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RESEARCH ARTICLE

Selecting Yield and Nutritional Traits in *Sphenostylis stenocarpa* Landraces for Food Improvement

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Abstract: ***Background*:** *Sphenostylis stenocarpa* is an underexploited African indigenous food crop that is enriched in nutritional quality.

***Objective*:** Exploring the robust genetic base of this landrace can help to maximize the benefit of the agricultural sector on the economy through production that is enhanced by packaging and patent. This as well will increase the quality of food production and promote African campaign on food sustainability.

***Method*:** Upon this, this research made use of multiple statistics to identify *S. stenocarpa* yield and nutritional trait relatedness that supported selection for maximum yield and nutritional trait output. Yield and related traits including protein and oil contents of twenty-three *Sphenostylis stenocarpa* landraces were studied under a four year planting seasons in Teaching and Research farm of Landmark University, Nigeria.

***Results*:** Trait variances from Landrace × Year (L × Y) interaction, Principal Component and Cluster analyses were evaluated and the variation patterns were identified. Some vegetative (maturity phase, height and branching) and yield traits (Pod traits, seed yield and oil content) correlated significantly ($P < 0.05$) in the L × Y interactions. This suggests the usefulness of these traits in improving *S. stenocarpa* grain and oil quality yield. Tuber and nodule yield including protein content did not differ significantly in the variance table.

***Conclusion*:** The result indicates that one location trial is insufficient to determine such trait performance. The first four PCs that accounted for 51 percent of the total variations were traceable to branching, maturity date, pod numbers, seed and oil content as main contributors to yield.

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1. INTRODUCTION

The relevance of indigenous legume in securing food for the undernourished and low-income African countries is gaining prominence especially when such crops are in the list of low-cost energy- protein source [1-3]. *S. stenocarpa* is one of the rich energy-protein underutilized traditional legumes. This crop is traditionally grown in a humid environment with natural irrigation.

In recent years, the total acreage of *S. stenocarpa* production is constantly declining [4], due to lack of acceptance and restriction to production areas, as compared to other grain legumes. This limited yield has been ascribed to yield instability characterized by high inter-annual yield variation [5, 6]. This, therefore, emphasizes the need for developing a high yield stable genotypes to survive the challenges of meteorological factor fluctuations.

Cultivation under wider environments is expected to further increase yield as well as encourage acceptance even as a source of cheap protein. Detecting yield stability at various years' variation patterns is important in defining the breeding goal for valued nutrient indigenous legumes. Yield contributory factors will be considered. These factors which are edaphic (soil, moisture, temperature, drought, among others) and/or biotic (microorganisms, nitrogen fixers, among others) do have consequences upon gain or loss in yield. Some researchers identified the effect of Edaphic and non-Edaphic

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factors on the yield of Bambara groundnut [7-9]. Intentional breeding effort to develop high yielding and nutrient enhanced varieties of *S. stenocarpa* across wider ecological regions will not only make the crop popular but also increase the acceptability especially in areas where the weather environments are unstable [10, 11].

The fact, that the performance of *S. stenocarpa* is strongly influenced by environmental variations at the very least stage indicates that yearly weather variation is a barrier for improving yield potential [11]. Yearly effects of multi-environment trials are mostly used typically in plant breeding programs to evaluate the genetic materials over a range of years in a target environment [12, 13]. However, when comparing these genetic materials, their interaction with the environment can be complex in nature [14] due to differential responses across the environment. This is considered an important source of year-to-year variation in trait performance [15]. Now, the understanding of year-to-year variability effects of weather elements on landrace stability is made possible by employing statistical tools that directly test for the presence of landrace x year(s) (L x Y) and also measure individual landrace trait performance [16]. On this note, it is imperative to identify the traits with a contributory role in producing high nutrient seeds and tuber yield qualities across the year.

According to [10], the most valuable economic traits in *S. stenocarpa* are the seed, tuber and nodule (in some landraces). Yield as a trait is a function of other trait components during growth and development phases [14]. In this study, the emphasis is on *S. stenocarpa* agro-nutritional yield. The yield accumulations occur through pathways in food nutrient translocations from different sources during photosynthesis [17]. Either significant or otherwise, yield improvement strategy must identify the contributory role of other trait components to yield improvement. Some vegetative (crop shoot parts supporting branching, height, flowering and maturity date) traits play a significant role in trapping sunlight under a range of temperature and humidity before photosynthetic accumulations [18]. Crop rooting parts such as podding and seed traits are affected by soil temperature, nutrient availability and some other biotic and abiotic factors [19]. It is important, therefore, to use statistical tools that will calculate and outline yield and yield component indices leading to intentional trait selection for yield improvement.

