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Phenotypic Diversity and Characterization of the Southern African Bambara Groundnut Germplasm Collection for Grain Yield and Yield Components

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Abstract: Bambara groundnut is a highly nutritious underutilized legume crop, which can be cultivated in unfavorable environments, has the potential to address food security and can significantly contribute to climate-smart agriculture. The objectives of this study were to determine the phenotypic diversity and characterize a southern African bambara groundnut germplasm collection for grain yield and yield components, to identify superior bambara accessions and to determine the correlation between measured traits. The 100 bambara accessions were planted in two different locations over two seasons. There was significant variability among the accessions, locations, seasons and their interactions for all traits. Low broad-sense heritability values (<0.5) were observed for almost all traits. Significant positive correlations between all measured traits were observed. High-yielding accessions; WS 42 (AS), MV 67-1, K 5, AS 9, SCORE 1 and SB 12-3 were identified. Bambara accessions 224 (RF-7684), 179 (AB 16-5C), 121 (Red Ex Zimbabwe), 62 (SB 8-3), 9 (SB 4-1), 181 (SB 8-1B), 89 (AS 20), 217 (RF-6221), 94 (K 5), 177 (S1 Sel2) and 74 (AS 5) were associated with a high grain yield, plant spread and plant height. These accessions could be used as potential parents in a breeding program for the development of high-yielding varieties.

Keywords: bambara groundnut; germplasm collection; phenotypic diversity; characterization; breeding; grain yield

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1. Introduction

Bambara groundnut (*Vigna subterranea* (L.) Verdc) is a hardy leguminous crop which originated in West Africa and is mainly cultivated in sub-Saharan Africa by subsistence farmers [1–3]. The crop is nutrient dense. Its grains contain 64.4% carbohydrate, 23.6% protein, 6.5% fat, 5.5% fiber, vitamins and essential minerals such as iron and zinc [4,5]. Even though bambara groundnut is not an oil crop, its fatty acid composition is mainly comprised of healthy fatty acids such as omega-6 (*n*-6) and polyunsaturated fatty acids [6]. Due to its nutrient density, the bambara groundnut crop is mainly grown for human consumption and livestock feeding. The crop has been grown for several millennia in sub-Saharan Africa, particularly in the harsh semi-arid Savannah environments where other grain legume crops perform dismally or fail completely [7]. Bambara groundnut is also important for soil health enhancement because of its ability to fix nitrogen in the soil, hence, the crop can significantly contribute to climate-smart agriculture [7,8].

Despite its importance, bambara groundnut is among the so-called orphan crops that have been neglected by the research community and are underutilized by both the con-sumers and the food processing industry [4,9–11]. Generally, bambara groundnut yields have remained low (<0.85 t ha^{-1}) due to several factors such as the general lack of improved varieties, crop production practices and good quality seed [5,12] when compared to cereal crops such as maize and wheat. These factors are the main drawback towards the full exploitation of bambara groundnut potential as a highly nutritious and, possibly, a commercially viable crop. In sub-Saharan Africa, farmers have maintained this crop under their own care and stewardship for many generations and there is a long list of accessions characterized by different plant and seed types. The Agricultural Research Council of South Africa has a collection of bambara groundnut accessions that possibly has the necessary genetic variation for viable crop improvement. These accessions were collected from different sources in the region and beyond and have not been fully characterized yet, particularly for grain yield and morphological traits, as well as the nutritional quality traits. The adaptability and stability of bambara groundnut accessions and landraces in South Africa are not known.

Previous studies focused on the assessment of the phenotypic diversity [12] and nutritional diversity [13] of 20 and 19 bambara groundnut landraces grown in South Africa, respectively, and reported significant variation. However, both studies [12,13] investigated a small proportion of the germplasm collection, further suggesting a need to extensively investigate the magnitude and nature of genetic diversity available in southern African bambara groundnut germplasm, particularly for grain yield and yield components.

A study conducted in Nigeria on the genetic analysis and selection of 15 bambara groundnut landraces for high yield revealed significant variation for the morphological and yield traits [14]. A study [15] on the assessment of the genetic diversity and structure of 78 bambara groundnut landraces in South Africa reported higher genetic diversity within landraces than between landraces, however, there was no reference to nutritional quality traits or yield and agronomic traits. A similar study was conducted in Nigeria on the assessment of the genetic diversity and structure of 270 bambara groundnut landraces which reported the presence of genetic diversity within and between landraces, as well as a significant variation between selected morphological traits [16]. It is noteworthy that these studies [15,16] investigated the genetic diversity of bambara groundnut landraces with different genetic backgrounds (no overlapping of accessions), highlighting that the amount of genetic variation present in germplasm collections and/or breeding populations depends on the genetic background of the material and the environmental conditions. This could also imply that inferences on the phenotypic diversity of bambara groundnut accessions and landraces cannot be generalized as their phenotype can mainly be determined by the genetic background and environmental factors.

Therefore, the assessment of the phenotypic diversity and characterization of bambara groundnut for grain yield and yield components is of the utmost importance in order to determine the variation present in the available material which will ultimately enable the identification and selection of superior genotypes. Superior genotypes for grain yield and yield components will then help breeders to make informed decisions in the selection of parents and the genetic improvement of adapted varieties, or for the development of new genotypes [17–19]. Furthermore, understanding the interrelationship between the traits associated with superior genotypes is expected to guide and improve the selection efficiency. Hence, the objectives of this study were to determine the phenotypic diversity and characterize a southern African bambara groundnut germplasm collection for grain yield and yield components, to identify superior bambara accessions and to determine the correlation between measured traits.

2. Materials and Methods

2.1. Study Materials and Experimental Sites

The 100 bambara groundnut accessions included in this study originated from South Africa, Botswana, Madagascar, Malawi, Namibia, the Kingdom of eSwatini (formerly known as Swaziland) and Zimbabwe and were part of the ARC (South Africa) germplasm collection. The trials were conducted over two seasons in 2016–2017 and 2017–2018 at

Vaalharts Research Station (VHT) (latitude 27.9576 S, longitude 24.8399 E and altitude 1180 m) in the Jan Kempdorp district, Northern Cape Province. The soil type in the VHT area is an alluvial Kalahari sand comprising about 75% sand, 15% clay and 10% silt [20]. Despite the high sand content in the soils of VHT, waterlogging is a hazard due to inadequate inherent drainage [20]. Table 1 shows the soil parameters at VHT during the 2016–2017 and 2017–2018 seasons. In the VHT, the pH values ranged from 6.4 to 6.9 and the location received an average annual rainfall of 410.21 mm.

Table 1. Soil characteristics at the Vaalharts site during the 2016–2017 and 2017–2018 cropping seasons.

Soil Depth (cm)	pH (KCl)	S (mg kg^{-1})	Cu (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	CEC cmol (+) kg^{-1}
Vaalharts in 2016–2017 cropping season							
15	6.5	25.27	0.30	5.41	15.65	2.99	3.40
30	6.4	26.24	0.32	5.88	17.65	3.07	3.92
Vaalharts in 2017–2018 cropping season							
15	6.9	17.95	0.39	6.45	13.85	2.79	4.15
30	6.5	30.31	0.35	5.46	8.21	3.27	4.13
Roodeplaat in 2016–2017 cropping season							
15	5.75	139.20	6.72	38.00	98.40	8.97	14.11
30	6.09	138.10	6.48	53.00	93.50	6.16	10.01
45	5.45	138.40	7.17	22.50	66.00	6.40	10.94

CEC = Cation exchange capacity.

One trial at Roodeplaat Research Farm (RPT) was planted during the 2016–2017 season. The RPT research farm is in the Gauteng province, South Africa at latitude 25.9833 S, longitude 28.3500 E and an elevation of 1164 m above sea level [21]. At RPT, the soil type is loamy clay [21]. The soil characteristics at RPT during the 2016–2017 season are presented in Table 1. In the RPT, the pH values ranged from 5.45 to 6.09 and the location received an average annual rainfall of 772.42 mm. Both VHT and RPT receive rainfall in summer, from October to March [21–23].

2.2. Experimental Design, Trial Establishment and Management

Trials were laid out in a randomized complete block design with three replications. All trials were established in the summer cropping season. Land was ploughed by a tractor at both locations and in both seasons. Planting furrows were made on the flat seed bed with a tractor planter at 90 cm inter-row spacing. Seeds were planted by hand at 10 cm intra-row spacing. The row length was 2 m and there were two rows per plot. No external inputs such as fertilizer, insecticides or herbicides were applied to simulate the low input agricultural production system practiced by smallholder farmers in South Africa. This is the normal practice for small-holder farmers who grow bambara groundnut. The trials were hand-weeded at both locations. Supplementary irrigation was applied as required. A fixed overhead sprinkler system was used at VHT, while a moveable sprinkler system was utilized at RPT Research Farm. Whole plots were harvested manually.

2.3. Data Collection

Based on the descriptors for bambara groundnut [24], data were collected on plant height (cm), plant spread (cm), number of nodes per stem, number branches per stem, number of stems per plant and number of leaves per plant. Grain yield (t ha^{-1}) was recorded after manually threshing the dried pods.

2.4. Data Analysis

Data were subjected to analysis of variance using AGROBASE Generation II SQL-Version 38, 2019 statistical software [25] to determine the significant differences between bambara groundnut accessions over locations and seasons. Single site and combined analyses for sites and growing seasons were carried out. The least significant difference (LSD) test at $p \leq 0.05$ was used to separate means. Accessions were considered fixed because their genetic background is unique in the available germplasm collection. The locations were considered random because they represent a random sample of all possible locations representing bambara groundnut growing conditions in South Africa. The seasons were considered random because they represent a random sample of the year-to-year weather variability. To understand genotypic variability among different traits measured, the genetic variance components were also estimated and used to calculate the broad-sense heritability (H^2), which was estimated as the ratio of the genotypic (σ^2_G) to phenotypic (σ^2p) variance [26].

A dendrogram was drawn using R software [27] on the average of measured characteristics for three trials. Heat maps were drawn with R software using the ggplot2 function [27]. Pearson's simple correlation coefficient was performed for estimation of the association between pairs of characteristics using AGRO-BASE Generation II SQL-Version 38 (Agronomix Software Inc., Winnipeg, MB, Canada).

3. Results

3.1. Analysis of Variance, Variance Components and Broad-Sense Heritability (H^2) for Grain Yield and Yield Components

For the VHT location in the 2016–2017 and 2017–2018 cropping seasons (Table 2), the accession (A) effect was highly significant ($p \leq 0.001$) for plant height (PH), significant ($p \leq 0.01$) for PS and significant ($p \leq 0.05$) for grain yield (GY), number of branches per stem (NBS) and number of nodes per stem (NNS). The season (S) effect was highly significant ($p \leq 0.001$) for almost all characteristics and significant ($p \leq 0.05$) for GY. The AS interaction effect was significant ($p \leq 0.01$) for NBS and significant ($p \leq 0.05$) for grain yield. Broad-sense heritability (H^2) values for GY, NBS, number of leaves per plant (NL), NNS, number of stems per plant (NSP), PH and plant spread (PS) were 0.20, 0.00, 0.35, 0.56, 0.41, 0.78 and 0.64, respectively.

