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Morphological Variation in Selected Accessions of Bambara Groundnut (*Vigna subterranea* L. Verdc) in South Africa

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Abstract

Bambara groundnut (*Vigna subterranea* L. Verdc) is an underutilized crop in the African continent. It is a drought tolerant crop and fixes atmospheric nitrogen. Bambara groundnut is primarily grown for the protein content of its seeds and is mainly produced by small scale farmers at subsistence level. The objective of the study was to assess the morphological variation of landraces of bambara groundnut in South Africa. Thirty accessions of bambara groundnut were evaluated for their variability in agronomic and morphological traits. The field experiment was conducted at ARC-VOPI in Roodeplaat research farm during the 2014/2015 summer cropping season. The field trial was arranged as a complete randomized block design with three replications. Eighteen quantitative traits were recorded to estimate the level of genetic variability among accessions. The analysis of variance revealed significant differences among the phenotypic traits evaluated. The UPGMA cluster analysis based on the quantitative traits produced four distinct groups of genotypes and a singleton. Genotypes SB11-1A, SB19-1A, SB12-3B and Bambara-12 were found to possess good vegetative characters and are recommended for use as suitable parents when breeding cultivars for fodder production. Desirable yield and yield-related traits were identified in B7-1, SB4-4C, SB19-1A, Bambara-12 and SB16-5A and are recommended as suitable parental lines for bambara groundnut grain production improvement. The phenotypic characters therefore provide a useful measure of genetic variability among bambara genotypes and will enable the identification of potential parental materials for future breeding programs in South Africa.

Keywords: morphological variability, multivariate, quantitative traits, *Vigna subterranea*

1. Introduction

Bambara groundnut (*Vigna subterranea* L. Verdc) is an indigenous African legume primarily grown for its seeds. It is becoming increasingly popular as a food crop in rural areas of many countries in Africa (Vurayai et al., 2011). Bambara groundnut has been ranked as the third most important grain legume after groundnut (*Arachis hypogaea* L.) and cowpea (*Vigna unguiculata*) (Howell et al., 1994) in Africa. The crop has been cultivated in the tropical regions of sub-Saharan Africa and in Madagascar for many centuries (Godwin & Moses, 2013). Bambara groundnut is essentially grown for human consumption and has been described as a complete balanced diet due to the high carbohydrate (65%) and protein (18%) content of its seed (Ouedraogo et al., 2008). The protein content of bambara groundnut is high in lysine (Massawe et al., 2005).

The immature seeds of bambara groundnut can be boiled or grilled before being eaten while the mature seeds can be roasted in oil or ground into flour and then mixed with oil or butter to form a porridge. In South Africa and Swaziland, bambara groundnut is used to add variety to the daily diets and the boiled seeds can also be pounded and mixed with samp or used to make soup (Masindeni, 2006). Traditionally, bambara groundnut is used to cure nausea especially in pregnant women by chewing and swallowing the raw bean (Department of Agriculture, Forestry and Fisheries, 2011).

The leaves can also be used to feed livestock. Bambara groundnut is a drought tolerant crop and is readily adaptable to different environmental conditions and has the ability to be intercropped making it an important economic crop in many developing countries (Rungnoi et al., 2012).

The breeding system of bambara groundnut is not well understood and there are no cultivars. Landraces of the crop are still cultivated. There is a need to develop improved varieties for particular agro-ecological conditions or production systems. Bambara groundnut is still regarded as a poor man's crop grown for subsistence and very little progress has been made in improving the crop germplasm (Ayana & Bekele, 2000). Many researchers have used several morphological traits to characterize bambara groundnut accessions. Goli et al. (1997) characterized and evaluated the collection of bambara groundnut at the International Institute of Tropical Agriculture. The variability between local and exotic bambara groundnut landraces in Botswana was reported by Karikari (2000). Jonah et al. (2012) evaluated the seasonal variation and the correlation between yield and yield components in bambara groundnut accessions in Nigeria. Another study in Nigeria used multivariate analysis and character association for the growth and yield of bambara groundnut (Jonah et al., 2014). Mohammed (2014) did pre-breeding of bambara groundnut accessions in Kano State of Nigeria. Shegro et al. (2013) reported morphological variation in bambara groundnut in South Africa. However, there are a large number of land races that are planted in South Africa and it is important to further assess the variation in this germplasm for use in the breeding programs. Consequently, this study examined the agro-morphological variation in selected accessions of bambara groundnut in South Africa.