A number of outstanding reviews of statistical selection parameters that test and measure *S. stenocarpa* genotypes' response to the varied growing environment have been published. Few among others included the studies by; [14] that investigated the impact of climate change on *Sphenostylis stenocarpa* in relation to sustainability and conservation. More so, [20] reviews the nexus among genetic resources, diversity and agronomy of African yam bean. Consequently, phenotypic, genotypic and environmental trait correlations with yield are also examined in the literature [21, 22]. It was documented by the scholars that there are significant variations of about 0.05 percent, and 0.01 percent is used to provide information on genotype performance across sources of variations in the literature. [17] considered significant variations of seed weight, plant biomass and pod filling time in *Vigna subterranean,* respectively. In addition, the outlined selection statistics were used to identify the contributory roles of traits to yield. Likewise, it is important to classify to ensure effective hybridization. The principal component (PC) and cluster (CL) analyses are veritable tools in this direction. Researchers have also explored these tools in identifying divergent cultivar groups for meaningful hybridization studies. [13] on okro; [23] and [24] on Bambara groundnut; [21] on *Chenopodium specie*s.

In studies using *S. stenocarpa*, several reports on seed genetic variability, path coefficients, correlations, morpho-seed metrics have been archived by the research efforts of [20, 25-28]. These reports are experimental, using genotypes with a limited genetic origin, planting environments as well as placing no emphasis on agro-nutritional trait selection. [4] noted that the lack of improved *S. stenocarpa* landraces restricted African farmers to rely on the existing landraces for production. This establishes the need to place emphasis on identifying desirable genotypes of *S. stenocarpa that can be* explored through hybridization to improve yield nutritional value as well as enhance yield. Testing genotypes from the origin across a wide environment will help to validate the selections for high and stable quality nutritional yield across growing environments. This information is not available when this research was carried out. Therefore, informed the niche of this study. Likewise, most African countries are regarded as low-income countries when high unemployment rate and poverty are the major macroeconomic problems [29-31]. Hence, *Sphenostylis stenocarpa* can help to improve the nutritional quality of these resource-poor countries. The Nigerian government in recent has stressed the importance of agricultural sector to promote inclusive growth. Investment in the agricultural sector alone is not enough rather should embark by research and development in nutritional crops, private sector patents, among others.

The objectives of this work are therefore listed as (a) determine the extent of variability among the landraces (b) identify divergent groups among the landraces (c) identify and reliably select landraces that show consistent performance with regards to yield and nutritional trait components across the test year environments. It is expected that the results from this research will inform researchers and breeders on yield and nutritional traits of *S. stenocarpa* that can be exploited under different growing environments to enhance quality yield output. Development of high yielding with enhanced nutritional quality using environment sensitive landraces of *S. stenocarpa* is a study area yet untapped. This work has tapped into this area. Better still, this work can be further tested under wider ecological regions and years, for stability where *S. stenocarpa* is not accepted due to unfavourable environmental restrictions. This is possible by exploring the prevalent weather conditions using different landraces for sustainability.

2. MATERIALS AND METHODS

2.1. Experimental Site, Landraces and Setup

In this study, four field experiments were conducted between the year 2014 to 2017 at Teaching and Research Farm of Landmark University, Omu-Aran, Nigeria lying on latitude 8'12390N; latitude 5'08340E. The study site is repre-

sentative of the Guinea Savannah ecological zone of North-central Nigeria suspended on 159 meters' altitude. Other weather details and soil type of this site are presented in Tables **A1** and **A2** in the appendix which is supported by soil classification methods of [7]. There are two main cropping seasons, early cropping within the period of April to July and late cropping within the period of August to November in the cropping location [32]. *Sphenostylis stenocarpa* is mostly planted during the early cropping season. During the early season, the temperature is generally cool and hot from October to April. The weather parameters during the experimental years were taken and provided a guide in the interpretation of the results. This study considered twenty-three (23) Landraces of *S. stenocarpa* (Table **A10** in the appendix) obtained from diverse eco-geographical origins of Nigeria were maintained in the seed bank of the Research Farm in the University. The initial source was from the gene bank of the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. These landraces were selected for this study based on their diversity for various agronomic traits.

