding (Buah, Abu, & Leduah, 2011; Ndiang et al., 2014). Numerous studies have assessed genetic diversity using different agro-morphological characteristics as reported by Goli (1995); Anchirinah & Bennet-Lartey (2002); Sesay, Edje, & Magagula (2003); Molosiwa (2012); Gbaguidi, Dansi, Dossou-Aminon, & Gbemavo (2017). In this study, analysis of variance revealed significant variability among the Bambara groundnut accessions for most of the characters studied; thus accessions possessing the desired characters may be used as pre-breeding materials for a national Bambara groundnut improvement program. The significant differences observed in some of the characters, such as the number of pods per plant aligns with the results of Masindeni (2006). Variation in seed length and seed width may be due to different seed shapes. One hundred seed weight varies possibly due to different seed sizes of the individual accessions. Fresh pod weight, dry pod weight, pod yield, and grain yield are highly variable due to different yield levels of the accessions. These variations in the crop's yield components imply that there is variability among the Bambara groundnut accession in term of their yield potential, which corroborates with the findings (Gonné, Félix-Alain, & Bargui, 2013). Therefore, if one wishes to increase the yield level of Bambara groundnut, then these are the characters to be considered for improvement. Furthermore, significant differences were observed in plant height, number of stems per plant, terminal leaflet length, terminal leaflet width, number of leaves, fresh biomass and dry biomass which are biomass component. These results are in line with those of Mohammed, Shimelis, & Laing (2016).

4.2 Principal Component Analysis

PCA clustered accessions into 20 components based on the characters studied. The first four components revealed the genetic variability of quantitative characters. Table 3 showed some characters that are closer to each other in the component as an indication of similarity or relationship among them. The actual genetic relationship among the closely related accessions can be further revealed by molecular and biochemical characterisation (Shengro, Rensburg, & Adebola, 2013).

By PCA procedure, day to 50% flowering, plant height, terminal leaf length, terminal leaf width, number of leaves, number of branched per plant, number of pods with two or more seeds, fresh pod weight per plant, dry pod weight per plant, hundred pod weight, hundred seed weight, seed length, seed weight, fresh biomass, dry biomass, shelling percentage, harvest index, pod yield and seed yield were substantial in accession grouping, constituting 45.2% of the variation in the first component (PC1), suggesting that they worth considering in selecting for superior agronomic performance. Ntundu et al. (2006) reported that in Tanzania, farmers used leaf morphology, seed colour, and size as criteria for selection. Farmers in Namibia may, therefore, have selected Bambara groundnut for specific agro-morphological characters using these criteria.

4.3 Principal Component Biplot

The principal component biplot further explained agro-morphological similarity and variation among the Bambara groundnut accessions as grouped in PC1 and PC2. The quantitative characters studied led to the grouping of accessions into four quadrants representing 59.55% of the total variation. The accessions were scattered in all the quadrants, showing genetic variability and also similarity for those that were closer to each other. For example, accessions from Zambia, Namibia, and Malawi appeared in the same quadrant, suggesting that farmers from these countries may have exchanged seeds.

Some accessions showed grouping or pairing within axes, irrespective of places of origin, which does not only imply sharing of features among the accessions for the 20 quantitative characters studied (Fig. 1), but it also indicates genetic variability. Some studies by Molosiwa et al. (2015) and Ntundu et al. (2016) reported Bambara groundnut accessions grouped according to their places of origins; however, this was not necessarily the case in this study. Moreover, the accessions that were scattered far apart within an axis or quadrant should have been distantly related to each other, for example, accession LR4 and NAM 1195/2 in quadrant 3. A strong relationship was observed between NAM RED and UNISWA RED, which were in the same quadrant and close to each other, implying that these accessions had common features or characters, notably high yield and the red seed coat. The grouping of Bambara groundnut accessions mentioned above showed relationships among individuals that had common features or common origins. The occurrence, within the same quadrant, of accessions originating in different locations, may be attributed to seed exchange among farmers. Subsistence farmers exchange planting materials, which sometimes result in the same accession being exchanged under different names (Shengro, Rensburg, & Adebola, 2013).

4.4 Cluster analysis

The results indicated that Bambara groundnut accessions were grouped into three superclusters (Fig. 2). These classifications may be based on the relationships among the accessions. Accessions NAM 3900, AHM 968, NAM BLACK, LR6, NAM 3804, NAM 1195/2, MW 791, ZAM 02, NAMFA, NAM 1762/2, NAM 1866, NYAKC, MW 2875 and LR4 grouped in one cluster displayed some degree of similarity in the PCA biplot. As explained earlier, accessions in the third cluster and second cluster comprised those with similar agro-morphological attributes; for instance, the third cluster solely comprises the accessions with a cream seed coat. Similarity among the accessions may have resulted from the same accessions bearing different names but grown in different regions. Similar results were reported by Mohammed (2016). Therefore, breeders should use accessions belonging to different clusters for hybridisation to maximise heterosis.

4.5 Correlation analysis

The correlation coefficient is an essential parameter in plant breeding since it measures the degree of genetic or non-genetic association between two or more characters (Jonah et al., 2014). In this study, the correlation coefficients detected between Bambara groundnut yields and its yield components were positively correlated (Table 4); for example, seed yield and pod yield, implying that the more the pods, the higher the seed yield. These results are in agreement with those obtained by Gonné, Félix-Alain, & Bargui (2013), who found a high correlation between seed yield and pod yield in Bambara groundnut. Moreover, seed yield was positively correlated with the number of pods with two or more seeds, the number of pods per plant, fresh pod weight per plant, and dry pod weight per plant. Similar results were reported by Ouedraogo et al. (2008). The dry pod weight per plant was positively correlated with pod yield. Dry pod weight per plant and fresh pod weight per plant were positively correlated; also, fresh pod weight per plant and the number of pods per plant were positively correlated. These are the characters that contribute to Bambara groundnut seed yield, hence crucial for yield improvement. Bambara groundnut farmers would prefer high yielding varieties to secure food. A positive correlation was observed between fresh biomass and dry biomass, an association which may be valuable for biomass production as some farmers use parts of the plant biomass (leaves and roots) as livestock feed. Moreover, there was a significant positive correlation between seed length and seed width of Bambara groundnut. The Bambara groundnut farmers prefer big sized seeds, as indicated by Fleissner (2006). Therefore, this association would be critical for seed size improvement.

5. Conclusion

Agro-morphological characters showed high variability among the Bambara groundnut accessions studied. The accessions exhibited differences in seed yield per plant, number of pods per plant, seed size, and biomass. The cluster analysis grouped the accessions into three clusters, signifying genetic variation among the accessions. PCA indicated the agro-morphological characters contributing to the components; the biplot further grouped the accessions and associated characters into two main principal component axes. Correlation analysis showed a significant positive correlation among most of the characters studied. The agronomic and morphological variations observed in this study may be used as pre-breeding tools to start the Bambara groundnut breeding program for Namibia. However, further studies, such as the use of molecular marker studies, may be needed to ascertain the observed variations.

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