2. Materials and Methods

2.1 Plant Material

Thirty accessions of bambara groundnut landraces were obtained from the germplasm bank of Agricultural Research Council-Vegetable and Ornamental Plant Institute (ARC-VOPI), Roodeplaat, South Africa. The list of bambara groundnut genotypes used in this study, their seed morphology, leaf shape and growth habit is given in Table 1. The accessions were planted under open field conditions at the ARC-VOPI Roodeplaat research farm during the 2014/2015 summer cropping season. Roodeplaat lies at 25º59′S latitude and 28º21′E longitudes at an altitude of 1164 meters above sea level. The soil type is a clay loam with the pH of 7.08 (ARC-VOPI, 2012).

Table 1. The list of bambara groundnut accessions used in this study with their seed colours, leaf shape and growth habit

No	Accessions names	Seed colour	Leaf shape	Growth habit
1	SB1-1	Brown/spotted purple	Lanceolate	Erect
2	SB7-1C	Dark red	Oval	Semi-erect
3	SB2-1B	Cream brown	Round	Semi-erect
4	SB4-1	Dark red	Oval	Semi-erect
5	SB4-2	Cream brown	Elliptic	Erect
6	SB4-4	Black	Oval	Spreading
7	SB4-4C	Cream	Oval	Erect
8	SB7-1	Dark red	Round	Spreading
9	SB7-1A	Light red	Oval	Semi-erect
10	SB7-2	Light Red	Lanceolate	Semi-erect
11	SB8-1	Brown	Round	Spreading
12	SB8-3A	Dark red	Round	Semi-erect
13	SB9-1A	Cream brown	Oval	Spreading
14	SB10-1	Dark red	Elliptic	Spreading
15	SB10-1A	Brown	Lanceolate	Spreading
16	SB10-1C	Black	Oval	Spreading
17	SB10-2	Dark red	Elliptic	Semi-erect
18	SB11-1A	Cream	Elliptic	Erect
19	SB11-5	Speckle brown	Elliptic	Erect
20	SB12-3B	Cream brown	Lanceolate	Erect
21	SB16-5A	Speckle brown	Elliptic	Erect
22	SB17-1	Dark red	Lanceolate	Spreading
23	SB17-1A	Light red	Oval	Semi-erect
24	SB19-1A	Brown	Lanceolate	Spreading
25	SB19-3	Black	Lanceolate	Spreading
26	SB19-3B	Black	Lanceolate	Semi-erect
27	BAMBARA-6	Cream	Elliptic	Semi-erect
28	BAMBARA-7	Speckle brown	Lanceolate	Erect
29	BAMBARA-9	Cream	Lanceolate	Semi-erect
30	BAMBARA12	Cream black	Lanceolate	spreading

2.2 Experimental Design

The seeds of the 30 bambara groundnut accessions were evaluated in an open field experiment that was laid out as a randomized complete block design with three replications. Recommended crop management practices (land preparation, land clearing, weeding and irrigation) were carried out during the cropping season. The distance between plants was 0.3 m, the row length was 0.5 m, plot distance was 1.5 m and the distance between replications was 2 m. Two seeds were hand sown per hole and the seedlings thinned to one at two weeks after planting when they were fully established. Five randomly selected plants were selected from each plot to estimate the genetic variability using the morphological traits among the accessions evaluated.

2.3 Parameters Measured and Data Analysis

Eighteen quantitative characters (Table 2) were measured among the thirty bambara groundnut accessions from 14 days after planting until harvest at weekly intervals.

Table 2. List of quantitative morphological characters recorded from 30 bambara groundnut accessions

Quantitative characters	Code	Description	Measurement type
Days to 50% flowering (count)	D50%F	Number of days from emergence to when 50% of the plants have started flowering in the plot	Observation
Leaf length (cm)	LL	Length of the middle leaf	Leaf area meter
Leaf width (cm)	LW	Width of the middle leaf	Leaf area meter
Leaf area (mm²)	LA	Area of the middle leaf	Leaf area meter
Initial plant stand (count)	IS	Number of plant after 50% emergence in the plot	Counting
Panicle length (cm)	PL	Length of panicle from its base to the tip	Tape measure
Plant Height (cm)	PH	Height of main stalk from the ground to the tip of the main panicle	Tape measure
Number of leaves per plant (count)	NLPP	Count of total number of leaves from the plant	Counting
Number of branches per plant (count)	NBPP	Count of total number of branches from the main stem	Counting
Days to 50% maturity (count)	D50%M	Number of days from emergence to when 50% of the plants have matured in the plot	Counting
Days to harvest (count)	DH	Total number of days from planting to harvest	Counting
Final plant stand (count)	FS	Number of plant after 50% maturity in the plot	Counting
Fresh weight (g)	Fwt	Average weight of five harvested fresh seed	Weighing balance
Dry weight (g)	Dwt	Average weight of five harvested dried seed	Weighing balance
Number of seed per plant (count)	NSPp	Total count of number of seed per five plant	Counting
Yield per plant (g)	YPP	Weight of seed per plant (average of five plants)	Weighing balance
Hundred seed weight (g)	Hswt	Weight of hundred seed counts at 12% moisture content	Weighing balance
Yield per plot (g)	YPPlot	Total weight of seed per plot	Weighing balance