The experimental sites were disc ploughed and then harrowed and raked to obtain a good seedbed for planting. Using randomized complete block design (RCBD) with three replications, two seeds of each genotype were sown in a single 5 meters' row plot to minimize the error from the source of variations when large plots are involved. Spacing was at 1m between and within rows giving a population density of 10 plants per row plot and 690 plants in all. The trials were conducted at each year, the period of April 30th, May 1st, May 31st and June 20th during the cropping seasons of 2014, 2015, 2016 and 2017, respectively. These dates were times when rainfall became stable. More so, in this study, the block was used to categorize the crops due to the vigorous growth of the crop as follows, plates 1 and 2 with 2 meters' alley to reduce inter-block plant competition. The four trials were conducted without supplemental irrigation. Hand weeding was carried out when needed to maintain a clean field. During harvesting, five plants from each row were separately harvested, seeds of all the sampled plants in each plot were bulked and weighed and the seed yield per plant (g) was then determined by dividing by five.

2.2. Method of Analysis

For the traits studied, a combined analysis of variance (ANOVA) for randomized complete block design across the years (environments) was first performed to test for the significance ($P < 0.05$; 0.01) of landraces, year and landrace by year interactions. From the combined ANOVA, test for homogeneity of residual variances was performed using Bartlett's test [33]. Secondly, trait means, variations and correlation coefficients (Kendall's method) were calculated to identify significant levels at which the traits contributed to yield. To further determine and link landraces performance to origin and planting environment, grouping techniques of principal component and cluster method (Ward's) were utilized. These analyses were carried out using the GLM procedure of Statistical Tool for Agricultural Research package (STAR) software 2013 for descriptive statistics and analysis of variance for agricultural data. Also, Genotype x Environment and crop stability analyses were performed using Plant Breeding statistical software of 2013. Finally, PRINCOMP SAS 9.3 version (2011) was used to determine and display two dimension plots (PC1 and PC2) and cluster groups among the landraces. The vegetative and yield components including nutritional trait performances over the years were ascertained numerically and carefully displayed using tables and figures.

2.3. Data Collection and Trait Measurement

Data on studied traits were collected between morning hours and evening hours for the vegetative and grain yield traits as follows:

Protein content was determined using the micro- Kjeldahl method outlined by [34]. The dry seed weight of each replicated *S. stenocarpa* was taken and 0.5 grams of each landrace sample weighed to determine the nitrogen content. Afterwards, the crude protein was obtained by nitrogen and the conversion factor to protein is 6.25. Fat content was determined using a Soxhlet extractor (EME 60500/CEB) method outlined by [34]. About 25 grams of each replicated dried seed of *S. stenocarpa* was taken and added into the thimble and weighed. Percentage extracted fat was determined by taking the weight of lipid in the flask after the initial extraction.

3. PRESENTATION OF RESULTS

3.1. Analyses of Variance for Variability Studies and the Mean Descriptive Statistics

It is quite revealing that the years and landraces showed significant variations ($P \leq 0.01$) for the vegetative, yield and quality traits except for time to germination as revealed Table **2** and Table **A3** in the appendix. Flowering and maturity times (Table **2**), pod and seed yield, quality protein and oil content (Table A3) traits also recorded significant variations ($P \leq 0.05$) for the landrace × year interactions. This showed that weather conditions such as temperature and humidity affected vegetative traits, protein and oil contents during the planting years. From Kendall's correlation values, these traits recorded relatively low correlation coefficients for flowering. The number of primary and secondary branches and maturity time (-0.11, -0.13, -0.15 and -0.15, respectively) as well as pods per peduncle (0.17), seed yield (0.21) and protein content (0.16). Better still, considerable variations were recorded for some vegetative (flowering, maturity times and branching traits) as well as yield and quality traits including pod filling time (59 per cent), seed per pod (70 per cent), tuber yield (87 per cent) and oil content (48 per cent) recording high minimum and maximum variations comparatively as depicted in Tables **A4** and **A5** in the appendix.

On a general note and comparatively too, mean values for some traits were relatively similar to the overall means *e.g.* flowering (86.78), germination (13.00) and maturity dates (157.09) from the ANOVA and descriptive statistics (Tables **A3** and **A5**). This is the case of TSS 10, TSs12, and TSs79. Whereas, non-similar mean values were recorded for these landraces for pod, yield and nutritional quality traits. This is an indication of environment effect on the landraces for these traits. Twenty principal components (PCs) were generated in Figs. (**1** and **2**) in the appendix section but only the first eight components cumulatively explained 72 percent of the total variations with Eigenvalues greater than one as

Table 1 Data on trait and abbreviation.

