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Research Paper

Diversity for growth, development and yield potentials among Bambara groundnut (*Vigna subterranea* L Verdc) landraces for advancing food security in Ghana

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Abstract. The dependence on low-yield landraces and inadequate improved agronomic practices have contributed to the existing yield gap of crops. Diversifying crop species to include high-yielding and drought tolerant but underutilized crops and integrating them into cropping systems is an alternate means of addressing food insecurity. A major concern of farmers is the low and unstable yield output which requires the development of yield improvement technologies for enhanced Bambara production. A field trial was conducted at the Council for Scientific and Industrial Research – Crops Research Institute (CSIR-CRI), over two growing seasons to determine the phenological and agronomic variation between eight bambara groundnut landraces, to identify landraces with productive and superior agronomic characteristics. The study utilized a randomized complete block design with three replications. The phenological (days to 50% flowering, days to physiological maturity and plant height) and yield (number of pods per plant, hundred seed weight, pod yield and dry matter) attributes were evaluated and showed substantial variations. The landraces Nav Red and Uniswa Red had the best pod yields of 1,672 and 1,640 kg ha^{-1} respectively in 2018. The landrace Nav Red stood out with superior development and yield qualities such as the number of pods per plant, hundred seed weight and dry pod yield. The research demonstrated that highly diverse populations with wide variability for maturity time could be subjected to routine selection for grain yield with a high degree of certainty. Also, genotypes with the highest grain yield are not necessarily those with the highest dry matter yields.

Keywords: Agronomic performance, morphology and phenology, landrace, pod yield.

INTRODUCTION

Bambara groundnut (*Vigna subterranea* L. Verdc.) is an underutilized legume crop that possesses wider genetic variability (Khan *et al*. 2020). The crop is adapted to a wide range of environments and is considered to be the third most important legume crop in Africa for food security. Its potential remains largely undiscovered (Mayes *et al.*, 2019), though it has been recognized as being endowed with numerous valuable traits such as efficient utilization of resources such as solar radiation and soil moisture (Muhammad *et al*., 2020). It has the potential to contribute to food and nutrition security in view of its ability to tolerate drought and acts as a nutritional complement to cereals (Tan *et al*., 2020). In spite of these attributes, bambara has not received much research attention as other leguminous crops such as groundnut and cowpea.

The productivity of bambara groundnut remains low compared with other leguminous crops. Mostly in Africa, locally adapted landraces of bambara groundnut are the most widely cultivated, in the absence of improved or released varieties (Muhammad *et al.*, 2020). However, each of these landraces has limitations in terms of its requirements such as specific soils, climate and manage-

Table 1. The landraces, seed colour and their country of origin used for the study.

	Landrace	Seed colour	Area of origin
1	Nav 4	Cream	Ghana
2	SI9- 3	Black	Namibia
3	TIGA-NECARU	Cream	Mali
4	Bolga Red	Red	Ghana
5	Burkina	White	Burkina
6	Nav Red	Red	Ghana
7	Kenya Capstone -1	Mottled black	Kenya
8	Mottled Cream	Cream with mottled red	Ghana

ment practices, and also in terms of agronomic performance (Chimonyo *et al.*, 2020). Thus, the choice of genotypes of bambara groundnut is based on its adaptation to these factors or their combination. Having in mind that the full expression of the genetic potentials of the crop is greatly influenced by the major abiotic stresses such as drought and heat (Kendabie *et al.*, 2020).

The existence of a wider genetic variability among bambara cultivars means that the morphological features of bambara groundnut can be utilized for its genetic improvement upon classification into homogenous seed material. Generally, the magnitude of the genetic diversity can be used to harness the huge repository of indigenous landraces cultivated and conserved by smallholder farmers for generations across variable climates in Ghana. However, the low productivity of bambara groundnut in farmer fields can be explained by the lack of improved varieties and inadequate knowledge of reproductive biology, genetics and quality traits (Ibrahim *et al*., 2018).

Bambara groundnut is perceived to be more tolerant to drought conditions than any other legumes (Mayes *et al*., 2019). However, the growth, development and yield of bambara are reduced under contrasting environmental conditions (Collinson *et al*., 1997). For this reason, quantification of reduction in growth and yield of bambara groundnut landraces under varied growing conditions is essential to screen for high yielding landraces.

More specifically, the impact of climate variability on yields and suitability of bambara groundnut is marked by the low productivity in Ghana. It is reported by Chaplin-Kramer and George (2013) that, increasing variability in seasonal temperature and precipitation patterns do not only influence crop productivity, but also the growing season length and phenology of the crop. For these reasons, focused research on manipulating management practices such as the selection of genotypes for a specific environment to achieve the highest economic returns is imperative. Unfortunately, limited attempts have been made in harnessing the full potentials of underutilized crops such as bambara for which literature is sparse.

To explore the potential growth and development of bambara groundnut landraces in various agro-ecological zones and to evaluate the possibilities of transferring them to different locations, it is vital to understand how growth processes are influenced by environmental factors. The objective of this study was to evaluate the genetic variations among eight genotypes of bambara groundnut collections from nine geographical zones using agro-morphology and phenology to classify and identify unique germplasm and analyze the association among agronomic traits with yield parameters.