The leaf area was measured using a leaf area meter (AM300 ADC BioScientific Limited, Hoddesdon, UK). The quantitative traits for all the accessions of the three replications were computed and subjected to analysis of variance (ANOVA), based on the lattice procedure using Agrobase statistical software (Agrobase, 2008). Means were compared by least significance difference (LSD) at $P \leq 0.01$. Cluster and Principal Component Analyses were conducted to determine similarities and dissimilarities among the genotypes based on the traits recorded using SPSS (IBM SPSS Statistics, 2015).

3. Results

3.1 Analysis of Variance

Analysis of variance (ANOVA) revealed significant differences among the phenotypic traits evaluated (Table 3). The mean number of days to 50% flowering (D50% F) ranged from 42 to 67 days, with a mean value of 59 days. The earliest flowering accession was SB11-1A and was followed by SB7-1 and SB7-1A. Bambara-12 and SB2-1B bloomed late.

The leaves of SB11-1A had the longest length and width (4.34 cm), while SB4-2 had the largest leaf surface area. SB7-1 had the shortest leaf, while SB10-1 had the narrowest leaf. The lowest leaf area was found in SB10-1. SB19-1A was the tallest plant with a height of 27.48 cm and longest petiole length. Furthermore, SB12-3B had the highest number of branches per plant and the highest number of leaves per plant. Accession SB11-1A was the shortest plant with the shortest petiole. The smallest number of leaves and branches per plant was recorded for SB7-1. There was a significant difference ($P \leq 0.05$) between plant height and petiole length in the accessions that were evaluated. The number of days to harvest ranged from 128 to 152 with an overall mean of 137. Early maturing varieties included SB7-1A and SB7-2, while Bamara-9 matured very late. There was a highly significant ($P \leq 0.01$) difference among all accessions for grain yield and other yield related traits.

The highest fresh and dry weight were observed in SB7-1. SB8-3A had the lowest fresh and dry weight. SB4-4C produced the highest number of seeds per plant, while SB16-5A produced the fewest number of seeds. The highest seed yield per plant was obtained from SB19-1A (37.81 g), while SB8-3A (2.97 g) had the lowest yield. The seed weight ranged between 20.45 g and 68.19 g with a mean of 43.03. The highest mean hundred seed weight was observed in SB16-5A while the lowest was found in SB11-1A. Bambara-12 had the highest yield per plot while SB11-1A had the lowest yield.

3.2 Correlational Matrix

The phenotypic correlation matrix among the 18 quantitative traits of 30 bambara groundnut is presented in Table 4. A high significant positive correlation was observed between number of branches and leaves per plant. The days to 50% flowering showed a positive correlation with plant height, days to harvest and yield per plot. Leaf length was negatively correlated with initial plant stand**,** days to 50% maturity, finial plant stand and hundred seed weight.

Conversely, a significant negative correlation was observed between initial plant stand and days to harvest, fresh weight, dry weight and number of seeds per plants. There was a strong positive correlation of plant height and petiole length (r = 0.85) and a moderate positive correction between petiole length and hundred seed weight. Yield per plot was moderately correlated with days to 50% flowering, petiole length, plant height, days to 50% maturity, days to, final plant stand, number of seed per plant and yield per plot. A very strong significant positive correlation coefficient was obtained between days to 50% maturity and days to harvest (r = 0.75). Days to 50% maturity correlated moderately with number of seeds per plant, yield per plant and yield per plot. A significant positive correlation was observed between days to harvest and fresh weight, dry weight, number of seed per plant and yield per plan). There was a strong significant and positive correlation (r = 0.95) between fresh and dry weight. Similarly, yield per plant had a very strong positive correlation with number of seeds per plant (r = 0.88), fresh (r = 0.71) and dry weight (r = 0.77). Finally, fresh weight was strongly and positively correlated with the number of seed per plants.