Table 2. Mean squares, variance components (σ^2) and broad-sense heritability (H^2) for grain yield and yield components for Vaalharts (VHT) and Roodeplaat (RPT) for 2016–2017 and 2017–2018.

Source	GY	NBS	NL	NNS	NSP	PH	PS
VHT in 2016–2017 and 2017–2018 cropping seasons							
Rep(S)	1.81 *	51.29 ***	101,675.40 ***	329.49 ***	230.24 ***	22.52	1321.87 ***
Accession (A)	1.43 *	6.62 *	7935.00	4.90 *	8.372	40.19 ***	167.43 **
Season (S)	19.54 *	3545.95 ***	8,633,079.79 ***	99.33 ***	6360.34 ***	690.16 ***	35,734.80 ***
AS	1.36 *	7.25 **	6962.00	3.71	7.06	20.78	115.87
Error	0.65	4.82	7323.12	3.65	8.71	24.48	113.88
σ^2_A	0.05	0.00	648.67	0.79	0.87	12.94	34.37
σ^2_{AS}	0.24	0.81	0.00	0.02	0.00	0.00	0.66
σ^2_P	0.23	0.65	1829.06	1.41	2.14	16.61	53.57
H^2	0.20	0.00	0.35	0.56	0.41	0.78	0.64
VHT and RPT during the 2016–2017 cropping season							
Rep(L)	0.46	49.31 ***	113816.52 ***	319.38 ***	227.16 ***	30.40 *	1585.48 ***
A	1.05 ***	7.16 *	9525.01	4.94	7.38	17.10 *	227.02
Location (L)	73.31 ***	4491.14 ***	2,618,804.71 ***	113.60 ***	9290.14 ***	87.48 **	22.43
AL	1.16 ***	7.45 *	8119.02	4.03	8.59	15.87	203.81
Error	0.49	5.47	8598.43	3.99	8.93	12.68	183.58
σ^2_A	0.00	0.00	937.33	0.61	0.00	0.82	15.47
σ^2_{AL}	0.22	0.66	0.00	0.01	0.00	1.06	6.74
σ^2_P	0.08	0.94	2317.13	1.28	0.64	3.29	48.32
H^2	0.00	0.00	0.40	0.48	0.00	0.25	0.32

Table 2. *Cont.*

Source	GY	NBS	NL	NNS	NSP	PH	PS
Across trials (locations and seasons)							
Rep(L)	1.33 *	38.68 ***	75,878.44 ***	220.62 ***	153.58 ***	20.85	1735.22 ***
A	1.06 ***	5.23 *	6990.64	4.40 **	5.70	31.81 ***	191.47
L	36.67 ***	2697.62 ***	4,331,373.75 ***	71.14 ***	5309.05 ***	354.64 ***	23,241.24 ***
AL	1.03 ***	5.33 **	5606.48	3.17	5.67	20.10	182.08
Error	0.48	4.03	5867.91	3.10	6.31	19.31	162.92
σ^2_A	0.03	0.00	1384.16	1.23	0.03	11.71	9.39
σ^2_{AL}	0.18	0.43	0.00	0.02	0.00	0.26	6.39
σ^2_P	0.14	0.49	2007.10	1.58	0.66	13.94	29.62
H^2	0.21	0.00	0.69	0.78	0.05	0.84	0.32

*** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$, σ^2_P, phenotypic variance; PH, plant height; PS, plant spread; NNS, number of nodes per stem; NL, number of leaves per plant; NSP, number of stems per plant; NBS, number of branches per stem; GY, grain yield.

For VHT and RPT locations during the 2016–2017 cropping season (Table 2), the A effect was highly significant ($p \leq 0.001$) for grain yield, significant ($p \leq 0.01$) for NBS and non-significant ($p > 0.05$) for other characteristics. The location (L) effect was highly significant ($p \leq 0.001$) for all the characteristics except for PS. The accession x location interaction effect was highly significant ($p \leq 0.001$) for grain yield and significant ($p \leq 0.05$) for NBS. H^2 values for GY, NBS, NL, NNS, NSP, PH and PS were 00.00, 0.00, 0.40, 0.48, 0.00, 0.25 and 0.32, respectively.

Across trials (locations and seasons), the A effect was highly significant ($p \leq 0.001$) for grain yield and significant ($p \leq 0.01$) for NBS (Table 2). The L effect was highly significant ($p \leq 0.01$) for all the characteristics. The AL effect was highly significant ($p \leq 0.001$) for grain yield and significant ($p \leq 0.01$) for NBS. H^2 values for GY, NBS, NL, NNS, NSP, PH and PS were 0.21, 0.00, 0.69, 0.78, 0.05, 0.84 and 0.32, respectively.

3.2. Accession Performance for Grain Yield and Yield Components

At VHT during the 2016–2017 and 2017–2018 cropping seasons, there was a wide variation for grain yield, NBS, NL, NNS, NSP, PH and PS ranging from 0.16 to 2.76 t ha^{-1}, 3.90 to 9.60, 69.90 to 268.10, 3.90 to 8.40, 6.90 to 14.40, 21.10 to 40.20 cm and 39.90 to 66.10 cm, respectively (Table 3). High-performing accessions for grain yield (SB 12-3), NBS (MV 67-1), NL (RF-6171), NNS (ZIM 003), NSP (AS 17), PH (K 7) and PS (K 7) were identified. These accessions could be further evaluated for nutritional quality traits and pest and disease resistance.

Table 3. Means of combined analysis of grain yield and yield components of bambara groundnut accessions at Vaalharts in 2016–2017 and 2017–2018 cropping season.

Origin	Acc. No.	Accession	GY (t ha^{-1})	NBS	NL	NNS	NSP	PH (cm)	PS (cm)
South Africa	9	SB 4-1	0.53	6.3	177.2	4.0	7.5	23.2	45.1
South Africa	19	SB 2-1	1.64	6.5	145.8	6.0	10.1	26.1	49.7
South Africa	21	SB 16-5A	0.54	5.4	230.7	6.7	7.8	26.6	58.2
South Africa	25	SB 19-3A	0.91	6.5	255.0	6.4	9.7	27.9	63.6
South Africa	49	SB 20-2A	0.81	7.1	229.8	7.6	8.4	26.7	54.3
South Africa	52	SB 4-4A	1.50	6.6	222.0	5.9	8.1	29.0	64.7
South Africa	53	SB 10-2A	1.08	7.8	218.7	5.6	8.1	29.8	58.1
South Africa	55	SB 12-3	1.64	7.1	230.0	4.4	10.0	26.6	65.7
South Africa	61	SB 19-3	0.99	6.8	233.4	5.6	7.9	26.5	56.3
South Africa	62	SB 8-3	0.58	5.2	136.1	4.3	7.7	26.8	56.9
South Africa	66	SB 1-1	1.13	5.2	253.1	7.5	7.1	27.9	58.8
Botswana	74	AS 5	0.93	5.7	136.7	4.9	6.6	27.1	54.0
Botswana	77	AS 8	0.16	6.1	209.6	5.9	9.8	22.7	58.5
Botswana	78	AS 9	2.20	6.8	248.7	5.8	7.9	25.4	49.2

Table 3. *Cont.*

Origin	Acc. No.	Accession	GY (t ha^{-1})	NBS	NL	NNS	NSP	PH (cm)	PS (cm)
Botswana	79	AS 10	1.05	6.2	257.2	5.5	8.2	26.5	57.3
Botswana	80	AS 11	0.98	6.8	188.8	6.4	10.8	26.6	61.0
Botswana	81	AS 12	0.84	4.1	247.3	5.6	7.4	25.8	50.5
Botswana	82	AS 13	0.15	5.3	249.7	7.3	9.4	25.5	54.6
Botswana	84	AS 15	0.90	5.9	230.8	6.1	7.6	26.9	58.7
Botswana	86	AS 17	1.24	5.5	253.3	6.5	13.3	27.4	65.2
Botswana	87	AS 18	0.56	7.2	191.5	6.5	10.8	27.1	58.2
Botswana	89	AS 20	0.31	5.3	214.3	4.9	9.0	26.3	52.6
Namibia	90	K 1	1.50	6.2	232.1	5.6	8.6	23.0	53.5
Namibia	92	K 3	1.24	4.9	269.9	6.3	6.3	26.0	51.1
Namibia	94	K 5	1.56	5.6	189.1	4.9	7.6	25.9	55.4
Namibia	95	K 6	1.56	6.4	289.5	6.8	8.5	27.2	65.5
Namibia	96	K 7	1.20	5.3	259.3	6.2	7.8	32.9	63.0
Malawi	97	M 1	1.38	5.8	174.3	5.8	8.2	30.2	63.8
Malawi	99	M 3	0.93	6.3	163.5	6.4	7.6	27.5	56.5
Malawi	100	M 4	0.18	6.4	231.5	4.9	8.2	27.0	58.4
Malawi	101	M 5	1.15	4.7	204.3	6.4	6.9	26.4	63.9
Swaziland	102	S 1	1.42	6.4	270.1	5.7	8.3	25.7	57.6
Swaziland	105	S 9	1.64	4.4	227.2	7.2	8.0	26.4	62.7
Swaziland	107	S 13	0.64	5.7	203.9	6.3	8.4	27.3	57.4
Undetermined	114	Sel ZEDRES 1	0.58	5.2	205.3	7.3	7.3	25.9	61.7
South Africa	116	PGR 3 S1	1.03	5.3	170.8	5.4	9.4	28.6	61.6
Swaziland	117	SWAZI V4	1.81	6.3	240.1	5.4	7.5	26.2	61.0
Swaziland	118	SWAZI V5A	0.90	5.6	230.9	6.2	7.6	25.5	60.2
Zimbabwe	121	Red Ex Zimbabwe	0.62	4.8	173.4	4.8	8.4	25.3	57.5
Zimbabwe	123	ZIM 003	0.85	7.8	220.2	7.4	9.1	27.5	61.9
Madagascar	127	MAD 3	0.27	6.6	215.4	6.4	10.2	26.9	55.5
South Africa	129	73223 Marabastad	0.30	6.8	277.8	4.7	10.0	23.5	65.7
South Africa	131	76467 Gravelotte	1.55	6.7	232.4	5.5	8.5	28.9	61.1
Undetermined	136	CAP S1	0.57	7.6	243.5	8.7	8.7	28.0	57.2
South Africa	140	ETL 76469	0.97	6.7	226.3	5.8	10.3	28.7	57.6
South Africa	141	PGR3 S2	0.66	5.9	222.9	5.0	7.6	28.0	61.7
South Africa	142	PGR3 S3	0.81	6.1	206.5	6.4	8.9	27.7	59.0
South Africa	144	Sel from V4 S3 Dalby	1.38	5.9	226.5	5.9	7.1	29.1	65.3
Undetermined	145	Sel 1 from ZR S4	1.29	5.7	219.7	5.2	7.9	25.4	65.7
Swaziland	146	Sel 2 from SWAZI V4 S1	0.71	7.3	257.3	6.9	7.8	25.4	56.5
Swaziland	148	SWAZI V5	0.56	6.2	221.3	5.8	8.8	25.8	50.0
South Africa	149	V4 S4 (AS)	0.84	5.7	170.7	5.9	9.2	26.8	48.6
South Africa	150	WS 42 (AS)	2.38	5.8	170.7	5.1	8.4	27.8	59.7
South Africa	151	WS 43	0.80	5.4	164.5	5.2	8.0	27.3	53.6
South Africa	156	WS 49	0.69	6.7	128.0	6.9	9.6	25.5	45.5
South Africa	160	ZB S1	0.76	4.6	148.8	6.3	8.0	25.4	51.6
South Africa	161	ZB S2	1.33	8.7	103.1	5.7	9.9	25.1	43.6
South Africa	165	ZR S3	1.24	5.4	198.7	7.8	8.8	27.9	55.8
South Africa	166	ZR S4	0.74	7.1	142.0	6.6	10.1	29.4	47.3
South Africa	168	Sel 1 Potch mengsel	1.40	6.6	136.6	6.1	8.9	24.9	43.1
South Africa	169	SB 10-1F	1.60	7.3	141.4	6.6	9.6	27.5	52.3
South Africa	173	SB 11-1C	0.35	6.4	161.3	7.1	6.9	24.3	54.1
South Africa	174	SB 4-4G	1.06	4.9	190.2	5.6	8.1	25.6	56.6
South Africa	175	SB 4-2B	1.14	5.8	161.9	7.2	7.7	28.0	52.9
South Africa	176	SB 4-4H	1.59	7.4	172.9	5.1	8.3	22.7	53.6
Undetermined	177	S1 Sel 2	1.40	6.6	111.3	5.7	7.7	22.8	47.3
Undetermined	179	AB 16-5C	0.75	5.7	88.6	5.5	8.2	23.3	47.6
Namibia	180	Caprivi Sel 1	0.64	6.6	168.1	8.0	9.4	27.6	45.4
South Africa	181	SB 8-1B	0.74	4.7	169.7	4.7	10.1	26.4	51.7
Undetermined	183	S1 Sel 1	1.67	8.4	165.4	3.9	7.8	22.5	51.0
South Africa	184	SB 14-7B	0.95	6.3	154.0	6.3	9.8	24.6	45.2