No	Trait	Abbreviation	Descriptions
	Vegetative		
1	Time of germination	DDG	Number of days from seed emergence to the appearance of plumule above the soil level
2	Time to flowering	DFW	Number of days from seedling emergence to when 50% of plants have flowered
3	Plant Height (cm)	PLHT	Length of the plant taken when plants have shown 50% maturity starting from Base of the plant from the soil level to the tip of the main stem
4	Number of primary branches	NBH	Number of main stems 9main vine) arising from the main plant stem
5	Number of secondary branches	SBH	Number of stems arising from the primary branch
6	Time to Maturity	DDM	Number of days from the date of germination (in 1above) to the stage when 95% of all pods turned from green to golden brown yield and quality traits
7	Number of peduncle per plant	NPD	Visual counting after flowering
8	Number of pods per peduncle	PP	Visual counting at the time of harvest
9.	Pod length (cm)	PLG	By measuring from the base of the pod to the tip using a ruler graduated in centimetre
10	Filled pod per plant	FPP	Measured as number of days from flowering to physiological maturity of the pod
11	Number of pods per plant	PPP	Counted at the time of harvest
12	Seed yield per plant (g)	SYP	This is the average weight of total seeds from the single row (5m) after harvest and de-podding and divided by 10
13	Nodule yield per plant (g)	NYP	This is the average weight of total tubers from the single row (5m) after harvest and divided by 10

Table 2. Variance analysis and correlation coefficient (Kendall's) on AYB vegetative traits grown in 4-year environments.

Source	DF	DFW	DDG	PLH (cm)	NBH	NS	DDM
Rep within landrace	46	89.54*	2.34	217.13*	0.33	0.79*	62.13*
Landrace (L)	22	428.04*	11.83	1085.76**	0.53*	0.55*	1220.67**
Year (Y)	3	2974.03*	66.71	7750.46**	14.61	4.84	3734.19**
L × Y	66	646.71**	6.14	801.71	1.56	2.89	1089.14**
Residual	138	98.02	1.69	256.76	0.28	0.70	62.56
Total	275	-	-	-	-	-	-
C.V (%)	-	9.82	13.12	12.81	17.11	11.53	4.65
R^2	-	0.03	-0.01	-0.02	0.02	0.04	0.54
rk (0.05%)		-0.11	-0.02	-0.13	-0.15*	-0.07	-0.15*

Note: NDF= Number of Days to Flowering; PLH= Plant Height; NBH= Number of Primary Branches; NSB= Number Of Secondary Branches, DDG= Days To Maturity, , R^2 = Coefficient of Determination.

shown in Table **A6** and **A7** in the appendix. The first component accounted for 23 percent of the total variations as described in pod traits (pod filling time, total pods) and seed yield. The second and third PCs accounted for 10.90 percent and 9.30 percent variations respectively. These were loaded in vegetative (flowering and height) and seed yield traits with negative influence on the number and length of the pod. In addition, tuber forming landraces contributed to the component loading than nodule forming types across eight principal components used. Strikingly, amino acid protein and oil contents contributed majorly to the variation loading in the third and fourth PCs indicating that these nutrition traits have some amount of genetic factors that can be exploited to improve nutritional quality in *S. Stenocarpa*.

Hierarchical clustering approach outlined by [35] clearly showed that the pattern of variations among the 23 landraces by displaying the seven significant principal components associated with the six standardized vegetative and the eleven yields and quality traits of the landraces evaluated as clusters as indicated in tables A8 and A9 in the appendix. By characterization, the seven clusters identified and grouped the 23 landraces into 1, 3, 2, 2, 6, 4 and 5 distinct clusters.

The only landrace in the cluster I (TSs118) was combined early maturity with high yield (157.97 days and 533.08 kg, respectively) in addition to relatively high protein and oil content. Three landraces (TSs51, TSs69 and TSs82) in cluster II and two (TSs45 and TSs48) in cluster III combined branching, pod trait and seed yield. Landraces in cluster IV include TSs7 and TSs57 from Zambia and Nigeria. The combined seed yields nutritional traits of protein and oil content. Interestingly, the six landraces in cluster V (TSs111, TSs66, TSs61, TSs79, TSs93 and TSs116) are from Mali, Nigeria, Malawi and Tanzania even as pod filling time, seed yield and height of each plant were captured by this group of landraces. Cluster VI had four landraces (TSs12, TSs119, TSs95 and TSs10) that contained tuber and nodule yield. These landraces are from wide origins of Cameroun, Mali and Tanzania respectively. Landraces TSs109, TSs49, TSs96, TSs58 and TSs148 are traceable to cluster VII, which supported pod traits and the ability of *S. stenocarpa* to grow tall.