Table 3. Mean values of the 18 quantitative traits evaluated on 30 bambara groundnut accessions during the 2014/2015 cropping season

No	Accessions	D50%F	LL	LW	LA	IS	PL	PH	NLPP	NBPP	D50%M	DH	FS	Fwt	Dwt	NSPp	YPP	Hswr	YPPlot
1	SB19-1A	62.33	6.27	3.00	1394.70	16.67	18.00	27.48	407.40	135.80	117.33	136.67	11.33	152.50	54.11	51.70	37.81	52.32	222.87
2	SB8-1	60.00	5.64	2.79	1229.70	14.67	13.58	19.12	248.60	82.87	119.33	139.33	10.33	20.50	6.91	8.60	6.36	41.08	150.50
3	BAMBARA-9	64.00	6.31	2.53	1222.90	5.33	16.42	23.48	307.27	102.42	125.00	151.67	5.00	135.17	43.93	56.60	31.19	42.62	128.30
4	SB7-1C	57.33	5.58	2.44	1164.00	17.00	16.08	22.71	291.80	97.27	109.00	137.33	10.00	58.00	24.15	42.60	15.24	41.20	108.40
5	SB19-3B	63.33	6.05	2.59	1192.00	13.00	12.50	23.40	360.10	126.70	119.00	139.33	4.00	94.00	30.60	51.10	16.61	40.20	104.70
6	SB10-2	59.33	5.70	2.81	1188.30	15.00	15.85	21.61	254.73	87.13	110.67	137.00	12.33	24.50	8.85	13.20	3.23	36.08	185.10
7	BAMBARA-7	65.33	6.35	2.83	1313.30	7.00	16.68	25.80	366.80	122.27	114.00	138.67	7.67	122.00	32.75	34.75	20.90	49.52	131.30
8	SB4-1	59.00	6.05	2.57	1219.30	13.00	15.01	21.15	388.13	114.00	115.00	136.00	12.33	78.50	30.67	43.10	20.27	45.97	138.00
9	SB17-1A	52.33	5.86	2.97	1290.70	17.67	16.93	23.63	264.00	88.00	112.67	131.67	13.67	39.00	26.64	18.00	4.03	45.28	153.40
10	SB16-5A	57.33	5.93	2.23	1177.60	17.00	16.17	22.90	348.00	116.00	112.67	130.67	10.33	43.00	13.70	7.90	4.56	68.19	56.80
11	SB10-1	57.33	5.49	1.70	883.80	17.67	12.38	19.91	340.00	113.33	109.33	130.33	13.00	37.50	17.89	23.20	8.33	37.11	48.75
12	SB4-4C	57.00	5.94	2.20	1106.70	6.67	14.49	20.38	364.17	121.40	119.00	144.33	5.67	101.00	40.43	67.80	27.13	40.98	154.1
13	SB10-1A	59.33	5.91	1.93	1043.40	11.67	12.91	20.83	248.40	82.80	108.33	131.00	7.00	16.50	5.98	33.40	15.55	48.75	138.77
14	SB4-2	55.00	6.70	2.52	1553.10	14.67	14.77	22.13	340.80	113.60	113.67	137.67	13.67	35.50	13.65	26.50	13.46	39.85	65.82
15	SB8-3A	64.00	5.98	2.46	1136.70	15.67	13.67	19.05	251.60	73.87	117.00	134.00	7.67	12.67	5.39	13.20	2.97	43.57	66.98
16	SB11-5	62.33	5.98	2.52	1112.00	12.00	17.11	24.73	338.60	112.87	116.20	140.67	15.67	45.00	14.44	17.70	6.26	49.54	42.34
17	SB7-2	59.00	6.01	2.47	1196.20	17.67	16.59	22.88	325.93	108.60	114.00	129.67	15.00	24.50	5.76	14.60	3.39	37.58	60.06
18	SB2-1B	67.33	6.08	2.52	1240.70	10.00	13.75	21.25	332.90	110.97	114.90	134.00	4.67	53.72	18.40	18.00	6.77	37.45	38.67
19	BAMBARA-6	64.67	5.85	3.09	1345.00	10.67	16.33	13.53	264.80	88.27	120.33	138.67	14.00	48.00	26.86	37.00	17.58	37.64	242.47
20	SB9-1A	58.67	5.53	2.49	1069.30	18.67	15.64	21.83	354.33	118.11	119.00	133.67	15.00	41.17	11.89	18.67	7.88	38.53	83.17
21	SB11-1A	41.67	10.82	4.34	1016.70	1.67	8.83	12.67	360.27	103.15	103.33	132.00	1.33	100.33	31.51	47.00	10.55	20.45	17.48
22	SB19-3	64.33	6.33	2.68	1287.80	3.00	13.80	21.16	352.53	117.50	120.33	145.33	9.33	91.00	35.53	57.25	23.59	45.21	143.77
23	SB12-3B	61.67	5.86	2.75	1254.00	13.67	16.41	24.53	482.40	160.80	114.33	140.00	11.67	51.45	22.11	29.60	15.06	54.48	253.10
24	SB10-1C	64.00	5.76	2.73	1173.00	12.3	12.21	19.28	351.60	117.20	111.67	134.33	13.67	55.50	15.89	18.40	12.17	33.72	121.00
25	SB1-1	62.33	6.24	2.47	1199.70	6.67	14.15	21.64	305.20	101.72	111.00	136.00	6.00	38.00	18.87	16.00	7.61	36.65	38.01
26	BAMBARA-12	66.00	5.75	2.42	1140.30	17.00	16.01	22.32	341.00	113.67	119.33	147.33	17.67	121.00	43.70	50.00	29.30	42.61	333.00
27	SB7-1	51.67	5.25	2.57	1029.00	1.67	14.17	21.33	180.73	60.24	114.00	136.67	1.33	188.77	55.04	30.00	11.78	51.14	40.07
28	SB17-1	64.67	6.07	2.52	1241.40	10.33	14.55	23.14	331.77	110.60	120.33	143.67	8.00	96.50	32.68	61.40	26.64	46.10	124.53
29	SB4-4	53.00	5.83	2.34	1137.70	5.00	10.82	19.82	304.30	131.43	120.00	143.33	4.67	46.88	16.96	27.63	13.66	47.21	54.15
30	SB7-1A	51.67	5.96	2.18	1130.30	17.67	15.71	22.77	304.60	113.53	108.00	128.00	11.67	27.50	9.49	9.90	5.97	41.47	62.03
	Grand Mean	59.53	6.10	2.59	1189.65	12.02	14.72	21.88	324.96	107.20	114.97	137.30	9.79	66.66	23.82	31.56	14.20	43.03	116.92
	Mean squares	92.59	2.65	0.59	47294.58	81.70**	12.48*	20.55*	10122.94	1138.29	69.41	94.51	56.95**	5870.16**	597.03**	926.07**	262.41**	201.74**	16678.30**
	CV(%)	15.47	25.26	23.00	26.30	11.62	17.51	15.26	29.17	30.96	8.24	6.04	20.15	8.38	18.01	16.52	21.73	15.55	5.00
	LSD	15.05	2.52	0.97	511.29	2.28	4.21	5.46	154.92	54.24	15.49	13.55	3.22	9.13	7.01	8.52	5.04	10.94	9.55