MATERIALS AND METHODS

Experimental site

The experiment was conducted in the 2017 and 2018 major rainfall seasons at the Council for Scientific and Industrial Research – Crops Research Institute (CSIR-CRI) experimental field at Fumesua (6°45 00.58′ N; 1°31 51.28′ W) in the semi-deciduous forest zone of Ghana. The soil type is Ferric Acrisol with low fertility and moisture retention capacity. This study site is characterized by a major cropping season between March and mid-August, followed by a minor cropping season with moderate rains from September to November. The average long-term maximum and minimum temperatures ranged from 20 to 32°C. Relative humidity is high in the morning and drops in the afternoons with a daily average of 85%.

Plant materials

Eight (8) landraces of the bambara groundnut were used for the field experiment (Table 1). These landraces were obtained from Crops for the Future Research Centre (CFFRC) in Malaysia as well as the various national research and development programs of Namibia, Burkina Faso, Kenya and Mali. The collections from Ghana were local landraces sourced from farmers who cultivate the crop across the country.

Experimental design

Each of the landraces was sown in an eight-row plot of 3.5 m × 5.0 m and spaced at 50 cm x 20 cm in a randomized

Table 2. Physical and chemical properties of soils of the experimental site.

Soil properties	Soil depth (cm) – 0-20	
	2017	2018
pH (1:2.5)	5.59	5.65
Organic carbon (%)	1.21	1.02
Total Nitrogen (%)	0.11	0.08
Available P (ppm)	14.6	12.3
Organic Matter (%)	2.09	1.76
Exchangeable cation (cmol/kg^{-1})		
Calcium	4.26	4.9
Magnesium	2.13	1.7
Potassium	0.35	0.25
Sodium	0.16	0.14
T.E.B	6.9	6.99
Ex. Acidity	0.6	0.55
ECEC (cmolc kg^{-1})	7.5	7.54
% Base Saturation	92	92.71
% Sand	86	84
% Silt	8	13
% Clay	6	3
Texture	Loamy sand	Loamy sand

complete block design with three replications. The experiment was carried out during the 2017 and 2018 major rainfall seasons. Land preparation involved complete soil inversion using disc-plough and disc-harrow. Missing stands were replaced within two weeks after sowing. Due to the incidence of leaf spot and *Fusarium* wilt, Mancozeb was sprayed at 200 ml ha^{-1}. Inorganic fertilizer was applied using the side placement method at 60-25-25 N-P_2O_5-K_2O kg ha^{-1} three weeks after sowing. Two hand weedings were carried out at 14 and 35 days after sowing for weed control.

Soil sampling and measurements

Composite soil samples were collected from the experimental field to analyze for the physicochemical properties of the soil at the start of the experiment. Mixed soil samples were collected using an auger at 0-20 cm depth from randomly selected positions of the field to provide baseline soil data. Each soil sample was air-dried, ground, passed through a 2 mm sieve to remove stones and analyzed for soil organic matter, pH, available P, available N and available K content (Table 2). Using routine analytical methods (Nelson and Sommers, 1975), soil pH was measured in a soil-to-water suspension ratio of 1:1, available N (AN) was determined by Alkali N proliferation method, available P (AP) and available K (AK) were determined by the molybdate blue and flame photometry methods, respectively. The hydrometer method was used to determine the texture of the soils.

Plant parameters

Data on the following phenological and morphological traits were recorded from all landraces for each year. Four inner rows were harvested to determine the yield. The day of sowing was considered as day zero in all the phenological data taken. Six plant samples were randomly selected and tagged to record the data of crop growth parameters such as number of leaves, number of branches, plant height (cm), leaf area (cm^2). Trifoliate leaves had been counted as a single leaf. Seedlings' emergence was recorded in two rows per plot from the date of sowing until the 21st day after sowing (DAS). Plant height was determined by measuring the distance from the soil surface to the tip of the leaf. Similarly, yield parameters such as pod diameter (cm), pod length (cm), number of fresh pods and yield of the fresh pod (g) were recorded at the time of harvest. Pod diameter was measured using a Vernier caliper.

After removing the pods from the harvested plants from the four inner rows, the leaves and the roots were removed and the remaining plant material was weighed and recorded as plant weight. In order to determine the moisture content of each lot of haulm, a sub-sample of the haulm was taken from each treatment, weighed and oven-