Table 3. *Cont.*

Origin	Acc. No.	Accession	GY (t ha^{-1})	NBS	NL	NNS	NSP	PH (cm)	PS (cm)
South Africa	185	SB 8-3C	0.99	6.9	234.8	6.2	9.6	24.4	53.4
South Africa	188	MV 40-38	1.25	6.5	185.2	5.9	10.2	25.1	56.9
South Africa	189	MV 67-1	2.39	9.6	149.6	5.7	7.4	26.0	52.3
South Africa	190	MV 51-5-1C	1.27	6.9	150.7	6.2	10.4	24.3	54.3
South Africa	192	MV 74-2	0.49	6.0	144.7	7.2	9.4	25.0	57.4
South Africa	196	MV 104-2	1.05	5.4	206.1	5.1	8.6	22.3	48.9
South Africa	197	MV 8817	0.86	7.7	155.1	5.9	7.8	26.3	56.1
Singapore	198	Ex Singapore	0.94	8.1	178.6	5.6	8.6	24.9	51.5
Undetermined	199	SCORE 1	2.04	8.0	102.9	6.6	9.9	26.8	56.2
Undetermined	200	SCORE 2	1.03	8.0	170.5	6.7	9.0	25.7	57.8
South Africa	204	SB 4-2BB	1.42	6.6	192.4	6.9	9.1	28.1	56.3
Namibia	207	07K1	1.28	6.4	213.4	5.7	8.8	28.8	52.1
Namibia	208	07K3	1.52	8.2	180.8	6.8	9.6	26.9	57.0
Undetermined	209	6046	0.62	6.3	69.9	6.8	7.9	26.2	53.6
Undetermined	210	6050B	1.40	8.9	129.1	6.2	9.6	21.1	43.4
South Africa	211	RF-6135	1.10	6.8	148.8	7.2	8.8	25.0	50.0
South Africa	212	RF-6158	1.69	7.1	197.2	5.3	10.7	31.8	53.4
South Africa	213	RF-6166	0.47	6.7	208.4	5.4	9.1	26.9	56.9
South Africa	214	RF-6171	0.46	6.3	268.1	6.7	9.7	24.8	59.3
South Africa	215	RF-6180	1.85	6.7	92.5	5.2	11.2	29.3	52.4
South Africa	216	RF-6188	1.33	6.0	184.5	6.3	7.6	24.5	55.5
South Africa	217	RF-6221	1.73	4.6	149.1	4.0	7.3	22.5	44.8
South Africa	218	RF-6234	1.02	7.3	204.5	7.0	9.1	27.1	56.8
South Africa	219	RF-6250	1.36	7.6	195.2	7.9	10.2	30.4	55.6
South Africa	220	RF-6255	1.35	7.8	131.8	6.3	8.8	25.4	52.6
South Africa	221	RF-6274	1.32	8.1	75.1	5.3	10.5	26.1	65.1
South Africa	222	RF-6303A	1.30	8.3	195.3	5.4	9.8	29.0	56.3
South Africa	223	RF-6304	1.34	6.2	207.1	5.8	9.6	23.8	53.0
South Africa	224	RF-7684	0.77	4.8	128.8	4.8	8.9	23.6	48.1
Mean			1.152	6.6	165.2	6.1	9.1	25.91	51.93
$LSD_{0.05}$			0.77	2.09	N/A	1.82	2.81	4.71	10.1579

PH, plant height; PS, plant spread; NNS, number of nodes per stem; NL, number of leaves per plant; NSP, number of stems per plant; NBS, number of branches per stem; GY, grain yield.

At VHT and RPT for the 2016–2017 cropping season, there was wide variation for grain yield, NBS, NL, NNS, NSP, PH and PS ranging from 0.15 to 2.20 t ha^{-1}, 3.70 to 9.60, 120.80 to 311.80, 4.00 to 8.70, 6.30 to 13.30, 22.70 to 32.90 cm and 45.10 to 98.40 cm, respectively (Table 4). High yielding accessions (AS 9), NBS (MV 67-1), NL (SB 8-3C), NNS (CAP S1), NSP (AS 17), PH (K 7) and PS (V4 S4 (AS)) were identified.

Table 4. Means of grain yield and yield components of bambara groundnut accessions from combined analysis of accessions planted at Vaalharts and Roodeplaat during the 2016–2017 cropping season.

Origin	Acc. No.	Accession	GY (t ha^{-1})	NBS	NL	NNS	NSP	PH (cm)	PS (cm)
South Africa	9	SB 4-1	0.53	6.3	177.2	4.0	7.5	23.2	45.1
South Africa	19	SB 2-1	1.64	6.5	145.8	6.0	10.1	26.1	49.7
South Africa	21	SB 16-5A	0.54	5.4	230.7	6.7	7.8	26.6	58.2
South Africa	25	SB 19-3A	0.91	6.5	255.0	6.4	9.7	27.9	63.6
South Africa	49	SB 20-2A	0.81	7.1	229.8	7.6	8.4	26.7	54.3
South Africa	52	SB 4-4A	1.50	6.6	222.0	5.9	8.1	29.0	64.7
South Africa	53	SB 10-2A	1.08	7.8	218.7	5.6	8.1	29.8	58.1
South Africa	55	SB 12-3	1.64	7.1	230.0	4.4	10.0	26.6	65.7
South Africa	61	SB 19-3	0.99	6.8	233.4	5.6	7.9	26.5	56.3
South Africa	62	SB 8-3	0.58	5.2	136.1	4.3	7.7	26.8	56.9
South Africa	66	SB 1-1	1.13	5.2	253.1	7.5	7.1	27.9	58.8

Table 4. *Cont.*

Origin	Acc. No.	Accession	GY (t ha^{-1})	NBS	NL	NNS	NSP	PH (cm)	PS (cm)
Botswana	74	AS 5	0.93	5.7	136.7	4.9	6.6	27.1	54.0
Botswana	77	AS 8	0.16	6.1	209.6	5.9	9.8	22.7	58.5
Botswana	78	AS 9	2.20	6.8	248.7	5.8	7.9	25.4	49.2
Botswana	79	AS 10	1.05	6.2	257.2	5.5	8.2	26.5	57.3
Botswana	80	AS 11	0.98	6.8	188.8	6.4	10.8	26.6	61.0
Botswana	81	AS 12	0.84	4.1	247.3	5.6	7.4	25.8	50.5
Botswana	82	AS 13	0.15	5.3	249.7	7.3	9.4	25.5	54.6
Botswana	84	AS 15	0.90	5.9	230.8	6.1	7.6	26.9	58.7
Botswana	86	AS 17	1.24	5.5	253.3	6.5	13.3	27.4	65.2
Botswana	87	AS 18	0.56	7.2	191.5	6.5	10.8	27.1	58.2
Botswana	89	AS 20	0.31	5.3	214.3	4.9	9.0	26.3	52.6
Namibia	90	K 1	1.50	6.2	232.1	5.6	8.6	23.0	53.5
Namibia	92	K 3	1.24	4.9	269.9	6.3	6.3	26.0	51.1
Namibia	94	K 5	1.56	5.6	189.1	4.9	7.6	25.9	55.4
Namibia	95	K 6	1.56	6.4	289.5	6.8	8.5	27.2	65.5
Namibia	96	K 7	1.20	5.3	259.3	6.2	7.8	32.9	63.0
Malawi	97	M 1	1.38	5.8	174.3	5.8	8.2	30.2	63.8
Malawi	99	M 3	0.93	6.3	163.5	6.4	7.6	27.5	56.5
Malawi	100	M 4	0.18	6.4	231.5	4.9	8.2	27.0	58.4
Malawi	101	M 5	1.15	4.7	204.3	6.4	6.9	26.4	63.9
Swaziland	102	S 1	1.42	6.4	270.1	5.7	8.3	25.7	57.6
Swaziland	105	S 9	1.64	4.4	227.2	7.2	8.0	26.4	62.7
Swaziland	107	S 13	0.64	5.7	203.9	6.3	8.4	27.3	57.4
Undetermined	114	Sel ZEDRES 1	0.58	5.2	205.3	7.3	7.3	25.9	61.7
South Africa	116	PGR 3 S1	1.03	5.3	170.8	5.4	9.4	28.6	61.6
Swaziland	117	SWAZI V4	1.81	6.3	240.1	5.4	7.5	26.2	61.0
Swaziland	118	SWAZI V5A	0.90	5.6	230.9	6.2	7.6	25.5	60.2
Zimbabwe	121	Red Ex Zimbabwe	0.62	4.8	173.4	4.8	8.4	25.3	57.5
Zimbabwe	123	ZIM 003	0.85	7.8	220.2	7.4	9.1	27.5	61.9
Madagascar	127	MAD 3	0.27	6.6	215.4	6.4	10.2	26.9	55.5
South Africa	129	73223 Marabastad	0.30	6.8	277.8	4.7	10.0	23.5	65.7
South Africa	131	76467 Gravelotte	1.55	6.7	232.4	5.5	8.5	28.9	61.1
Undetermined	136	CAP S1	0.57	7.6	243.5	8.7	8.7	28.0	57.2
South Africa	140	ETL 76469	0.97	6.7	226.3	5.8	10.3	28.7	57.6
South Africa	141	PGR3 S2	0.66	5.9	222.9	5.0	7.6	28.0	61.7
South Africa	142	PGR3 S3	0.81	6.1	206.5	6.4	8.9	27.7	59.0
South Africa	144	Sel V4 S3 Dalby	1.38	5.9	226.5	5.9	7.1	29.1	65.3
Undetermined	145	Sel 1 ZR S4	1.29	5.7	219.7	5.2	7.9	25.4	65.7
Swaziland	146	Sel 2 SWAZI V4 S1	0.71	7.3	257.3	6.9	7.8	25.4	56.5
Swaziland	148	SWAZI V5	0.71	5.8	265.6	5.6	8.2	27.3	64.4
South Africa	149	V4 S4 (AS)	0.81	6.3	258.2	6.6	8.9	26.5	98.4
South Africa	150	WS 42 (AS)	1.54	5.8	222.0	5.5	7.7	28.5	61.1
South Africa	151	WS 43	0.83	5.2	196.1	5.8	7.0	28.2	60.1
South Africa	156	WS 49	0.41	5.8	164.4	5.9	8.7	25.5	51.8
South Africa	160	ZB S1	0.47	3.7	204.2	5.5	7.0	27.6	51.7
South Africa	161	ZB S2	0.84	9.0	163.0	5.8	10.3	24.7	47.9
South Africa	165	ZR S3	1.37	4.8	263.9	8.1	7.8	28.6	60.0
South Africa	166	ZR S4	0.41	5.9	172.5	5.9	9.4	25.1	59.0
South Africa	168	Sel 1 Potch mengsel	1.15	6.3	192.9	6.4	8.7	26.1	52.9
South Africa	169	SB 10-1F	1.09	6.8	204.5	5.4	8.6	26.5	58.0
South Africa	173	SB 11-1C	0.42	6.1	215.5	7.0	6.3	27.2	61.0
South Africa	174	SB 4-4G	0.83	5.0	240.9	5.9	6.8	25.5	54.1
South Africa	175	SB 4-2B	1.06	6.2	230.7	7.6	7.7	27.0	61.4
South Africa	176	SB 4-4H	1.16	7.3	229.6	5.6	7.8	24.3	58.4
Undetermined	177	S1 Sel 2	1.63	6.1	150.9	5.9	7.8	26.6	59.7
Undetermined	179	AB 16-5C	0.81	5.8	130.5	4.8	7.8	23.6	57.2
Namibia	180	Caprivi Sel 1	0.61	7.5	225.4	8.4	8.6	25.6	58.0
South Africa	181	SB 8-1B	0.57	4.6	208.4	4.6	9.3	27.1	54.2
Undetermined	183	S1 Sel 1	1.79	8.3	251.7	4.4	7.9	25.6	62.2