4. DISCUSSIONS OF FINDINGS

Some landraces had significant environment influence under year and landrace × year effect for maturity time, peduncle and pod number, seed and tuber yield. This indicates that the year significantly influenced the studied traits and the subjection of this data to the landrace improvement may be less successful unless the landraces are grown in wider locations and not repeated year trials in a single location. This is a strong indication that performances of the landraces were to a great extent influenced by the environment. This result provides further insight into defining the extent of the contributory roles of the traits to *S. stenocarpa* yield. The food nutritional qualities of protein and oil content were not significant under year and interaction with landrace is a strong indication of a strong genetic base of the traits and that there is appreciable hope in breeding for high protein and oil nutritional component. [22, 24] reported a statistically significant relationship between genotype and environment interactions on nutritional improvement in breeding for quality traits for Bambara groundnut and wheat respectively. This is an untapped area in *S. stenocarpa* improvement breeding.

However, the obtained low Kendall's correlation for most of the studied traits may be attributed to their wide origin; landraces from different regions would have undergone adaptation to their respective locations. This can also be used to explain the low mean value of some traits of some landraces compared to the overall mean. This clearly shows that the disparities in the origin of these landraces have influenced their vegetative and yield performance. Discovery of wide genetic variation among landraces/genotypes forms the basis for directional varietal improvement. Origin and source culminate into some level of variation in mean performance due to geographical boundaries. In this study, most of the landraces exhibited an appreciable amount of variation for vegetative and yield traits. Reliably, most of the vegetative and yield quality traits recorded minimal error variation sources. This validates that population size is a true measure of variability among the twenty-three landraces studied. [23, 24] reported that there is evidence of the 'origin' contributing to the mean differences in Bambara groundnut. Wide mean variations occurred among the landraces from different origins. TSs118 had a mean flowering date of 104 whereas TSs 57 recorded 97 as average mean performance for the same trait.

Cluster analysis presents patterns of relationships between genotypes and hierarchical grouping such that similar descriptions are mathematically gathered into the same cluster [36]. The study by [37] also emphasized the roles of physiological traits in grouping plant accessions. The relatively high variations observed for the vegetative traits and seed production is indicative of the existence of genotypic differences among the evaluated landraces. Landraces with lower values for plant height, the number of primary and secondary branches produced higher seed yield. This is in support of the findings of [38] who had reported similar relationships between the morphological traits and seed yield of African Yam Bean.

The first eight principal components explained 72 percent of the total variation. Most of the observed variations were attributable to vegetative traits, podding and seed yield. These findings are closely related to those reported by [38], where they reported 70 percent of the total variation in some African Yam Bean accessions to be explained by the first six principal components. The highest genetic distance was observed between G5 and G8 and these can be exploited for heterosis in crosses. Scholars like [39, 40] have all signified the possibility of exploiting variability in breeding programs in African Yam Bean and Mung bean, respectively. These variations foreclose a holistic similarity matrix between the landraces and justify the importance of grouping techniques in exposing the relatedness of the 23 *S. stenocarpa* landraces.

At this point, subjecting the landraces to Principal component (PC) analysis and hierarchical clustering becomes crucial in providing a vivid account of the variation pattern. Interestingly, as podding and seed number per pod increased, some vegetative (growth phase during germination and plant height) were also decreasing as clearly marked in the negative coefficients. The explanation is that as vegetative parts were accumulating the photosynthesis in the seeds, podding time was decreasing. This also explains that from the 23 landraces studied, tuber producing landraces are certainly more in number than nodule producing types. In all, principal component analysis has revealed these traits to have genetic linkage which is referred to pleiotropic gene actions. By this, a possible hybridization using combinations from each cluster could lead to improvement. Essentially, amino acid and oil content are the major components of the proximate contents of *S. stenocarpa*; the useful amount of variations arising from mean and ranges, the coefficient of variation and error limit values were recorded. The study by [41] had similarly reported high protein, crude fibre, potassium, sodium, iron and copper content. The amino acid and oil contents of the evaluated landraces varied across the landraces as revealed by the cluster analyses where these two nutritional traits majorly occupied the third and fourth PCs. These variations may have existed as a result of the diverse nutritional status of the soils of the origins of these landraces, thereby resulting in the synthesis of different types of proximate contents. From the foregoing, the benefit of *S. stenocarpa* has

been undervalued. Nigeria can improve the nutritional quality among the citizen by appropriate investment in research and development will on the other hands grant more patents. [42] stressed that agricultural productivity growth in emerging economies has improved importation in recent times. The investment in research and development in *S. stenocarpa* may have an indirect benefit on the employment situation in the country.