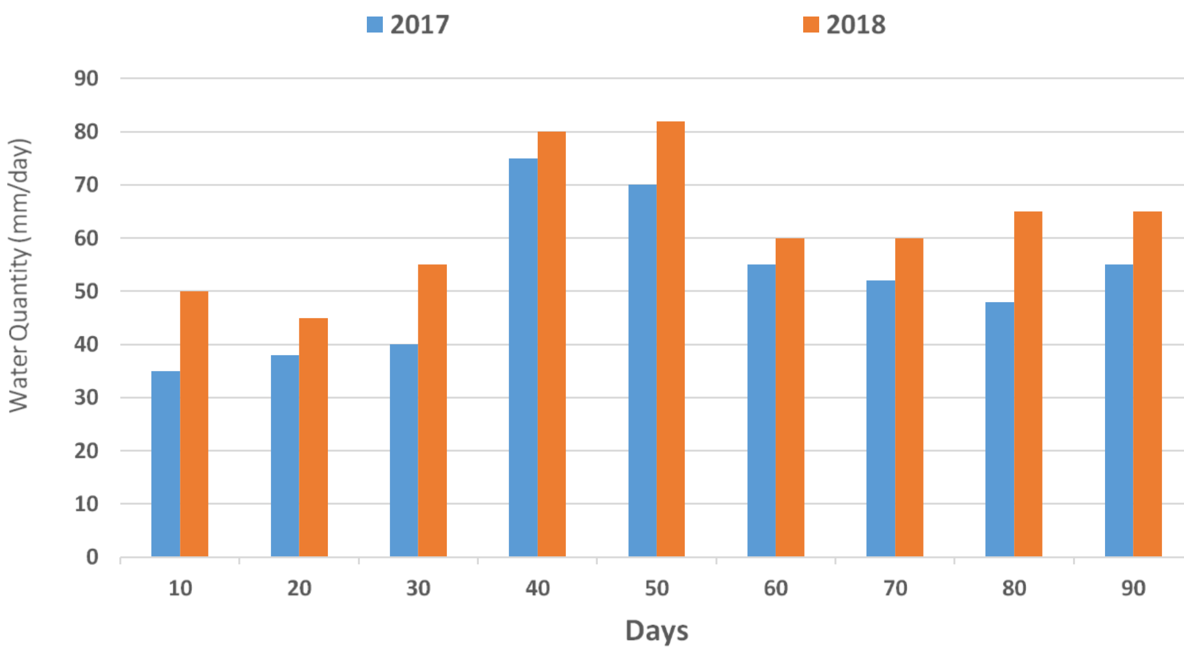

Figure 1. Rainfall distribution at Fumesua between September and December 2017 and 2018, when the study was conducted (CSIR-CRI, 2018).

dried at 60°C to a constant weight. The percent moisture content of the sub-sample and the field weight of the bulk haulm were used to calculate the dry weight of the bulk haulm.

Pod and seed harvest indices were calculated with Equations 1 and 2 as follows:

$$\text{Pod harvest index (PHI)} = \frac{\text{Total pod yield}}{\text{Total dry matter yield}} \quad (1)$$

$$\text{Seed Harvest Index (SHI)} = \frac{\text{Total seed yield}}{\text{Total dry matter yield}} \quad (2)$$

Statistical analysis

Data were subjected to Analysis of Variance (ANOVA) test for randomized complete block design with a probability level of 5% ($P \leq 0.05$) using GenStat Statistical Software (GenStat, 2007). Differences between the means were determined using the Standard Error of Difference (SED).

RESULTS

Soil properties at the study site

The result of the physical and chemical analysis of the soil in 2017 and 2018 is shown in Table 2. The soil was sandy and moderately acidic. The values of total nitrogen, available phosphorus, and potassium of the experimental soil were below the critical values of soil for legume production in Ghana.

Precipitation trend

The total annual precipitation recorded increased from 1448 mm in 2017 to 1469 mm in 2018 (Figure 1). The 2017 crop suffered short dry spells, particularly, during the reproductive phase. The area experienced a mean minimum and maximum temperatures of 21 and 31°C respectively.

Landraces differences in phenological traits of Bambara groundnut in 2017 and 2018 cropping seasons

The data results on the mean performance of the 8 genotypes on days to seedling emergence are recorded in Table 4, which indicated that genotypes showed a significant difference in both years. The data, however, showed no significant interaction between genotypes and season (Table 4). Days to 50% emergence ranged between 8 to 14 and 9 to 14 days for 2018 and 2017, respectively. The highest seedling emergence days were observed for genotypes *Burkina, Gresik, Cream with Mottled Eye, Mottled Cream, Zebra, Nav Red* and *Tiga Necuru*. Among these genotypes, *Bolga Red, Mottled Brown* and *Techiman Brown* presented the lowest mean emergence time.

Genotype and season showed no interactive effect for days to 50% flowering (Table 3). Thus, seasons were relatively stable for days to mid-flowering. However, significant differences were observed among the genotypes in days to 50 % flowering, which ranged from

Table 3. The influence of Genotype (G) and Season (S) and their interaction (G*S) on the phenology and yield performance of bambara groundnut genotypes

Source	Df	Emergence	Mid-flowering	Maturity	Plant height	No. of pods/plant	100 seed weight	Pod yield	Dry matter	Harvest index
Genotype (G)	7	30.08**	72.8**	366.3**	13.17**	112.48**	87.85**	667.7**	11.67**	15.95**
Season (S)	1	7.11	4.45	8.14**	7.53*	1364.7**	1116.07**	4359.0**	11.35*	48.95**
G * S	7	2.03	1.75	0.44	1.88	10.79**	5.91**	28.15**	1.28	1.80

39 to 41 and 39 to 44 days after sowing (DAS) for the 2017 and 2018 seasons, respectively. In terms of the mean days to mid-flowering, the best genotypes to flowers early were *Burkina* and *Nav 4.*

The analysis showed that Bambara groundnut landrace's maturity days were significantly ($P<0.05$) affected by season, landraces but not significant for genotype x season interaction (Table 3). The significance of genotype indicated that the relative performance of genotypes for days to 50% maturity was not consistent for all genotypes. This variability made it possible to identify early genotypes with short crop cycles (3 months), Genotypes *Bolga red, Burkina, Mottled Cream, Mottled Brown* and *Cream with mottled eye* significantly reached physiological maturity earlier than other genotypes and were classified as early maturing (<100 days). The local genotypes had a similar maturity period, however, matured much earlier than the foreign "Kenya Capstone" and "Uniswa Red". Averaged across the years, Uniswa Red matured 20 days later than local genotype Bolga Red.