Note. CV = coefficient of variation, LSD = least significant difference. $P \leq 0.05$ = significant (*), $P \leq 0.01$ = significant (**).

Table 4. Pearson correlation coefficients (r) among 18quantitative traits of 30 bambara groundnut accessions.

	D50F	LL	LW	LA	IS	PL	PH	NLPP	NBPP	D50M	DH	FS	Fwt	Dwt	NSPp	YPP	Hswr	YPPlot
D50F	1.00																	
LL	-0.49**	1.00																
LW	-0.30	0.75**	1.00															
LA	0.33	0.03	0.24	1.00														
IS	0.13	-0.41*	-0.34	0.07	1.00													
PL	0.38*	0.47**	0.16	0.45*	0.45*	1.00												
PH	0.51**	0.54**	0.28	0.50**	0.33	0.85**	1.00											
NLPP	0.18	0.23	0.12	0.21	0.10	0.11	0.22	1.00										
NBPP	0.24	0.08	0-.01	0.25	0.17	0.20	0.37*	0.96**	1.00									
D50M	0.57**	-0.38*	-0.14	0.33	-0.13	0.26	0.36	0.06	0.10	1.00								
DH	0.41*	-0.10	0.02	0.25	-0.44*	0.11	0.19	0.14	0.15	0.75**	1.00							
FS	0.24	-0.37	-0.19	0.22	0.74**	0.55**	0.37*	0.20	0.24	0.04	-0.13	1.00						
Fwt	0.03	0.15	0.26	0.04	-0.51**	0.08	0.19	0.14	0.11	0.30	0.49**	-0.39*	1.00					
Dwt	0.04	0.12	0.27	0.12	-0.45*	0.14	0.23	0.17	0.14	0.33	0.53**	-0.30	0.95**	1.00				
NSPp	0.13	0.24	0.17	0.11	-0.43*	-0.05	0.07	0.31	0.26	0.39*	0.65**	-0.29	0.68**	0.76**	1.00			
YPP	0.33	0.04	0.06	0.29	-0.28	0.18	0.33	0.37*	0.37*	0.50**	0.68**	-0.10	0.71**	0.77**	0.88**	1.00		
Hswr	0.21	-0.48**	-0.41*	0.17	0.14	0.49**	0.60**	0.11	0.17	0.26	0.10	0.08	0.15	0.13	0.05	0.16	1.00	
YPPlot	0.42*	-0.25	0.10	0.33	0.22	0.43*	0.38*	0.22	0.25	0.36*	0.44*	0.42*	0.21	0.35	0.39*	0.56**	0.17	1.00

Note. **: Correlatioin is significant at the 0.01 level (2-tailed); *: Correlatioin is significant at the 0.05 level (2-tailed).