Table 4. *Cont.*

Origin	Acc. No.	Accession	GY (t ha^{-1})	NBS	NL	NNS	NSP	PH (cm)	PS (cm)
South Africa	184	SB 14-7B	0.87	6.6	220.1	6.8	9.4	27.1	58.2
South Africa	185	SB 8-3C	1.42	5.8	311.8	5.9	8.5	26.0	63.3
South Africa	188	MV 40-38	1.50	6.4	213.8	6.0	9.4	26.1	59.1
South Africa	189	MV 67-1	1.40	9.6	241.0	6.2	7.2	28.1	57.8
South Africa	190	MV 51-5-1C	1.04	6.3	194.5	5.4	9.2	26.2	60.6
South Africa	192	MV 74-2	0.60	5.3	188.7	5.7	9.3	23.7	68.8
South Africa	196	MV 104-2	1.17	6.3	262.7	6.0	7.6	25.0	64.4
South Africa	197	MV 8817	0.75	7.4	194.8	7.3	7.4	26.6	60.4
Singapore	198	Ex Singapore	0.95	8.6	222.6	6.3	7.8	26.5	61.1
Undetermined	199	SCORE 1	1.47	7.6	146.3	6.4	9.6	28.9	66.7
Undetermined	200	SCORE 2	1.09	6.9	223.3	6.6	8.1	27.8	64.3
South Africa	204	SB 4-2BB	0.87	6.5	265.5	7.7	8.8	29.4	67.8
Namibia	207	07K1	1.04	6.1	262.0	5.7	8.3	26.9	57.9
Namibia	208	07K3	0.92	7.9	282.2	6.4	8.6	26.5	66.5
Undetermined	209	6046	0.65	5.8	124.8	7.5	8.2	30.0	63.4
Undetermined	210	6050B	1.32	9.2	209.3	6.6	8.5	23.3	57.6
South Africa	211	RF-6135	1.05	5.7	206.0	6.3	8.6	26.8	61.9
South Africa	212	RF-6158	1.06	7.1	214.2	5.3	8.9	29.4	61.5
South Africa	213	RF-6166	0.42	6.5	235.1	6.2	8.8	25.5	58.3
South Africa	214	RF-6171	0.48	5.8	309.7	6.6	9.2	23.3	58.5
South Africa	215	RF-6180	0.98	7.3	176.9	5.7	9.8	26.8	61.3
South Africa	216	RF-6188	1.05	5.4	249.8	6.9	6.9	26.9	62.7
South Africa	217	RF-6221	1.72	4.7	197.6	4.4	6.7	23.9	51.4
South Africa	218	RF-6234	0.44	6.7	259.6	5.9	8.3	26.0	62.9
South Africa	219	RF-6250	1.40	6.8	241.8	6.9	8.8	27.0	57.4
South Africa	220	RF-6255	0.81	7.2	195.6	6.8	8.1	25.3	54.6
South Africa	221	RF-6274	0.81	7.7	120.8	6.0	10.3	26.4	67.0
South Africa	222	RF-6303A	1.12	8.2	226.7	5.6	8.8	25.0	50.1
South Africa	223	RF-6304	1.18	6.9	292.0	6.9	8.9	26.1	63.8
South Africa	224	RF-7684	0.84	4.2	182.5	4.9	8.2	26.0	56.7
Mean			0.98	6.3	219.1	6.1	8.4	26.6	59.46
$LSD_{0.05}$			0.67	2.23	88.27	1.90	2.84	3.39	12.90

PH, plant height; PS, plant spread; NNS, number of nodes per stem; NL, number of leaves per plant; NSP, number of stems per plant; NBS, number of branches per stem; GY, grain yield.

Across all trials (locations and seasons), there was variation for grain yield, NBS, NL, NNS, NSP, PH and PS ranging from 0.18 to 1.96 t ha^{-1}, 3.70 to 7.70, 91.60 to 232.00, 4.30 to 8.10, 6.00 to 11.00, 21.30 to 35.40 cm and 43.80 to 76.50 cm, respectively (Table 5). Accessions SB 12-3, MV 67-1, RF-6171, Caprivi Sel 1, AS 17, K 7 and V4 S4 (AS) gave the highest values for grain yield, NBS, NL, NNS, NSP, PH and PS, respectively.

Table 5. Means of grain yield and yield components of bambara groundnut accessions from combined analysis of accessions planted at Vaalharts in 2016–2017 and 2017–2018 and at Roodeplaat during the 2016–2017 cropping seasons.

Origin	Acc. No.	Accession	GY (t ha^{-1})	NBS	NL	NNS	NSP	PH (cm)	PS (cm)
South Africa	9	SB 4-1	0.63	5.4	133.5	4.3	6.6	22.9	43.8
South Africa	19	SB 2-1	1.29	5.4	109.6	6.0	8.5	25.3	46.0
South Africa	21	SB 16-5A	0.63	5.0	160.9	6.3	7.0	25.4	52.6
South Africa	25	SB 19-3A	0.77	6.0	186.6	6.2	8.7	25.3	55.5
South Africa	49	SB 20-2A	0.96	6.5	169.9	7.0	8.0	25.4	49.9
South Africa	52	SB 4-4A	1.51	5.6	161.7	5.8	7.1	28.0	60.2
South Africa	53	SB 10-2A	0.88	6.7	161.9	6.1	7.4	26.9	52.8
South Africa	55	SB 12-3	1.96	6.0	169.1	4.7	8.5	26.2	63.2
South Africa	61	SB 19-3	1.02	5.6	170.3	5.8	7.5	26.4	52.7
South Africa	62	SB 8-3	0.50	4.9	111.6	4.9	7.0	25.2	52.0