Table 3 presents the interaction between genotype and season on plant height of bambara groundnut. The results show that the interaction between genotype and season was not significantly different for plant height. However, significant differences between the bambara groundnut genotypes for plant height were observed (Figure 2). The plant height recorded in this study ranged from 16 cm to 26 cm. Genotypes *IITA 686* and *Kenya Capstone* showed good plant height performance, which is valuable for resource capture and dry matter accumulation for dual-purpose cultivars. Growth performances of the genotypes were generally better in terms of plant height and leaf area development in the 2018 season than in 2017 (Table 4).

Genotype differences in yield and yield parameters of bambara groundnut in 2017 and 2018 cropping seasons

Season and genotype had significant effects on the number of pods per plant. The interaction between season and genotype was also significant. In 2018, the number of pods per plant was higher than in 2017 (Table 5). In both seasons, the number of pod yield per plant from *Nav Red* was significantly higher than that of the other genotypes and increased by 48.2 % over the low pod producing genotype "*Ankpa*". A major capacity to use assimilates for reserve structures may therefore exist in the latter genotypes. *Burkina, Nav-4, Nav Red, S19-3, Uniswa Red* and *Techiman Brown* consistently produced pods per plant exceeding the average mean in both seasons.

Our study showed significant differences in pod yield between the eight bambara groundnut genotypes (Table 6) over the two seasons. Pod yield increased significantly in 2018 over 2017, with *Nav Red* recording yield increase of 16.6 % and 12.1% over Mottled Cream in 2018 and 2017 respectively (Table 6). The genotypes showed wide variability for pod yield. The local genotype "*Nav Red*" had pod yield similar to that of "*Uniswa Red*" in both years. The growing season had a significant effect on the growth and development of the bambara groundnut genotypes in the two seasons.

Further, the analysis of the 100-seed weight among the eight bambara genotypes (Table 5) showed that Nav Red recorded the highest hundred seed weight (65 and 56g), representing 21 and 25% seed weight increase over *Mottled Cream* in 2018 and 2017, respectively. The data results on the effect of interaction between genotype and season on 100 seed weight are presented in Table 5. The result also demonstrated the effect of season on seed development of bambara groundnut genotypes, depicting considerable variability between the eight genotypes studied.

Season and genotype had significant effects on the dry matter performance of the eight bambara groundnut genotypes (Table 6). The interaction between season and genotype was also significant. Kenya Capstone produced the highest dry matter (3580 and 3430 kg ha^{-1}) while Mottled Cream produced the lowest dry matter (1950 and 2077 kg ha^{-1}) in 2018 and 2017, respectively. Moreover, the interaction effect between season and genotype on dry matter attribute of Kenya Capstone was significantly superior over the other genotypes.

Significant differences were observed in the harvest index of the bambara groundnut genotypes studied (Table 6). The harvest index of the genotypes decreased with decreasing dry matter content. The highest harvest index was obtained

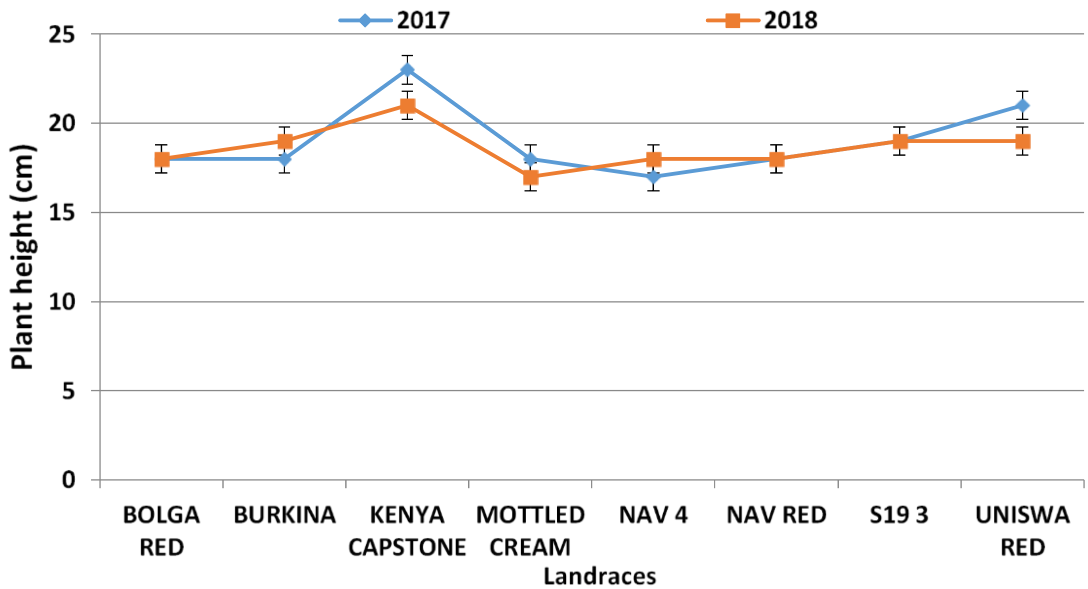

Figure 2. Variations among bambara groundnut genotypes for Plant height at Fumesua at flowering stage.