3.3 UPGMA Cluster Analysis

The cluster analysis of the 30 bambara groundnut accessions are presented Figure 3. With the exception of SB11-1A, the dendrogram clustered the accessions into four clusters. Cluster I consisted of six accessions including SB7-1, SB4-4, SB16-5A, SB10-1A, SB10-1 and SB4-2. The second cluster comprised of twelve accessions, namely SB7-1A, SB9-1A, SB7-2, SB11-5, SB17-1A, SB7-1C, SB10-1C, SB1-1, SB2-1B, SB10-1C, SB8-3A, andSB8-1. The third cluster included nine accessions including Bambara-12, Bambara-6, Bambara-7, Bambara-9, SB19-3, SB4-4C, SB4-1, SB19-3B and SB17-1. The last cluster contained two accessions, namely, SB12-3B and SB19-1A.

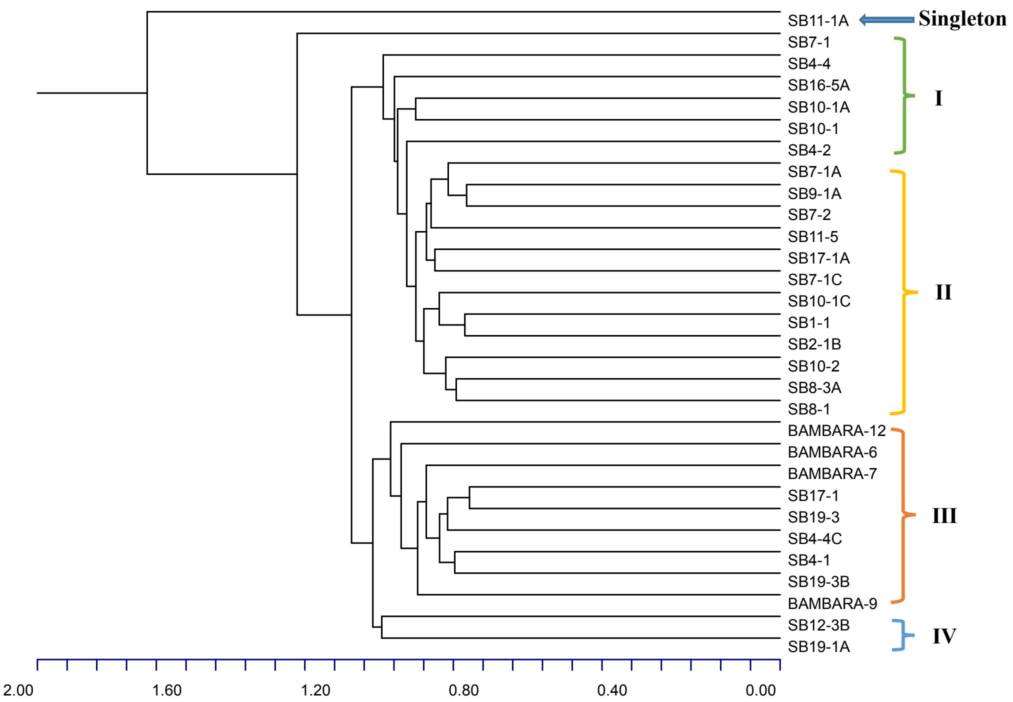

Figure 3. A pair-wise genetic distance matrix of 30 bambara groundnut accessions generated by UPGMA using the data set

4. Discussion

4.1 Morphological Variability

Characterization of bambara groundnut germplasm can provide useful information for a breeding program aiming to genetically improve the crop. The results of this study showed that there was wide genetic variability among the bambara groundnut evaluated for 18 morphological quantitative characters recorded. Days to 50% flowering was quite variable among the bambara groundnut accessions ranging from 42 to 67 days. Similarly, a study by Massawe et al. (2005) showed that days to flowering in bambara groundnut ranged from 64 to 76 days in the Free State Province in South Africa, while Masindeni (2006) recorded 43-80 days in Loughborough, United Kingdom.