Table 5. *Cont.*

Origin	Acc. No.	Accession	GY (t ha^{-1})	NBS	NL	NNS	NSP	PH (cm)	PS (cm)
South Africa	66	SB 1-1	1.27	4.9	185.6	7.1	6.6	26.6	54.3
Botswana	74	AS 5	0.91	5.1	106.7	5.1	6.2	25.4	50.1
Botswana	77	AS 8	0.18	5.3	158.0	5.8	8.7	21.3	51.5
Botswana	78	AS 9	1.57	6.0	183.5	5.8	7.1	23.6	45.6
Botswana	79	AS 10	1.11	5.5	183.7	5.5	7.6	24.3	50.2
Botswana	80	AS 11	0.84	6.2	139.2	6.7	9.3	25.0	54.9
Botswana	81	AS 12	1.18	3.7	181.7	5.5	6.7	25.8	51.3
Botswana	82	AS 13	0.38	5.2	188.9	7.0	8.4	25.4	53.5
Botswana	84	AS 15	0.76	5.6	165.9	5.9	7.0	27.9	49.6
Botswana	86	AS 17	1.21	5.2	184.8	6.1	11.0	26.2	57.9
Botswana	87	AS 18	0.77	6.9	139.6	6.1	9.3	27.0	54.7
Botswana	89	AS 20	0.45	4.8	154.5	5.0	7.9	25.9	47.8
Namibia	90	K 1	1.16	5.2	175.2	5.8	7.7	22.8	48.7
Namibia	92	K3	1.47	4.1	194.6	6.0	6.0	25.7	51.2
Namibia	94	K 5	1.65	5.2	137.5	5.0	6.6	25.7	50.7
Namibia	95	K 6	1.30	5.9	213.7	6.7	7.7	26.7	59.7
Namibia	96	K 7	1.08	5.1	188.7	6.1	7.4	35.4	61.9
Malawi	97	M 1	1.11	5.3	139.1	6.2	7.5	28.7	57.6
Malawi	99	M 3	0.89	5.5	121.7	7.1	6.9	28.0	51.7
Malawi	100	M4	0.45	5.5	173.8	4.9	7.4	26.2	52.4
Malawi	101	M5	1.41	4.8	151.9	6.3	6.8	26.3	58.7
Swaziland	102	S1	1.29	5.6	197.2	5.3	7.5	25.0	52.7
Swaziland	105	S9	1.35	4.7	171.6	6.9	7.6	26.5	57.9
Swaziland	107	S 13	0.86	5.0	148.5	6.1	7.6	27.9	55.1
Undetermined	114	Sel ZEDRES 1	0.56	4.9	150.2	6.6	7.0	26.0	54.3
South Africa	116	PGR 3 S1	0.87	4.9	132.8	5.7	8.5	26.6	54.3
Swaziland	117	SWAZI V4	1.39	5.6	175.5	5.7	6.8	25.4	52.5
Swaziland	118	SWAZI V5A	0.70	5.1	173.7	6.2	7.0	24.3	54.4
Zimbabwe	121	Red Ex Zimbabwe	0.59	4.5	127.5	4.8	7.3	24.4	50.4
Zimbabwe	123	ZIM 003	0.62	6.4	166.3	7.3	7.9	30.0	59.3
Madagascar	127	MAD 3	0.55	5.8	168.0	6.1	9.1	26.7	56.0
South Africa	129	73223 Marabastad	0.89	5.9	201.8	4.7	8.5	23.9	62.7
South Africa	131	76467 Gravelotte	1.39	5.6	166.4	5.4	7.5	27.5	55.1
Undetermined	136	CAP S1	0.73	6.8	173.7	7.7	7.5	27.3	55.0
South Africa	140	ETL 76469	0.93	5.9	162.7	5.5	8.7	26.8	52.3
South Africa	141	PGR3 S2	0.74	5.3	162.7	5.0	7.2	27.6	54.8
South Africa	142	PGR3 S3	0.79	5.3	145.9	5.9	7.9	26.3	52.5
South Africa	144	Sel V4 S3 Dalby	1.20	5.2	160.1	5.7	6.5	26.4	55.8
Undetermined	145	Sel 1 ZR S4	1.14	5.2	169.0	5.6	7.6	25.2	62.5
Swaziland	146	Sel 2 SWAZI V4 S1	0.65	6.3	181.8	6.4	7.2	24.2	49.0
Swaziland	148	SWAZI V5	0.65	5.2	194.8	5.7	7.1	26.1	56.2
South Africa	149	V4 S4 (AS)	0.65	5.2	181.0	6.1	7.8	26.7	76.5
South Africa	150	WS 42 (AS)	1.88	5.2	165.2	5.3	7.1	27.7	59.1
South Africa	151	WS 43	0.79	4.7	139.2	5.5	6.4	27.1	54.5
South Africa	156	WS 49	0.61	5.7	129.4	6.2	8.0	26.4	51.0
South Africa	160	ZB S1	0.69	4.2	146.9	5.9	7.0	26.6	50.9
South Africa	161	ZB S2	0.97	7.3	114.2	5.6	8.8	25.0	47.3
South Africa	165	ZR S3	1.07	4.4	201.1	7.2	7.1	27.6	56.0
South Africa	166	ZR S4	0.63	5.8	135.6	6.1	8.3	27.9	50.9
South Africa	168	Sel 1 Potch mengsel	1.08	5.7	140.4	6.0	7.4	24.9	48.3
South Africa	169	SB 10-1F	1.28	5.9	148.7	6.0	7.8	26.6	55.0
South Africa	173	SB 11-1C	0.49	5.5	154.2	6.5	6.2	25.0	54.9
South Africa	174	SB 4-4G	0.73	4.6	176.9	5.6	6.6	25.3	52.4
South Africa	175	SB 4-2B	0.94	5.4	162.5	7.2	6.8	26.9	53.8
South Africa	176	SB 4-4H	1.19	6.5	164.7	5.3	7.1	23.1	52.6
Undetermined	177	S1 Sel 2	1.28	5.3	112.3	5.7	6.5	24.5	51.4
Undetermined	179	AB 16-5C	1.02	5.0	102.4	5.1	7.4	23.8	54.5
Namibia	180	Caprivi Sel 1	0.49	6.4	169.2	8.1	7.6	26.7	51.5

Table 5. *Cont.*

Origin	Acc. No.	Accession	GY (t ha^{-1})	NBS	NL	NNS	NSP	PH (cm)	PS (cm)
South Africa	181	SB 8-1B	0.69	4.3	153.5	4.7	8.1	26.3	51.6
Undetermined	183	S1 Sel 1	1.20	6.8	181.4	5.1	6.8	24.0	53.8
South Africa	184	SB 14-7B	0.89	5.6	156.9	6.0	8.0	24.7	49.0
South Africa	185	SB 8-3C	1.05	5.4	223.2	6.0	8.1	24.8	55.2
South Africa	188	MV 40-38	1.12	5.6	161.7	5.8	8.4	25.1	54.9
South Africa	189	MV 67-1	1.70	7.7	178.3	5.9	6.7	27.0	53.5
South Africa	190	MV 51-5-1C	1.08	5.5	145.0	5.6	8.3	24.5	53.5
South Africa	192	MV 74-2	0.57	4.9	133.8	6.0	7.8	25.2	60.5
South Africa	196	MV 104-2	1.01	5.4	186.7	5.8	7.0	23.4	56.0
South Africa	197	MV 8817	0.84	6.6	141.3	6.5	6.8	25.6	57.2
Singapore	198	Ex Singapore	0.80	6.7	162.3	5.7	7.0	25.0	53.4
Undetermined	199	SCORE 1	1.53	6.4	111.1	6.0	8.1	27.7	62.2
Undetermined	200	SCORE 2	0.88	6.1	172.2	6.4	7.4	27.1	60.4
South Africa	204	SB 4-2BB	1.21	6.1	184.1	6.7	7.7	28.0	60.0
Namibia	207	07K1	1.04	5.4	183.7	5.5	7.5	27.4	52.4
Namibia	208	07K3	1.11	6.7	204.5	6.3	7.7	25.9	61.2
Undetermined	209	6046	0.60	5.2	92.1	6.7	7.1	27.3	55.9
Undetermined	210	6050B	1.12	7.5	149.2	6.4	7.9	22.1	50.8
South Africa	211	RF-6135	1.03	5.6	150.1	6.4	7.6	26.0	54.0
South Africa	212	RF-6158	1.38	5.8	166.3	5.4	8.1	31.1	57.8
South Africa	213	RF-6166	0.51	5.6	181.0	5.7	7.7	26.1	56.2
South Africa	214	RF-6171	0.41	5.2	232.0	6.3	8.1	23.6	55.8
South Africa	215	RF-6180	1.42	6.4	131.0	5.6	8.6	28.4	54.8
South Africa	216	RF-6188	1.11	4.9	180.4	6.4	6.4	25.5	57.1
South Africa	217	RF-6221	1.41	4.4	142.5	4.4	6.3	23.1	47.4
South Africa	218	RF-6234	0.82	6.1	192.8	6.3	7.6	26.3	57.8
South Africa	219	RF-6250	1.04	6.1	182.9	7.0	8.1	29.4	55.2
South Africa	220	RF-6255	1.05	6.4	142.6	6.4	7.3	25.3	52.3
South Africa	221	RF-6274	1.01	6.5	91.6	5.6	8.8	26.2	63.1
South Africa	222	RF-6303A	1.11	6.9	171.9	5.4	7.8	26.9	51.2
South Africa	223	RF-6304	1.30	5.9	209.7	6.1	7.8	24.9	56.8
South Africa	224	RF-7684	0.84	4.0	138.0	5.2	7.7	24.9	50.8
Mean			0.98	5.6	161.1	5.9	7.6	26.01	54.4
$LSD_{0.05}$			0.54	1.56	-	1.37	1.95	3.41	-

PH, plant height; PS, plant spread; NNS, number of nodes per stem; NL, number of leaves per plant; NSP, number of stems per plant; NBS, number of branches per stem; GY, grain yield.

3.3. Grouping of the Germplasm Entries in the Dendrogram

From the dendrogram (Figure 1) it was clear that the accessions did not group according to geographic region of origin, but rather based on plant characteristics. The accession numbers and their corresponding accession names are indicated in Tables 3–5. The dendrogram consisted of two large clusters, I and II. Cluster IA had all the red-colored entries, which were further divided into two clusters. Cluster IAi was comprised of entries (99, 209, 145, 192, 166, 165, 116, 142, 97, 107, 169, 211, 148, 213, 207, 84, 141, 173, 114, 21, 118, 174, 151 and 160) with a high number of branches per stem and cluster ii consisted of entries with the highest number of stems per plant and a high number of branches per stem and nodes per stem. Cluster IBi consisted of entries (224, 179, 121, 62, 9, 181, 89, 217, 94, 177 and 74) with the highest grain yield, plant spread and plant height. Cluster IIAi consisted of entries (210, 49, 146, 197, 220, 100, 198, 53, 61, 222, 189, 176, 183, 78, 79 and 102) with the lowest grain yield and intermediate values for the other characteristics and cluster IIAii consisted of entries (86, 80, 87, 127, 19, 161, 77, 90, 168, 184, 25, 140, 188 and 190) with the lowest values for almost all characteristics, except for intermediate values for grain yield and stems per plant. Cluster IIBi had entries (131, 52, 150, 212, 55, 215, 199, 221 and 96) with high values for the number of leaves per plant and nodes per stem, as well as grain yield.

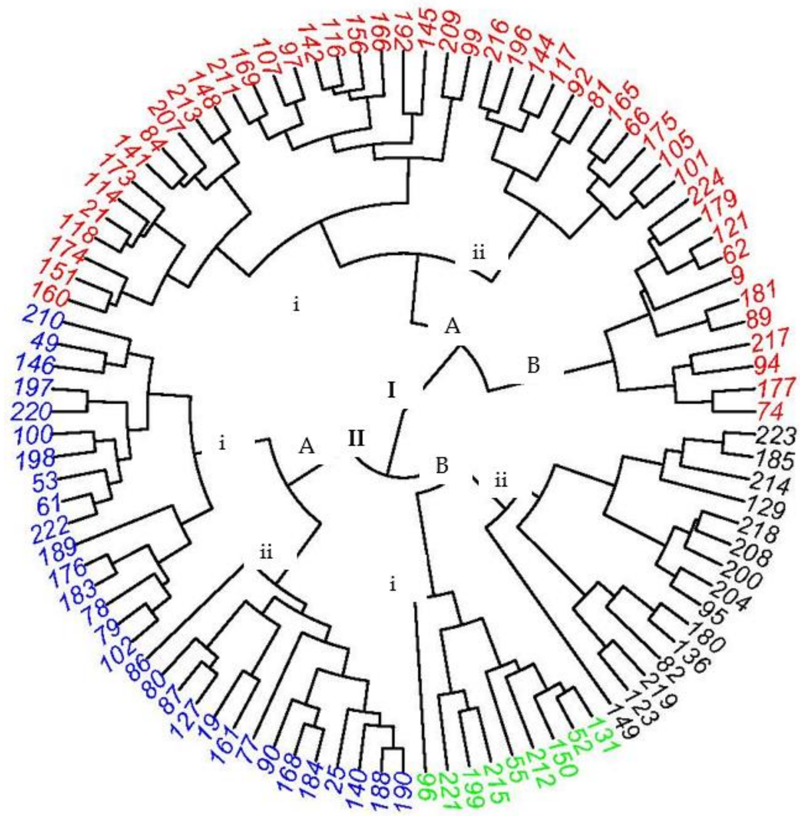

Figure 1. Dendrogram of 100 bambara groundnut accessions based on phenotypical characteristics combined for three trials. The main clusters were represented using uppercase roman numerals (I and II), the sub-clusters were represented using uppercase alphabet letters (A and B), and the sub-sub clusters were represented using lowercase roman numerals (i and ii).