Table 4. Combined means for phenological traits of eight bambara groundnut genotypes in 2017 and 2018 seasons.

Genotype	Days to emergence		Days to 50% flowering		Days to maturity	
	2018	2017	2018	2017	2018	2017
Bolga Red	9	10	40	40	98	99
Burkina	14	14	39	39	99	100
Kenya Capstone	10	11	45	44	116	116
Mottled Cream	10	10	39	39	98	99
Nav 4	10	10	39	39	101	102
Nav Red	13	14	41	40	100	102
S19-3	12	11	44	44	109	111
Uniswa Red	11	11	43	43	118	118
Mean	11	12	41	41	105	106
SED (Genotype, G)	0.3		0.3		0.6	
SED (Season, S)	0.2		0.2		0.3	
SED (G x S)	0.5		0.5		0.9	

from genotype *Mottled Cream* (71.5 and 63.9) in the 2018 and 2017 respectively, while the lowest harvest index was obtained from *Kenya Capstone* (43.7%) and (35.9%) in 2017 and 2018, respectively.

DISCUSSION

The sampled soils showed low levels of N and available P as well as exchangeable calcium and magnesium-based on soil testing interpretation manual by Landon (2014). While the variability in N content of the soil among the two depths remained relatively low, the difference in available P was also found to be low. Available potassium and organic carbon levels were below the critical values required for the proper growth and development of legumes (Aune and Lai, 1995).

The genetic resources of a crop depict a valuable source of genetic diversity that is fundamentally helpful in current and future breeding programs (Bhandari *et al*., 2017). For a successful improvement of bambara groundnut, the availability of genetic resources and the extent of genetic variations play a significant role. Variability was observed in the phenological traits of the bambara groundnut genotypes used in this experiment. The results from this study showed wide variations for all studied characters and indicate the existence of considerable diversity.

The observed variations in days to seedling emergence

Table 5. Variation among bambara groundnut genotypes for the number of pods per plant and hundred seed weight in 2017 and 2018 at Fumesua.

Genotype	Number of pods per plant		100 seed weight (g)	
	2018	2017	2018	2017
Bolga Red	47	23	60	51
Burkina	41	24	58	50
Kenya Capstone	38	28	58	46
Mottled Cream	34	19	51	42
Nav 4	40	25	57	44
Nav Red	53	35	65	56
S19-3	40	24	54	41
Uniswa Red	54	34	55	45
Mean	43	27	57	47
SED (Genotype)	0.9		0.7	
SED (Season)	0.4		0.3	
SED (G x S)	1.2		0.9	

Table 6. Variation among bambara groundnut genotypes for pod yield, dry matter and harvest index in 2017 and 2018 at Fumesua.

Genotype	Pod yield (kg)		Dry matter (kg)		Harvest index	
	2018	2017	2018	2017	2018	2017
Bolga Red	1523	1328	2880	2823	52.9	47.1
Burkina	1537	1369	2640	2653	58.6	52.2
Kenya Capstone	1493	1284	3430	3580	43.7	35.9
Mottled Cream	1394	1270	1950	2077	71.5	63.6
Nav 4	1443	1313	2453	2735	58.9	63.5
Nav Red	1672	1445	2553	3013	65.6	48.2
S19-3	1455	1287	2603	3200	56.0	48.0
Uniswa Red	1640	1408	2388	3220	68.7	44.6
Mean	1520	1338	2617	2913	59.5	47.7
SED (Genotype)	147.7		3.13		0.5	
SED (Season)	87.3		1.57		0.3	
SED (G x S)	247		4.43		0.8	

indicate a high level of heterogeneity in genotypes of bambara. Diversity in seedling emergence in bambara has been reported by Berchie *et al*. (2010) and showed a high level of susceptibility to seasonal variabilities (Daws *et al*., 2008). Days to emergence were influenced by complex interactions between genetic traits on individual genotypes and prevailing micro-site conditions, which have not been measured at the various collection locations for this study. In spite of this, available results from this study suggested that the differences in the days to emergence were because of the variations in the response of individual genotypes to these environmental factors such as light quantity/ quality and temperature, an observation that has been confirmed by De Souza *et al*. (2020). The variability of response between the genotypes in terms of emergence appears to indicate that the seeds are inconsistent when it comes to germination quality, which is probably due to their health, physiological condition and size.