The mean days to flowering (60 days) obtained in this study were higher than the values reported in previous studies. Ouedraogo et al. (2008) observed that flowering ranged from 32 to 53 days among bambara groundnut germplasm accessions from Burkina Faso. Similarly, Shegro et al. (2013) reported that flowering occurred between 36-53 days among 20 bambara groundnut accessions assessed under similar conditions to this study in Pretoria, South Africa. A number of environmental factors such as temperature, altitude and soil conditions as well as genotypic factors can affect flowering in bambara groundnut (Shegro et al., 2013). Similar factors may be responsible for the variation in days to flowering in this study. Swanevelder (1997) also reported variation in days to flowering among bambara groundnut accessions in South Africa. Bambara groundnut is a short day plant and when planted during long days there is either delayed or no flowering, a trait which is also cultivar dependent. Generally, first flowering in bambara groundnut occurs about 30 to 45 days after planting (DAP) and might continue until it reaches maturity. It has been reported that 50% flowering may take from 60 up to 80 DAP depending on the cultivar. Early flowering implies early maturity (Shegro et al., 2010) and it is an important trait in bambara groundnut cultivation in South Africa. In this study, the early flowering accessions SB11-1A, SB7-1C and SB7-1A could be selected for early maturity.

Days to physiological maturity was significantly different ($P \leq 0.05$) between genotypes and days to harvest ranged from 128 to 152. A similar maturity range was observed in other studies (Goli et al., 1997; Masindeni, 2006). According to Swanevelder (1998), maturity of the bambara groundnut is dependent on cultivar and climatic conditions, and ranges from three to six months. However, it is also influenced by photoperiod. Linnemann et al. (1995) reported that under long photoperiods maturity is delayed. It was observed that the earlier a genotype flowers, the earlier is the physiological maturity (Shegro et al., 2010). A similar finding was observed in this study. Assessing days to maturity of crops facilitates escape from drought-stressed environmental conditions and may enable selection for adaptation to drought-prone areas of South Africa (Shegro et al., 2010).

No significant difference was observed in the morphological traits such as terminal leaf length and width, leaf area, number of leaves and branches per plant. The mean values obtained for these traits in this study are congruent with those reported by Mohammed (2014) for the same characters. However, there was a significant difference ($P \leq 0.05$) between petiole length and plant height among the accessions. This is similar to the results reported by Ntundu et al. (2006) in Tanzania and Shegro et al. (2013) in South Africa.

A highly significance difference ($P \leq 0.01$) was obtained between grain-yield and yield related traits such as shoot fresh and dry weight, number of seeds per plant, yield per plant and hundred seed weight indicating high genetic variation among these traits. This is in disagreement with those reported by Ntundu et al. (2006), who reported that there was no significant difference among bambara groundnut accessions for the number of stems per plant, seed number per pod, hundred seed weight and yield per plot over two seasons in Tanzania. However, variation in yield related traits was also reported by Shegro et al. (2013) who suggested that there may be genotype by environmental influence on yield in bambara groundnut.

The yield per plant ranged from 2.97 g to 37.81 g. The mean yield value obtained from this study was significantly higher than those reported by Massawe et al. (2005) and Ouedraogo et al. (2008). Slightly higher yields ranging from 4.0 g to 57.52 g was reported by Shegro et al. (2013) and Mohammed (2014).

Hundred seed weight has been reported as a tool for the assessment of morphological traits (Massawe et al., 2005; Masindeni, 2006; Ntundu et al., 2006; Ouedraogo et al., 2008; Mohammed, 2014; Shegro et al., 2015). The hundred seed weight in this study ranged from 20.45 g to 68.19 g. The phenotypic coefficients of variation for the traits such as number of seeds per plant, plant height, petiole length and hundred seed weight in this study were almost similar, suggesting that the variations for these traits might be due to genetic rather than environmental factors (Kulkarni et al., 2002). In order to assess the real extent of genetic diversity of bambara groundnut accessions, agronomic, physiological, biochemical and molecular evaluation and characterization should be done since morphological genetic markers may be influenced by environmental conditions (Kumar, 1999). Nevertheless, agronomic evaluation and characterization is the first step in assessing the genetic diversity of a crop for breeding programs. The wide genetic variation observed in this study may be useful for breeders planning to enhance the germplasm of bambara groundnut.