3.4. Principal Component Analysis (PCA)

All 100 bambara accessions were included in the PCA to visualize the relationship between grain yield and yield components and to determine the association of accession based on these traits. Considering a minimum threshold eigenvalue of one, the seven measured characteristics were reduced to three PCs that explained 59.36% of the total variation observed in the bambara accessions (Table 6). Only PC1 and PC2 were interpreted since they explained most of the variation in the data set. PC1 was strongly and positively influenced by NBS, NNS, NSP, PH and PS. PC2 was strongly and positive influenced by NBS and NSP and was also strongly and negatively influenced by GY.

Table 6. Eigenvectors from principal component (PC) analysis for the 100 bambara groundnut accessions.

Traits	PC1	PC2	PC3
GY	0.102	−0.517	0.665
NBS	0.324	0.440	0.486
NL	0.297	−0.222	−0.199
NNS	0.452	0.201	−0.445
NSP	0.302	0.541	0.270
PH	0468	−0.297	−0.105
PS	0.531	−0.262	0.005
Eigenvalue	1.791	1.249	1.115
Variability (%)	25.592	17.837	15.932
Cumulative (%)	25.592	43.429	59.361

PS, plant spread; NNS, number of nodes per stem; NL, number of leaves per plant; NSP, number of stems per plant; NBS, number of branches per stem; GY, grain yield.

The plot of PC1 against PC2 distinguishes the bambara accessions based on their potential traits (Figure 2). About half of the Bambara accessions were displayed on the positive side of the PC1, indicating that those accessions have high values for NBS, NNS, NSP, PH and PS. The PCA demonstrated two main groups of traits, namely, (i) NSP, NBS and NNS, and (ii) NL, PH and PS, while GY was separated from other traits. The NSP and NBS was associated with accessions 80, 87, 127 and 180. The NNS was associated with accessions 86 and 136. The NL was associated with accessions 55, 165 and 212. The PH and PS was associated with accession 149. The GY was associated with accession 150.

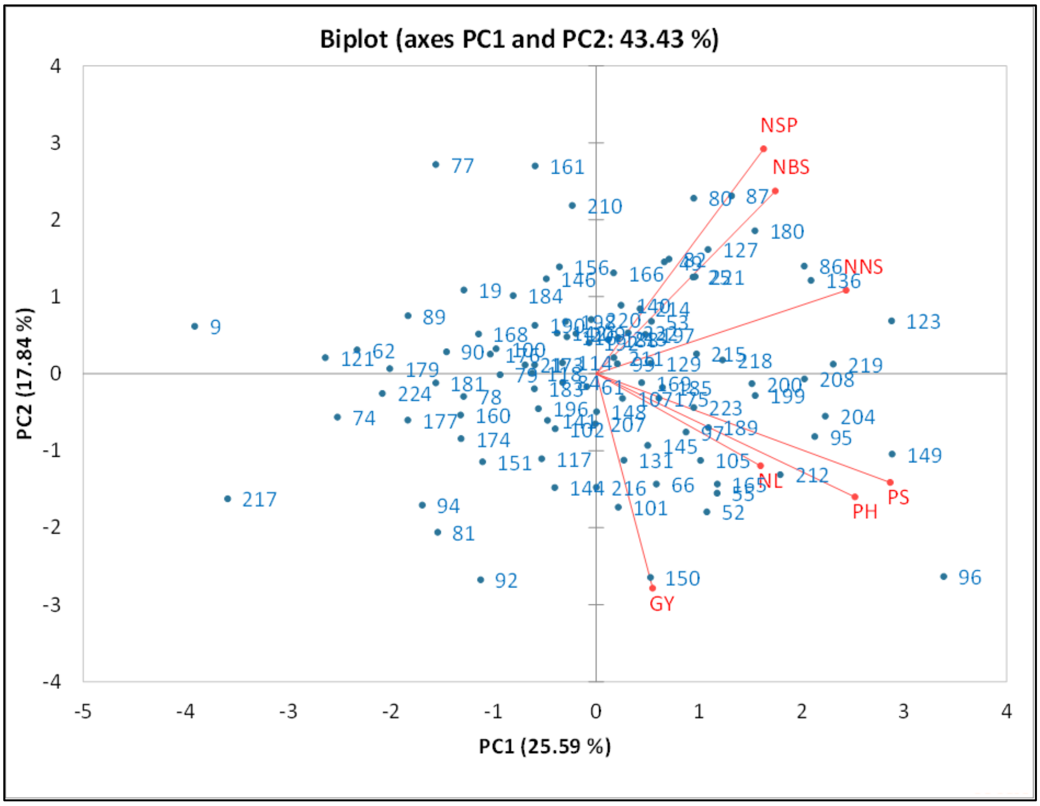

Figure 2. Biplot analysis for principal component 1 (PC1) on the x-axis plotted against principal component 2 (PC2) on the y-axis for the 100 bambara accessions (in numbers) for all traits. PS, plant spread; NNS, number of nodes per stem; NL, number of leaves per plant; NSP, number of stems per plant; NBS, number of branches per stem; GY, grain yield.

3.5. Phenotypic Correlations between Grain Yield and Yield Components and Clustered Heat Map

Generally, the correlations between traits were highly significant ($p < 0.001$), positive and low (Table 7). Highly significant ($p < 0.001$) and positive correlations were found for PS with PH (r = 0.34), NNS with PH (r = 0.15) and PS (r = 0.14) and NL with PH (r = 0.23), PS (r = 0.45) and NNS (r = 0.30). Highly significant ($p < 0.001$) and positive correlations were found for NSP with PH (r = 0.13), PS (r = 0.18), NNS (r = 0.40) and NL (r = 0.54). Highly significant ($p < 0.001$) and positive correlations were found for NBS with PH (r = 0.12), PS (r = 0.23), NNS (r = 0.25), NL (r = 0.56) and NSP (r = 067). GY was highly significant ($p < 0.001$) and positively correlated with PH (r = 0.17), PS (r = 0.16), NL (r = 0.18), NSP (r = 0.25) and NBS (r = 0.28) and non-significantly ($p > 0.05$) correlated with NNS (r = 0.01).

Table 7. Phenotypic correlations between grain yield and yield components at Vaalharts in 2016–2017 and 2017–2018 growing seasons and at Roodeplaat 2016–2017 season.

Trait	PH	PS	NNS	NL	NSP	NBS
PS	0.34 ***					
NNS	0.15 ***	0.14 ***				
NL	0.23 ***	0.45 ***	0.30 ***			
NSP	0.13 ***	0.18 ***	0.40 ***	0.54 ***		
NBS	0.12 ***	0.23 ***	0.25 ***	0.56 ***	0.67 ***	
GY	0.17 ***	0.16 ***	0.01	0.18 ***	0.25 ***	0.28 ***

*** $p \leq 0.001$, PH, plant height; PS, plant spread; NNS, number of nodes per stem; NL, number of leaves per plant; NSP, number of stems per plant; NBS, number of branches per stem; GY, grain yield.

In the heat map (Figure 3), the number of leaves (NL) was an outlier in the clustering of the measured characteristics, while all the other characteristics grouped together in one cluster, although plant spread was an outlier in this cluster. Grain yield, number of stems per plant, branches per stem, nodes per stem and plant height were closely related. The 100 accessions grouped into two distinct clusters mainly based on leaf number and plant spread, and to a lesser extent, plant height. These were, therefore, the main discriminating characteristics. Cluster I was further separated into A (140, 21, 175, 188, 131, 127, 212, 52, 105, 145, 174, 100, 136, 61, 49, 79, 183, 81, 213, 219, 86, 196, 82, 218 and 102) and B (149, 129, 95 and 214) based on high values for the yield and number of branches in cluster A. Cluster II was also separated into A (87, 151, 97, 192, 224, 217, 215, 156 and 99) and B (169, 211, 160, 190, 210, 181, 184, 101, 62, 161, 179 and 221) groups based on a combination of characteristics.

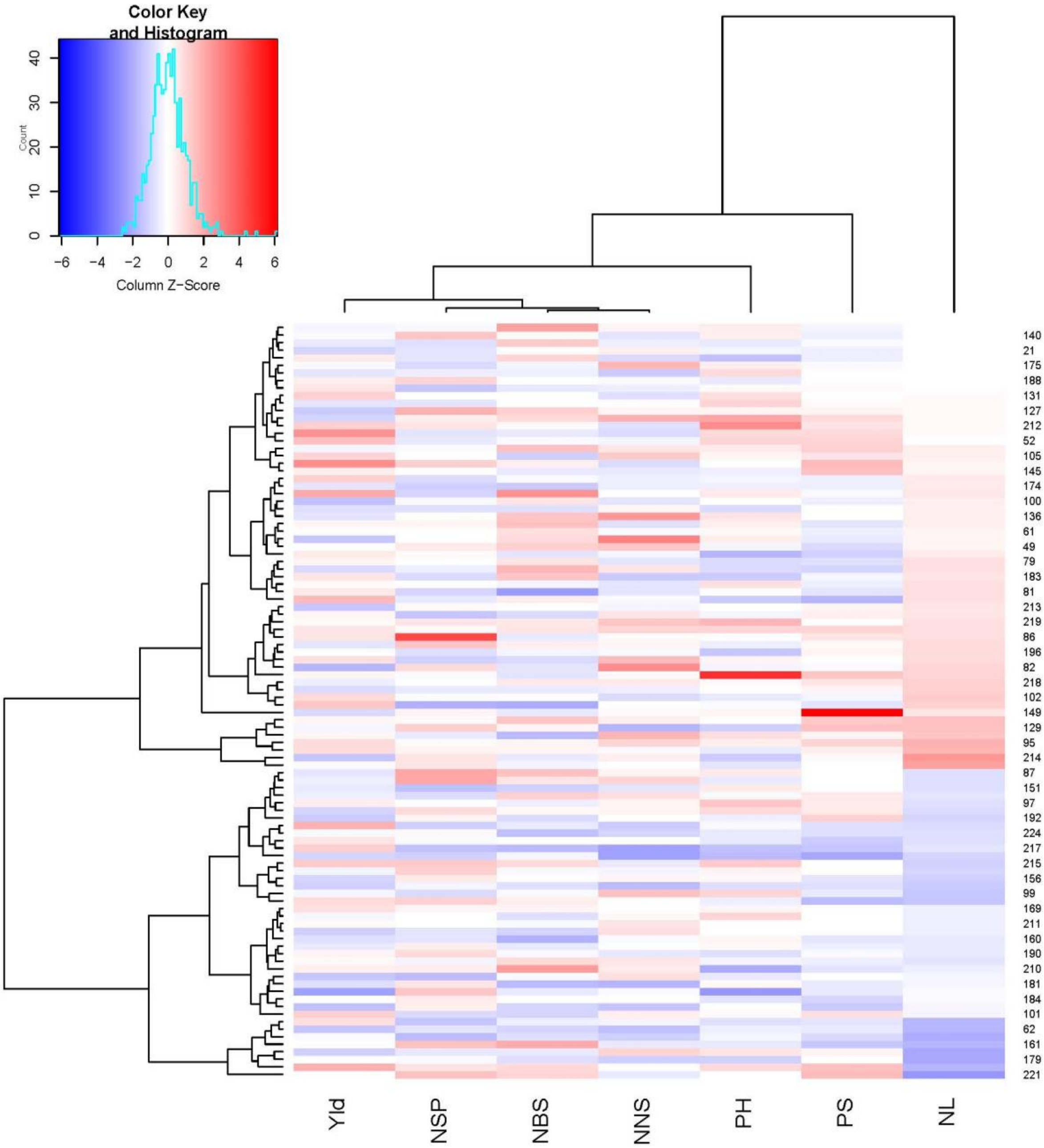

Figure 3. Heat map of grain yield and yield components measured in 100 accessions in Vaalharts in 2016–2017 and 2017–2018 growing seasons and at Roodeplaat 2016–2017 season. PH, plant height; PS, plant spread; NNS, number of nodes per stem; NL, number of leaves per plant; NSP, number of stems per plant; NBS, number of branches per stem; YLD, grain yield.