Flowering is an important trait when evaluating genotypes for adaptation and selection for drought tolerance. Variability in days to flowering observed among the genotypes indicates a high level of heterogeneity in bambara groundnut. The variations observed in this study agree with Weller and Ortega (2015) who reported significant and wide variation for days to flowering in bambara germplasm. For purposes of crop improvement, different genotypes require exposure to specific photoperiods and/or temperatures to flower and flowering may be significantly delayed or prevented if these requirements are not met. The identified early flowering genotypes from this study could be utilized by breeders as parent materials for hybridization in bambara groundnut and develop early flowering varieties

Earliness with regards to maturity is a trait of major importance in the breeding of bambara groundnut and this in a way, influences the expectations in meeting production targets by escaping drought and producing reasonable yield. The variability in this parameter has been used to identify early genotypes with short crop cycles (< 4 months). The present results identified *Bolga Red* and *Mottled Cream* as early maturing (<100 days) bambara genotypes. Likewise, Redjeki *et al*. (2013) reported an average of 123 DAS for S19-3 bambara genotypes. In the sub-tropics, the phenomenon of developing early maturing varieties has been used to escape terminal heat and drought and increase the crop`s adaptation to changes in the environment (Shavrukov *et al*., 2017). The observed variability could be partly due to the inherent genetic constituents of the plants as well as the delay in formation and translocation of assimilates resulting from water deficit. The identified early maturing genotypes with reasonable yield traits could be exploited for the development of early maturing bambara varieties. This will contribute enormously to the promotion of bambara as a food security crop in the region, particularly during the short rainy seasons.

The performance of legume crops including bambara groundnut can mostly be determined by the number of filled pods per plant (Tesfamichael *et al.*, 2015). The problem of low yields in bambara groundnut could be linked to the poor development of pods in quantity and weight. The idea of enhancing flower development and escaping drought during flowering are all pathways to promoting pod development. The pod per plant attribute of any crop has been described as the single most important selection criteria to increase crop yield and directly established a significant correlation between grain yield and the number of pod loads (Bos and Caligari, 1995). The variations in the number of pods per plant among these genotypes are in line with findings of Tesfamichael *et al*. (2015) and Berchie *et al*. (2010). The observed variations could partly be assigned to the genotypic difference in the number of pods and size; which demonstrates the potential of the evaluated bambara genotypes to develop high-yielding varieties for specific and broad adaptation.

A wider genetic variation in hundred seed weight contributes significantly as a selection criterion for increased yield prospect of bambara groundnut. The comparably abundant genetic diversity in the eight bambara groundnut genotypes for hundred seed weight was primarily due to different seed sizes of the individual genotypes and aligns with the results of Masindeni (2006). This trait may largely reflect the different amounts of seed reserves. Clearly, in large seeds, other factors such as the ability to translocate or utilize the reserves may become limiting; this may have been the case in most of the genotypes with hundred seed weight below 40 g. In Khan *et al.* (2020) however, variations in hundred seed weight were attributed to genotype by environment (G × E) effect. In the present study, the large variations in hundred seed weight correspond with Berchie *et al*. (2010).

According to Valombola *et al.* (2019), bambara groundnut showed higher genetic diversity among genotypes and confirms this study where wider genetic variability was identified among the eight bambara genotypes. However, the growth and yield variability observed for genotypes of bambara groundnut were influenced by season. Limited studies of the yield variability of Bambara landraces have been conducted in Ghana (Berchie *et al*., 2010). In the current research, a wider variability in growth and yield was found among the “local” and “exotic” genotypes. The observed significant differences indicate a wider genetic variation among the Bambara groundnut genotypes for the variables studied. Invariably, these observed differences may be attributed to the genetic potentials (Mohammed, 2014) and favorable season of growth (Khan *et al*., 2020). These variations in the crop’s yield components imply that there is variability among the Bambara groundnut genotypes in terms of their yield potential, which corroborates with the findings of Valombola *et al*. (2019). Yield losses are estimated at 57% in bambara groundnut (Mahalakshmi *et al*., 1987); and are partly affected by multiple factors, thus, necessitating breeding programs to emphasize mainly the improvement of individual traits known as yield components or yield-related traits such as number of seeds per pod, seed weight, and the number of pods per plant among several others.

Relevant observation of high variation for the dry matter was confirmed by Goli *et al*. (1997) and indicates the existence of a massive heterogeneity among the genotypes recorded. The dry matter yield of the late-maturing bambara groundnut landraces was higher than the dry matter yield of the early maturing genotypes in this study. This means that there is a shift in assimilates distribution which is directed towards an increase in height and this partitioning of assimilates tends to be greater under a longer growth period. This result is similar to that of Brown, (1984) who reported that the importance of vegetative growth is simply to produce large photosynthetic factories to obtain maximum growth.

The harvest index varied between bambara groundnut genotypes and ranged from 35 to 71.5% in both years. In most grain legumes, variable harvest indices have been a major determinant of yield instability among them. Moot (1993) and Anwar *et al.* (1999) reported a high degree of harvest index in grain legumes, which varied from 0 to 74%. In high-yielding pea crops, 95% of plants had a plant harvest index (PHI) from 0 to 70% while in low-yielding genotypes PHI varied between 0 and 70% (Ambrose and Hedley, 1984). In this study, the harvest index was variable with the Mottled Cream genotype recording the greatest HI. In fact, yield variability is a global problem in bambara groundnut, a phenomenon that has been generally identified as the cause for low yields in legumes (Hedley and Ambrose, 1985). Lack of increase in harvest index in some genotypes with increasing dry matter production may have been due to partitioning efficiency which seems to be higher at maturity in some genotypes than others. Harvest index of Mottled Cream (71.5%) at maturity of 98 DAS was greater than Kenya Capstone (43%) at maturity of 116 DAS. The observed variation in harvest index may partly be due to the conversion of a higher proportion of the dry matter of the Mottled cream genotype to seed than in high dry matter producing genotypes and consequently given a higher harvest index as Moot (1993) reported in different pea genotypes.