CONCLUSION

This work is germane because it identified the nutritional and yield trait components in *S. stenocarpa* that can be exploited to improve seed yield and nutritional qualities of this underused crop for acceptance even at wider locations. More importantly, the nutritional quality when enhanced through breeding will serve as rich energy –protein source with low cost. The derived classifications revealed the existence of relationships between the landraces and the geographic background of the evaluated landraces. The identified landrace groups will serve as a guide in developing superior hybrids of *S. stenocarpa* with enhanced nutritional qualities. Also, to maximize the benefit on the aggregate economy, there is a need to encourage research and development with the aim to grant more patents, improve marketing, preservation and packaging which believes that in the long run will create employment and improve the general well begin of the citizens

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

HUMAN AND ANIMAL RIGHTS

No Animals/Humans were used for studies that are base of this research.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

Not applicable.

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None.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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Appendix

Table A1. Soil – Physico- chemical properties (0 – 30 cm) of the AYB landrace planting site.

Parameter	Minimum Value	Ratings	Maximum Value	Ratings	Mean ± SD (n = 18)
% Gravel	25.4	Low	78.9	High	62.6 ± 13.0
Textural class		Sand		loamy sand	
%Clay	4.32		8.32		5.38 ± 1.11
%Silt	8.56		15.56		11.06 ± 1.76
%Sand	78.12		86.12		83.56 ± 2.04
pH (Water)	5.9	moderately acid	6.67	Neutral	6.3 ± 0..2
pH (0.01 M $CaCl_2$)	5.24		6.03		5.7 ± 0.3
pH (1 M KCl)	5.19		6.06		5.5 ± 0.2
% Total Nitrogen	0.12	moderately. low	0.61	very high	0.22 ± 0.12
%Total Carbon	1	Low	2.21	very high	1.45 ± 0.38
C:N	1.8		11.7		7.6 ± 2.2
Avail P (mg P/kg)	8.5	moderate	36.7	High	15.1 ± 7.0
Ca^{2+} (cmol/kg)	1.6	very low	4.5	Low	2.9 ± 0.7
Mg^{2+} (cmol/kg)	3.8	High	9.2	very high	5.1 ± 1.2
K^{+} (cmol/kg)	0.25	Low	0.3	Low	0.28 ± 0.02

(Table A1) Contd…

Parameter	Minimum Value	Ratings	Maximum Value	Ratings	Mean ± SD (n = 18)
Na^+ (cmol/kg)	0	very low	0.1	very low	0.04 ± 0.01
Al+H (cmol/kg)	0		0.9		0.34 ± 0.31
CEC (cmol/kg)	7.2	Low	14.8	moderate	8.6 ± 1.7
%Base saturation	89.5	very high	100	very high	96.2 ± 3.3
Fe (mg/kg)	9.5		23.4		15.5 ± 4.3
Cu (mg/kg)	28.1		105.9		72.0 ± 24.0
Mn (mg/kg)	8		41.3		22.0 ± 7.8
Zn (mg/kg)	3.3		35.4		15.3 ± 7.1

Table A2. Average weather conditions across the 4 year study period at the derived savannah ecology.

Year	Temp (^{0}C)		Rainfall (mm)		Humidity		Solar Radiation (mjm^2)	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
2014	23.76	30.25	137.1	159.46	49.11	54.66	10.99	12.85
2015	23.58	28.95	140.4	161.02	59.28	66.08	10.96	12.31
2016	25.37	29.86	116.2	161.43	57.84	63.25	10.64	11.93
2017	24.21	28.66	170.5	178.86	61.5	70.23	10.13	11.47

Table A3. Variance analysis and correlation coefficient (Kendall's) on AYB yield and quality traits grown in 4 year environments.