4. Discussion

Knowledge of the phenotypic diversity in the existing breeding program is very important for further crop improvement. This study quantified the phenotypic diversity of 100 bambara groundnut accessions for grain yield and related traits to identify potential accessions for use in the breeding program as potential parents. There were significant differences among bambara groundnut accessions for all traits, indicating the presence of genetic variation which can be exploited in the breeding program for further crop improvement. The variability also indicated that superior bambara groundnut accessions could be identified and used as potential parents in the breeding program. Significant morphological variation was reported among 20 bambara groundnut accessions evaluated in South Africa [12]. A study conducted in Tanzania also reported significant variation among bambara groundnut landraces for morphological traits [28]. Significant accession by a location interaction effect for grain yield and related traits indicated that bambara groundnut accessions performed differently in different locations, highlighting a specific location adaptation. Furthermore, grain yield and yield-related characteristics are polygenic traits with small additive effects and such traits are most likely to be influenced by the environment [29]. When the environmental influence is large, it may lead to the change in mean performance of each accession per test location, suggesting that prior to cultivar release, the bambara accessions should be tested and evaluated in different environments to determine their adaptation and stability. A significant accession by a season interaction effect for grain yield and related traits indicated the change in the performance of accessions over the growing seasons, further highlighting the existence of a year-to-year variability among bambara groundnut accessions for grain yield components.

Generally, the accession variance was lower than the phenotypic variance for grain yield and almost all the yield components, which resulted in low broad-sense heritability values (H^2). H^2 values give an indication of the accuracy with which selection will take place. Therefore, the low H^2 values indicated that the phenotypic differences observed among the bambara groundnut accessions were mainly caused by environmental effects, which further suggested that selection under such circumstances will not be very effective. Although, the H^2 values were low for almost all traits, the mean squares used to determine variance components were significant, thus, the significant and complex interaction effects for grain yield and yield components also indicated the complex genetic control of yield-related traits [29].

In the VHT over two seasons, accessions SB 12-3, MV 67-1, RF-6171, ZIM 003, AS 17, and K 7 had the highest mean values for grain yield, NBS, NL, NNS, NSP, PH and PS, respectively. These accessions could be considered as potential parents for breeding and crossing to develop high-yielding varieties. Further, high yielding accessions can further be evaluated for adaptability and stability across South African growing conditions. In VHT and RPT, bambara groundnut accessions AS 9, MV 67-1, SB 8-3C, CAP S1, AS 17, K 7 and V4 S4 (AS) had the highest mean values for grain yield, NBS, NL, NNS, NSP, PH and PS, respectively. These accessions could have a broad adaptation, however, it should be noted that these accessions were only evaluated in two different locations for one season. Therefore, multi-location and multi-season trials are required to evaluate for the adaptability and stability of these potential bambara groundnut accessions.

Across trials (locations and seasons), there was a large variation for grain yield, NBS, NL, NNS, NSP, PH and PS ranging from 0.18 to 1.96 t ha-1, 3.70 to 7.70, 91.60 to 232.00, 4.30 to 8.10, 6.00 to 11.00, 21.30 to 35.40 cm and 43.80 to 76.50 cm, respectively. Accessions SB 12-3, MV 67-1, RF-6171, Caprivi Sel 1, AS 17, K 7 and V4 S4 (AS) gave the highest values for grain yield, NBS, NL, NNS, NSP, PH and PS, respectively. These accessions should be evaluated for nutritional quality traits and pest and disease resistance. Bambara groundnut accessions SB 12-3, MV 67-1, AS 17, K 7 and V4 S4 (AS) consistently gave the highest values for grain yield, NBS, NSP, PH and PS and performed well for these specific traits. Various studies on legume crops have shown a positive strong correlation between grain yield, NBS, NL, NNS, NSP, PH and PS [12,18,19]. The results from these studies and the current study indicate that an improvement of one of these traits will have a positive influence on grain yield, further indicating that accessions with these yield traits could be potential high yielders.

Other studies have reported negative correlations between PS and grain yield [30]. Studies [30,31], in environments where precipitation is limiting, especially towards the end of the rainy season, showed that bambara groundnut landraces with wider canopies yield less than the bunchy or semi-bunchy genotypes because accessions with a spreading growth habit have a longer vegetative phenological stage, thereby being subjected to terminal moisture stress. Further, accessions with a spreading growth habit suffer from decreasing temperatures because of delayed maturity, thereby giving lower yields than their bunchy counterparts. Accessions with a bunchy growth habit also yield more because of a better radiation capture than the spreading types [31]. Significant positive correlations between PH and grain yield have been reported in previous studies [32–34], while other studies have reported the opposite [9,21].

The positive and significant correlation between PS and NNS may be explained by the fact that as the bambara plant adds more nodes, it grows away from the point of germination, even in bunchy accessions. The stems and branches do not grow perpendicular to the ground. In addition, an increase in the number of nodes represents an increase in the growth of the plant and, therefore, a widening of the canopy. Significant positive correlations between PS and NNS was previously reported [33].

The significant positive correlation between PS and NL indicates that an increase in the number of leaves will have a positive influence on the growth and, hence, leads to the expansion of the canopy. As leaves arise at the nodes, the increase in the number of leaves should be the same as the increase in the number of nodes of the plant. Similar results were reported in previous studies [12,35]. The significant positive correlations among PS, NSP and NBS observed in the present study may be expected because intra-canopy competition would make the stems grow wide apart and, hence, increase the canopy diameter. Moreover, stems do not stand perpendicular to the ground, therefore, for a given genotype, the higher the number of stems, the wider the canopy is likely to be.

The non-significant correlation between the number of nodes and the yield detected in the present study suggests that breeding for a higher number of nodes would not be a viable option for improving grain yield in bambara groundnut. It may appear surprising that NNS should relate negatively when in fact, flowers, and hence pods, develop on the nodes in the bambara groundnut, a morphological arrangement that should lead to a positive correlation between the two traits. However, bambara groundnut plants continue to grow and produce flowers even when the pods that develop earlier close to the stem have ripened and are ready for harvest. Therefore, flowers that develop later do not produce consumable or marketable pods as these pods will be immature at the time of harvest. The correlation might be positive in semi-arid environments where terminal moisture stress stops the plant from further production of nodes and leaves by the time the initial pods mature, for in such environments, the yellowing, bleaching and falling of leaves even serves as an indicator of crop physiological maturity [36,37]. In contrast, in environments with ample moisture, such as in the wet humid areas or where supplementary irrigation is applied, bambara groundnut matures while the leaves are still green.

The dendrogram and clustered heat map provided a visual demonstration of the relationship among different characteristics and accessions. The dendrogram showed four distinctive groups or clusters of entries indicating the presence of wide genetic variation in these populations, which should be considered for breeding and future cross combinations to broaden the genetic base of the bambara groundnut collection. The groupings were mainly characterized by specific characteristics, but not according to their country of origin, indicating similarities among the accessions from different genetic backgrounds. Of the four distinctive clusters, a sub-cluster IBi, which consisted of accessions/entries (224 (RF-7684), 179 (AB 16-5C), 121 (Red Ex Zimbabwe), 62 (SB 8-3), 9 (SB 4-1), 181 (SB 8-1B), 89 (AS 20), 217 (RF-6221), 94 (K 5), 177 (S 1 Sel2) and 74 (AS 5)), was characterized by the highest grain yield, plant spread and plant height. The results could also suggest that breeders need to take plant spread and plant height into consideration when selecting for high-yielding genotypes. High-yielding bambara groundnut accessions should also be evaluated for other characteristics such as nutritional quality attributes, resistance to diseases and pests and adaptability and stability in diverse environments. A similar study [38] on the morphological characterization of selected African accessions of bambara groundnut reported different trait combinations for high-yielding bambara groundnut accessions.

The heat map of the grain yield and yield characteristics showed that the number of leaves was the main discriminating trait for all the accessions. This was followed by plant spread and, to a lesser extent, plant height. Grain yield was the least discriminating factor. So, the accessions were largely grouped for more leaves (cluster I) with more spread of the plants and higher plant length in this cluster. Clusters I and II were then further sub-divided due to different combinations of the measured characteristics in the accessions. There was no relationship between geographic origin and clustering of accessions.

The PCA showed that approximately half of the Bambara accessions studied were associated with high values for NBS, NNS, NSP, PH and PS, indicating that these are important for improving the grain yield of Bambara ground. The PCA also identified the accessions that were associated with specific traits. The NSP and NBS was associated with accession 80 (AS 11), 87 (AS 18), 127 (MAD 3) and 180 (Caprivi Sel 1). The NNS was associated with accession 86 (AS 17) and 136 (CAP S1). The NL was associated with accession 55 (SB 12-3), 165 (ZR S3) and 212 (RF-6158). The PH and PS was associated with 149. The GY was associated with accession 150 (WS 42 (AS)). Within the main two groups that were distinguished by PCA, there were positive correlations between traits, further indicating that an improvement of one trait will have a positive influence on the other traits, which will enable the indirect or simultaneous selection of most of the grain yield components.

5. Conclusions

The variability observed in the growth and growth-related characteristics as well as grain yield in this study offers opportunities for genetic improvement of adapted varieties of bambara groundnut. This study has shown that different bambara groundnut accessions respond differently in diverse environments for various characteristics. Therefore, different accessions can be recommended for production in specific environments. High-yielding bambara groundnut accessions WS 42 (AS), MV 67-1, K 5, AS 9, SCORE 1 and SB 12-3 were identified and can be recommended for direct use for bambara ground-nut production by the small-scale farmers in South Africa. The dendrogram showed that bambara accessions; 224 (RF-7684), 179 (AB 16-5C), 121 (Red Ex Zimbabwe), 62 (SB 8-3), 9 (SB 4-1), 181 (SB 8-1B), 89 (AS 20), 217 (RF-6221), 94 (K 5), 177 (S 1 Sel2) and 74 (AS 5) were associated with a high grain yield, plant spread and plant height. The PCA showed that approximately half of the Bambara accessions studied were associated with high values for NBS, NNS, NSP, PH and PS, indicating that these are important for improving the grain yield of Bambara ground. The PCA also identified the accessions that were associated with specific traits. Significant positive correlations between morphological characteristics and yield were observed, which indicated the possibility of the simultaneous improvement of these traits. The heat maps showed that the number of leaves was the most discriminating trait in the germplasm collection in terms of plant characteristics.