The seed yield and harvest index of the eight genotypes were highly variable. For some genotypes (*Kenyan Capstone*), high dry matter production often resulted in poor seed yields, which is in line with similar findings by Gomoung *et al.* (2017). As mentioned earlier, the performance of these genotypes was not consistent under different planting seasons. The challenge, however, is to identify these genotypes with stable and high harvest index in the selection. For a greater availability and release of improved bambara groundnut variety that meets the demands of farmers and consumers, characterization of genotypes is imperative and must include an evaluation of introduced accessions towards the selection of superior genotypes. Categorization of these genotypes into high-yielding and maturity groups using phenological and morphological traits is the single most important step towards crop improvement. Some of these traits including the number of pods per plant and hundred seed weight are of commercial importance and have been used as selection criteria by farmers in the choice of promising varieties.

CONCLUSION

The eight genotypes exhibited differences in days to flowering and maturity, number of pods per plant, pod yield and biomass. The observed variations provide an understanding of the agronomic potentials for use as a pre-breeding tool in the development of ideotype varieties with desirable phenotypic traits, that is, early flowering days, hundred seed weight, short life cycle and high harvest index. The yield potentials of bambara groundnut genotypes derived from different geographical locations (*Uniswa Red* and *S19-3*) compares favorably with local genotype *Nav Red* in terms of growth and yield attributes is suggest having positive competition for assimilating between vegetative development and yield accumulation. The results show that *Nav Red* genotype combines desirable growth and yield traits with the potential to enhance bambara groundnut development which can be exploited for future breeding programmes of bambara groundnut in the region.

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REFERENCES

Ambrose ML, Hedley CL (1984). A population study to aid the selection of improved dried pea (*Pisum sativum*) crop plants. Ann. Bot. 53:655-662.

Anwar MR, McKenzie BA, Hill GD (1999). Water use efficiency of chickpea (*Cicer arietinum* L.) cultivars in Canterbury: effect of irrigation and sowing date. Agron. New Zealand 29:1-8.

Aune JB, Lai R (1995). The Tropical Soil Productivity Calculator-a Model for Assessing Effects of Soil Management Ion Productivity. In: Soil Management Experimental Basis for Sustainability and Environmental Quality, Lai, R. and B.A. Stewart (Eds.). Chapter 17, Lewis Publishers, Boca Raton, FL., USA. ISBN-13: 9781566700764, pp. 499-520.

Berchie JN, Sarkodie-Addo J, Adu-Dapaah H, Agyemang A, Addy S, Asare E, Donkor J (2010). Yield evaluation of three early maturing Bambara groundnut (*Vigna subterranea* L. Verdc) landraces at the CSIR-Crops Research Institute, Fumesua Kumasi, Ghana. J. Agron. 9:175-179.

Bhandari HR, Bhanu AN, Srivastava K (2017). Assessment of genetic diversity in crop plants - an overview. Adv. Plants Agric. Res. 7(3):279-286. doi:10.15406/apar.2017.07.00255.

Bos I, Caligari P (1995). Selection Methods in Plant Breeding. Published by *Chapman and Hall*, 2-6 Boundary Row, London, SE1 8HN, UK.

Brown RH (1984). Growth of the Green Plant. In Physiological Bases of Crop Growth and Development. *American Society of Agronomy*. Crop Science Society of America. Madison, Wisansin. pp. 153-173.

Chaplin-Kramer R, George MR (2013). Effects of Climate Change on Range Forage Production in the San Francisco Bay Area. *PLoS ONE* 8(3): e57723. https://doi.org/10.1371/journal.pone.0057723.

Chimonyo VGP, Wimalasiri EM, Kunz R, Modi AT, Mabhaudhi T (2020). Optimizing Traditional Cropping Systems under Climate Change: A Case of Maize Landraces and Bambara Groundnut. Front. Sustain. Food Syst. 4:186.

Collinson ST, Clawson EJ, Azam-Ali SN, Black CRI (1997). Effects of soil moisture deficits on water relations of bambara groundnut (*Vigna subterranea* L. Verdc.). J. Expl. Bot. 48:877-884.

Daws MI, Crabtree LM, Dalling JW, Mullins CE, Burslem DFRP (2008). Germination responses to water potential in neotropical pioneers suggest large-seeded species take more risks. Ann. Bot. 102:945-951. [PMC free article] [PubMed].

GENSTAT (2007). GENSTAT Release 7.2DE, Discovery Edition 3, Lawes Agricultural Trust, Rothamsted Experimental station.

Goli AE, Begemann F, Ng NQ (1997). "Characterization and evaluation of IITA's Bambara groundnut collection," in Conservation and Improvement of Bambara Groundnut *(Vigna subterranea (L.) Verdc.)*, J. B. F. Heller and J. Mushonga, Eds., International Plant Genetic Resources Institute. pp. 101-118.