Source	Df	NPD	PP	PLG	FPP	PPP	SP	SYP	NYP	TY	Sy/ha	PCA	OC%
Replicate (landrace)	46	20.84	0.39	11.3*	7.84	31.67*	7.51*	69.02*		17.06	9744.39**	16.24	33.92
Landrace (L)	22	632.36*	4.03*	173.61*	201.59*	5553.71**	164.64*	4037.17*		706.78*	75791.84**	53.61*	181.89*
Year (Y)	3	286.73*	6.62	74.42	271.08	856.57*	371.34	83.71		47	705917.1**	0.9	6.63
L X Y	66	128.83*	1.41	45.75	32.52	100.49*	34.83	376.84		455.06*	53117.17**	10.91	0.61
Residual	138	18.13	0.33	13.97	7.21	27.58	7.14	28.92		29.84	9058.59**	1.09	0.82
Total	275												
C.V (%)	-	18.25	26.43	19.23	21.3	10.78	22.11	36.92		80.31	24.97	1.09	7.32
R^2	-	o.24	0.03	-0.05	0.22	0.13	0.25	0.06		0.04	0.12	-0.003	-0.41
$r_{k(\ 0.05\%)}$		0.51*	0.17	-0.22	0.47*	0.36	0.50*	0.25		0.2	0.27	0.36*	0.33*

Note: DF= Degree of Freedom; NPD= Number of Peduncle/ Plant; PP= Number of Pods/Peduncle, PLG= Pod Length, FPP = Filled Pod/ Plant, PPP= Number of Pods/ Plant, SP= Number of Seeds/Pod, SYP= seed yield/plant,NYP= Nodule Yield/Plant, TY= Tuber Yield/ Plant, Sy/ha= Seed Yield/Hectare, PCA= Crude Protein Content, OC%= Oil Content in percentage, R^2= Coefficient of Determination, r_k= correlation Coefficient (Kendall's).

Table A4. AYB Mean Vegetative trait performance across the 4 year growing.

Landrace/Origin	DFW		DDG		Pit Ht (cm)		No Pr brch		No sec brch		DDM	
Togo	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
	98	110	5	9	93	140	3	4	7	9	148	170
Cameroun												
TSs10	93	120	7	20	95	120	2	4	5	8	157	187
TSs12	87	119	7	13	87	119	1	4	5	9	157	193
TSs5	88	120	8	13	90	151	2	4	5	8	158	192
Mail												
TSs119	78	120	9	12	99	141	2	4	7	8	155	182
TSs109	87	116	7	12	87	116	2	4	7	8	155	183
TSs111	90	125	7	15	90	176	2	4	5	9	159	191
TSs148	88	130	7	15	88	130	2	4	4	8	154	197
Zambia												
TSs45	45	121	7	12	90	151	2	4	4	9	158	184
TSs49	98	119	10	13	97	171	2	3	5	9	149	191
TSs48	91	140	7	10	109	172	2	3	6	9	158	191
TSs7	91	130	8	13	98	151	2	4	7	8	157	191
Malawi												
TSs93	97	115	8	13	121	180	2	4	6	9	161	190
Tanzania												
TSs95	97	118	7	12	107	108	2	3	5	8	165	183
TSs96	99	115	6	15	98	142	1	3	5	9	177	193
TSs116	85	115	8	16	97	132	1	4	7	9	158	194
Nigeria												
TSs57	78	120	8	15	99	181	2	4	7	9	157	187
TSs58	95	110	8	11	102	191	2	4	7	9	153	197
TSs60	60	123	10	15	105	181	2	4	6	10	159	197
TSs61	80	191	8	12	115	181	3	4	7	10	151	183
TSs69	91	121	6	11	91	121	3	4	7	9	157	187
TSs79	87	115	7	10	87	131	3	4	6	8	159	191
TSs82	93	111	8	12	93	119	3	4	7	8	151	192
Mean	86.78	122.78	7.52	13.00	97.30	191.52	2.09	3.83	5.96	8.70	157.09	188.96
SE	2.63	3.42	0.24	0.50	1.91	43.09	0.12	0.08	0.22	0.13	1.21	1.29
STD	12.59	16.38	1.16	2.39	9.15	206.63	0.60	0.39	1.07	0.63	5.82	6.19
CV	14.51	13.34	15.46	18.41	9.40	107.89	28.58	10.13	17.88	7.30	3.71	3.28

Note: DFW= Number of days to flowering; Plt h = Plant height; no pr brch = Number of Primary branches; no sec brch = Number of Secondary Branches, DDM = Days To Maturity, R^2 = coefficient of determination

Table A5. AYB Mean Yield and quality trait performance across the 4 year growing season.