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References

1. National Research Council. *Lost Crops of Africa: Volume II: Vegetables*, 1st ed.; The National Academic Press: Washington, DC, USA, 2006; pp. 53–64.
2. Eltayeb, A.R.S.; Ali, A.O.; Abou-Arab, A.A.; Abu-Salem, F.M. Chemical composition and functional properties of flour and protein isolate extracted from bambara groundnut (*Vigna subterranean*). *Afr. J. Biotechnol.* **2011**, *5*, 82–90.

3. Emendu, N.B.; Emendu, R.E. Proximate analysis, characterisation and utilization of bambara nut oil (*Mmanu*—Okpa). *Int. J. Sci. Res.* **2014**, *4*, 1–5.
4. Halimi, R.A.; Barkla, B.J.; Mayes, S.; King, G.J. The potential of the underutilized pulse bambara groundnut (*Vigna subterranea* (L.) Verdc.) for nutritional food security. *J. Food Compos. Anal.* **2018**, *77*, 47–59. [CrossRef]
5. Majola, N.; Gerrano, A.S.; Shimelis, H. Bambara groundnut (*Vigna subterranea* [L.] Verdc.) Production, utilisation and genetic improvement in sub-Saharan Africa. *Agronomy* **2021**, *11*, 1345. [CrossRef]
6. Mbuma, N.W.; Labuschagne, M.; Siwale, J.; Hugo, A. Diversity in seed protein content, selected minerals, oil content and fatty acid composition of the Southern African bambara groundnut germplasm collection. *J. Food Compos. Anal.* **2022**, *109*, 104477. [CrossRef]
7. Khan, F.; Azman, R.; Chai, H.H.; Mayes, S.; Lu, C. Genomic and transcriptomic approaches towards the genetic improvement of an underutilised crops: The case of bambara groundnut. *Afr. Crop Sci. J.* **2016**, *24*, 429–458. [CrossRef]
8. Mayes, S.; Ho, W.K.; Chai, H.H.; Song, B.; Chang, Y.; Massawe, F. Bambara Groundnut (*Vigna Subterranea* (L) Verdc)—A Climate-Smart Crop for Food and Nutrition Security. In *Genomic Designing of Climate-Smart Pulse Crops*, 1st ed.; Kole, C., Ed.; Springer International Publishing: Cham, Switzerland, 2019; pp. 397–424. [CrossRef]
9. Ouedraogo, M.; Ouedraogo, J.; Tignere, J.; Bilma, D.; Dabire, C.; Konate, G. Characterization and evaluation of accessions of bambara groundnut (*Vigna subterranea* (L.) Verdcourt) from Burkina Faso. *Sci. Nat.* **2008**, *5*, 191–197. [CrossRef]
10. Okpuzor, J.; Ogbunugafor, H.A.; Okafor, U.; Sofidiya, M.O. Identification of protein types in bambara nut seeds: Perspectives for dietary protein supply in developing countries. *EXCLI J.* **2010**, *9*, 17–28.
11. Adzawla, W.; Donkoh, S.A.; Nyarko, G.; Reilly, O.P.J.; Olayide, O.E.; Mayes, S.; Feldman, A.; Azman, H.R. Adoption of bambara groundnut production and its effects on farmers welfare in Northern Ghana. *Afr. J. Agric. Res.* **2016**, *11*, 583–594. [CrossRef]
12. Gerrano, A.S.; Jansen van Rensburg, W.S.; Adebola, P.O. Assessment of genetic variability in bambara groundnut (*Vigna subterrenea* L. Verdc.) using morphological quantitative traits. *AJAR* **2013**, *1*, 45–51.
13. Hlanga, N.C.; Modi, A.T.; Mathew, I. Evaluating nutritional content among bambara groundnut lines. *J. Food Compos. Anal.* **2021**, *102*, 104053. [CrossRef]
14. Khan, M.M.H.; Rafii, M.Y.; Ramlee, S.I.; Jusoh, M.; Mamun, M.A. Genetic analysis and selection of bambara groundnut (*Vigna subterranea* [L.] Verdc.) landraces for high yield revealed by qualitative and quantitative traits. *Sci. Rep.* **2021**, *11*, 7597. [CrossRef]
15. Minnaar-Ontong, A.; Gerrano, A.S.; Labuschagne, M.T. Assessment of genetic diversity and structure of bambara groundnut [*Vigna subterranea* (L.) verdc.] landraces in South Africa. *Sci. Rep.* **2021**, *11*, 7408. [CrossRef]
16. Uba, C.U.; Oselebe, H.O.; Tesfaye, A.A.; Abtew, W.G. Genetic diversity and population structure analysis of bambara groundnut (*Vigna subterrenea* L) landraces using DArT SNP markers. *PLoS ONE* **2021**, *16*, e0253600. [CrossRef]
17. Upadhyaya, H.D.; Ortiz, R. A mini core subset for capturing diversity and promoting utilization of chickpea genetic resources in crop improvement. *Theor. Appl. Genet.* **2001**, *102*, 1292–1298. [CrossRef]
18. Hornakova, O.; Zavodna, M.; Zakova, M.; Kraic, J.; Frantisek, D. Diversity of common bean landraces collected in the Western and Eastern Carpatien. *Czech J. Genet. Plant Breed.* **2003**, *39*, 73–83. [CrossRef]
19. Upadhyaya, H.D.; Kashiwagi, J.; Varshney, R.K.; Gaur, P.M.; Saxena, K.B.; Krishnamurthy, L.; Gowda, C.L.L.; Pundir, R.P.S.; Chaturvedi, S.K.; Basu, P.S.; et al. Phenotyping chickpeas and pigeon peas for adaptation to drought. *Front. Physiol.* **2012**, *3*, 179. [CrossRef]
20. Maisela, R.J. Realizing Agricultural Potential in Land Reform: The Case of Vaalharts Irrigation Scheme in the Northern Cape Province. Master's Thesis, University of the Western Cape, Cape Town, South Africa, 2007.
21. Unigwe, A.E.; Gerrano, A.S.; Adebola, P.; Pillay, M. Morphological variation in selected accessions of bambara groundnut (*Vigna subterranea* L. Verdc) in South Africa. *J. Agric. Sci.* **2016**, *8*, 69. [CrossRef]
22. Mabhaudhi, T.; Modi, A.T. Growth, phenological and yield responses of a bambara groundnut (*Vigna subterranea* (L.) Verdc.) landrace to imposed water stress under field conditions. *S. Afr. J. Plant Soil* **2013**, *30*, 69–79. [CrossRef]
23. Adeyemo, J.; Otieno, F.; Ojo, O. Analysis of temperature and rainfall trends in Vaal-Harts Irrigation Scheme, South Africa. *Am. J. Eng. Res* **2014**, *3*, 265–269.
24. PGRI/IITA/BAMNET. *Descriptors for Bambara Groundnut (Vigna subterranea)*; International Plant Genetic Resources Institute: Rome, Italy, 2000.
25. AGROBASE. *Generation II SQL,* Version 38; Agronomix Software Inc.: Winnipeg, MB, Canada, 2019.
26. Shimelis, H.; Shiringani, R. Variance components and heritabilities of yield and agronomic traits among cowpea genotypes. *Euphytica* **2010**, *173*, 383–389. [CrossRef]
27. R Core Team. *A Language and Environment for Statistical Computing*; R Foundation for Statistical Computing: Viena, Austria, 2020; Available online: http://www.R-project.org/ (accessed on 8 November 2020).
28. Ntundu, W.H.; Shillah, S.A.; Marandu, W.Y.F.; Christiansen, J.L. Morphological diversity of bambara groundnut [*Vigna subterranea* (L.) Verdc.] landraces in Tanzania. *Crop Evol. Genet. Resour. Crop Evol.* **2006**, *53*, 367–378. [CrossRef]
29. Falconer, D.S.; Mackay, T.F.C. *Introduction to Quantitative Genetics*, 4th ed.; Longmans Group: Harlow, UK, 1996; pp. 1–376.
30. Abu, H.B.; Saaka, S. Characterization of bambara groundnut landraces and their evaluation by farmers in the Upper West Region of Ghana. *Int. J. Agric. Sustain.* **2011**, *6*, 64–74. [CrossRef]
31. Karikari, S.K. Variability between local and exotic bambara groundnut landraces in Botswana. *Afr. Crop Sci. J.* **2000**, *8*, 145–152. [CrossRef]

32. Chijioke, O.B.; Ifeanyi, U.M.; Blessing, A.C. Comparative study on growth and development of some accessions of local germplasm of bambara groundnut (*Vigna subterrenea* L. Verdc.) of Nigeria in two cropping seasons. *J. Crop Sci. Biotechnol.* **2010**, *13*, 21–27. [CrossRef]
33. Onwubiko, N.I.C.; Odum, O.B.; Utazi, C.O.; Poly-Mbah, P.C. Studies on the adaptation of bambara groundnut [*Vigna subterranea* (L.) Verdc] in Owerri South-eastern Nigeria. *Agric. J.* **2011**, *4*, 60–65. [CrossRef]
34. Amadou, H.I.; Doumma, A.; Katsileros, A.; Zoubeirou, A.M.; Nourou, S.S.M. Agro-morphological variability in fourteen bambara groundnut (*Vigna subterranean* (L.) Verdc.) morphotypes cultivated in Niger. *SAJB* **2015**, *3*, 774–781.
35. Benoît, K.B.; Gonné, S.; Félix-Alain, W. Assessment of twenty bambara groundnut (*Vigna subterranea* (L.) Verdcourt) landraces using quantitative morphological traits. *Int. J. Plant Res.* **2013**, *3*, 39–45. [CrossRef]
36. Musa, M.; Massawe, F.; Mayes, S.; Alshareef, I.; Singh, A. Nitrogen fixation and N-balance studies on bambara groundnut (*Vigna subterranea* L. Verdc) landraces grown on tropical acidic soils of Malaysia. *Commun. Soil Sci. Plant Anal.* **2016**, *47*, 533–542. [CrossRef]
37. Temegne, N.C.; Taffouo, V.D.; Tadoh, T.C.; Gouertoumbo, W.F.; Wakem, G.A.; Nkou, F.T.D.; Nuemsi, P.P.K.; Youmbi, E. Effect of phosphate fertilization on growth, yield and seed phosphorus content of bambara pea (*Vigna subterranea*) land races. *J. Anim. Plant Sci.* **2019**, *29*, 703–713.
38. Atoyebi, J.O.; Oyatomi, O.; Osilesi, O.; Adebawo, O.; Abberton, M. Morphological characterisation of selected African accessions of bambara groundnut (*Vigna subterranea* (L.) Verdc.). *Int. J. Plant Res.* **2017**, *7*, 29–35. [CrossRef]