Gomoung D, Mbailao M, Toukam ST, Ngakou A (2017). Influence of Cross-Inoculation on Groundnut and Bambara Groundnut-Rhizobium Symbiosis: Contribution to Plant Growth and Yield in the Field at Sarh (Chad) and Ngaoundere (Cameroon). Am. J. Plant Sci. 8:1953-1966. doi: 10.4236/ajps.2017.88131.

Hedley CL, Ambrose MJ (1985). The application of plant physiology to the development of dried pea crop plants. In The Pea Crop - a basis for improvement.

Ibrahim AR, Dansi A, Salifou M (2018). Farmers' practices, utilization, conservation and marketing of Bambara groundnut (*Vigna subterranea* (L.) Verdc.) in Dosso Region, Western Niger. Genet. Resour. Crop Evol. 65:1907-1914.

Kendabie P, Jorgensen ST, Massawe F, Fernandez J, Azam-Ali S, Mayes S (2020). Photoperiod control of yield and sink capacity in Bambara groundnut (*Vigna subterranea*) genotypes. Food Energy Secur. 9:e240.

Khan MD, Mahmudul H, Mohd YR, Shairul IR, Mashitah J, Al Mamun (2020). Genetic Variability, Heritability, and Clustering Pattern

Exploration of Bambara Groundnut (*Vigna subterranea* L. Verdc) Accessions for the Perfection of Yield and Yield-Related Traits. *BioMed Research International*, 2020(2195797):31. https://doi.org/10.1155/2020/2195797.

Landon JR (2014). Booker Tropical Soil Manual: A handbook for soil survey and Agricultural Land Evaluation in the Tropics and Subtropics. *Routledge, New York. U.S.A*.

Mahalakshmi V, Bidinger FR, Raju DS (1987). Effect of Timing of Water Deficit on Pearl-Millet (*Pennisetum americanum*). Field Crops Res. 15:327-339. [CrossRef]

Masindeni MR (2006). Evaluation of Bambara groundnut (*Vigna subterranea*) for yield stability and yield related characteristics. *M.Sc. Thesis, University of the Free State*, Bloemfontein, South Africa.

Mayes S, Ho WK, Chai HH (2019). Bambara groundnut: an exemplar underutilised legume for resilience under climate change. Planta 250:803-820. https://doi.org/10.1007/s00425-019-03191-6.

Mohammed SM (2014). Pre-breeding of Bambara Groundnut (*Vigna subterranea* [L.] Verdc). A doctor of Philosophy Thesis. College of Agriculture, Engineering and Science. University of KwaZulu-Natal. Pietermaritzburg campus. South Africa.

Moot DL (1993). Harvest index variability within and between field pea (*Pisum sativum* L.) crops. PhD Thesis. Lincoln University, Canterbury, New Zealand.

Muhammad I, Rafii MY, Ramlee SI, Nazli MH, Harun AR, Oladosu Y, Musa I, Arolu F, Chukwu SC, Sani Haliru B, Silas AI, Halidu J, Arolu IW (2020). Exploration of Bambara Groundnut (*Vigna subterranea* (L.) Verdc.), an Underutilized Crop, to Aid Global Food Security: Varietal Improvement, Genetic Diversity and Processing. *Agronomy*. 10(6):766.

Redjeki ES, Mayes S, Azam-Ali S (2013). Evaluating the Stability and Adaptability of Bambara Groundnut (*Vigna subterranea* (L.) Verdc.) Landraces in Different Agro-Ecologies. Proc. 2nd Int. Symp. On Underutilized Plants Species "Crops for the Future – Beyond Food Security" Eds.: F. Massawe et al. *Acta Hort.* 979, ISHS 2013.

Shavrukov Y, Kurishbayev A, Jatayev S, Shvidchenko V, Zotova L, Koekemoer F, de Groot S, Soole K, Langridge P (2017). Early Flowering as a Drought Escape Mechanism in Plants: How Can It Aid Wheat Production? Front. Plant Sci. 8:1950. DOI 10.3389/fpls.2017.01950.

Tan XL, Azam-Ali S, Goh EV, Mustafa M, Chai HH, Ho WK, Mayes S, Mabhaudhi T, Azam-Ali S, Massawe F (2020.). Bambara Groundnut: An Underutilized Leguminous Crop for Global Food Security and Nutrition. Front. Nutr. 7:276.

Tesfamichael SM, Githiri SM, Nyende AB, Rao NVPRG (2015). Variation for Agro-Morphological Traits among Kabuli Chickpea (*Cicer arietinum* L.) Genotypes. J. Agric. Sci. 7:7. ISSN 1916-9752 E-ISSN 1916-9760. pp. 75-92.

Valombola JS, Akundabweni LM, Awala SK, Hove K (2019). Agronomic and morphological diversity of Bambara groundnut (*Vigna subterranea* (L) Verdc.) accessions in North-Central Namibia. *Wewitschia* Int. J. Agric. Sci. 1:88-99.

Weller JL, Ortega R (2015). Genetic control of flowering time in legumes. Front. Plant Sci. 6:207. http://doi.org/10.3389/fpls.2015.00207.