4.2 Correlation among the Traits

Days to 50% flowering showed a non-significant positive correlation with all the traits evaluated except for leaf length and leaf width where a negative correlation was observed. It appears that plant height, petiole length and the number of days to 50% maturity were most significant in affecting the days to 50% flowering. The positive correlation between plant height and days to 50% flowering observed in this study was also observed in previous studies (Zongo et al., 1993; Ayana, 2001; Kebede et al., 2001) suggesting that these traits are heritable and can be transferred into desired genotypes. Plant height was positively associated with fresh weight, dry weight, number of seeds per plants, yield per plant, hundred seed weight, yield per plot and the final plant stand was also positively and significantly associated with plant height. This suggests that selection based on these characters may be effective for improving seed yield. As expected, leaf area was positively correlated with leaf length and width. Ayana and Bekele (2000) also reported a functional relationship for these traits in sorghum.

Correlation coefficient is an important parameter in plant breeding since it measures the degree of association, genetic or non-genetic between two or more characters (Jonah et al., 2014). Correlation studies between traits have been of great value for selection of superior genotypes (Adebisi et al., 2004). The highly significant correlation between the number of leaves and branches per plant coupled with the high correlation between fresh and dry weight may suggest that selection based on these traits may be useful for breeding bambara groundnut for fodder production. The highly significant correlation among fresh weight, dry weight and the number of seeds per plant and the moderate positive association among the number of leaves and branches per plant, days to 50% maturity and days to harvest are congruent with the results obtained by Karikari (2000) and Jonah et al. (2014). These characters may be useful to plant breeders for selecting parents that could improve yield in bambara groundnut. However, the hundred seed weight was negatively correlated with the number of seeds per plant. This was due to the variation in seed size among the different accessions.

Panicle length had a very strong positive significant correlation with plant height and a moderate positive correlation with days to 50% flowering, leaf length and width, leaf area and initial plant stand. The positive correlations among and between the various traits recorded in this study clearly indicate that selecting for any of these traits will have a positive effect on selecting for associated traits in a Bambara groundnut improvement program.

4.3 UPGMA Cluster Analysis

The results showed that there was a high level of genetic diversity among the bambara groundnut accessions. The separation of accession SB11-1A as the most divergent is perhaps due to its late flowering, leaf length and width, shortest petiole length and plant height and lowest hundred seed weight and yield per plot. Some of the accessions formed relationships on the basis of shared morphological traits. The separation of accession SB7-1 in cluster 1 is perhaps due to the fact that it had the lowest leaf length, lowest number of branches and leaves per plant. A sister relationship was observed between accessions SB10-1A and SB10-1 and both genotypes were closely associated in the second quadrant in the principle component biplot (data not shown). This sister relationship indicates that these accessions may have a common ancestry. The grouping of the accessions in cluster II may be due to the presence of similar morphological traits in these genotypes. This cluster consisted of accessions with intermediate days to 50% flowering and number of leaves and branches per plant, smallest leaf area, lowest fresh and dry weight, lowest number of seeds and yield per plant. The close grouping of accessions SB8-1 and SB8-3A, SB1-1 and SB2-1B, SB17-1A and SB7-1, and SB9-1A and SB7-2 in this cluster may be due to the similarities in their morphological traits including similar values for plant height and panicle length, lowest fresh and dry weight and lowest yield per plant. The rest of the accessions in this cluster appeared independently.

The clustering of nine accessions in the third cluster appears to be due to shared morphological traits such as days to 50% flowering, smallest leaf length and average leaf width, average panicle length and plant height, late maturing, highest number of seed per plant and medium yield per plant. The uniqueness of Bambara-12 within the cluster may be due to its largest final plant stand and grain yield per plot.

The accessions SB12-3B and SB19-1A were the only accessions contained in cluster IV. This cluster consisted of accession with the longest and widest leaves, largest leaf area, tallest plant, highest number of leaves and branches per plant, medium number of seeds, highest yield and hundred seed weight. Characterization and clustering of accessions on the basis of their morphological traits and genetic similarity can help in the identification and selection of the best parents for hybridisation (Souza & Sorrells, 1991). Therefore, the grouping of accessions by univariate and multivariate methods of analysis based on their similarity in the present study presents important information that will be valuable for bambara groundnut breeders.

5. Conclusions

Characterization and evaluation of bambara groundnut germplasm and identification of the best parents is important for improvement of the crop. The genotypes in this study showed significant variation in phenotypic characters, indicating that the accessions had high genetic diversity which can be exploited for use in a breeding program. The accessions SB19-1A, Bambara-9 and Bambara-12 were associated with desirable grain yield characteristics and may be suitable parental lines for improvement of grain production. Similarly, accessions SB19-1A, SB12-3B and SB7-1 were identified as possessing favorable vegetative traits and these accessions could be used as parents when breeding bambara groundnut for use as fodder production. The genetic potential of the accessions as revealed in this study can assist in choosing suitable parental lines thereby maximizing the efficiency of a bambara groundnut breeding program.

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