Landrace /origin	NPD		PP		PLG (cm)		FPP		PPP		SP		NYP/g		TY/g		Syha/kg		PCA		OC	
Togo	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Max**	**Min**	**Max**	**Min**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
TSs118	26	28	2	4	15	23	10	21	13	31	9	22	0	0	0	0	268	520	16	18	6.9	8.5
Cameroun																						
TSs10	9	18	2	5	18	28.9	10	20	20	82	7	20	0	50.2	0	41.2	180	498	16.7	23.7	9.5	20.7
TSs12	26	61	2	4	18.3	26	9	18	23	43	7	19	0	51.4	0	0	238	442	20	23.4	10.9	18.2
TSs5	15	39	1	3	10	29	11	25	18	37	7	19	2	37	0	0	40	740	18.8	21	5.8	9.7
Mail																						
TSs119	19	41	2	4	15	30.3	8	26	15	19	8	23	0	0	0	46.4	160	620	16	22	6.7	9
TSs109	0	22	1	4	17	25	5	25	9	15	3	15	0	73	0	46.2	24	560	17.7	24.7	11.9	18.9
TSs111	19	34	1	3	15.4	23.1	0	12	9	21	1	18	37.1	82	0	43.7	60	374	16.9	19	6	10
TSs148	18	40	1	1	17	24	10	23	21	61	0	18	29.6	49.1	0	0	264	640	20.3	22.9	0.8	5.8
Zambia																						
TSs45	19	39	1	3	15	23	4	21	10	18	0	17	35.3	55.7	0	0	0	780	20.4	23.8	0.8	9
TSs49	15	41	0	2	0	22.6	0	12	10	18	0	10	28.1	55	0	37.2	34	820	21.9	23.4	0.5	8.9
TSs48	0	25	2	3	0	20.2	9	29	9	21	7	15	28.1	71.2	0	39.5	158	626	23	24	6.9	10
TSs7	15	32	1	2	0	23.3	0	12	10	32	0	20	0	0	0	31.2	48	740	16	32.9	6	10
Malawi																						
TSs93	15	32	1	3	17	37.1	9	21	11	29	7	18	0	0	0	54.3	164	640	16	19	10.9	16
Tanzania																						
TSs95	18	40	2	3	17	23	8	22	15	50	7	15	0	0	0	63.1	138	526	16	17	10.9	14
TSs96	18	33	1	3	12	22.3	0	12	10	22	0	17	0	0	0	42.1	160	660	18	18.9	9.5	20
TSs116	20	41	1	3	15	23	9	23	18	43	5	21	0	55.9	0	29.6	246	660	18	18.2	10	22
Nigeria																						
TSs57	10	20	1	4	12	25.2	9	22	17	37	6	22	0	0	0	0	272	640	16	18	14.4	22.3
TSs58	19	40	1	3	16	39.2	11	23	17	51	6	21	0	0	0	0	140	640	16	18	7.3	16
TSs60	2	3	0	3	0	23	0	12	10	20	0	12	0	0	0	32.5	50	620	16	20	13	18
TSs61	15	40	1	3	12	27	9	29	18	41	5	19	0	0	0	43.6	386	760	21	23.7	11.5	13.4
TSs69	15	35	2	4	18	25	11	40	15	49	6	20	0	0	0	0	60	558	16	20	10.7	14.1
TSs79	17	32	1	4	15	26	11	25	15	41	6	18	0	0	0	31.2	98	588	17	23	15.9	20.7
TSs82	15	30	1	4	15	24	7	23	15	35	6	20	0	0	0	0	174	678	20	24	13	18
Mean	15	33.3	1.2	3.39	12.6	25.8	6.96	21.6	14.3	35.5	4.48	18.2	6.97	25.2	0.0	25.3	146	623	18	21.7	8.69	14.5
SDV	6.88	11.2	0.6	0.72	6.27	4.59	4.13	6.70	4.27	16.3	3.15	3.18	14.4	30.7	0.0	22	99.9	108	2.22	3.51	4.2	5.11
CV	45.9	33.7	49.2	21.3	49.8	17.8	59.4	31.1	30	46	70.3	17.4	193	121	0.0	86.8	68.3	17.3	12.4	16.2	48.4	35.3
S.E	1.44	2.34	0.13	0.15	1.31	0.96	0.86	1.40	0.89	3.4	0.66	0.66	2.8	6.39	0.0	4.58	20.8	22.5	0.46	0.73	0.88	1.07

Note: NDF= Number of Days to Flowering; PLH= Plant Height; NBH= Number of Primary Branches; NSB= Number Of Secondary Branches, DDG= Days To Maturity, SDV= Standard Deviation, CV= Coefficient of Variation, S.E= Standard Error

Table A6. Variance analysis description using principal component analysis on AYB vegetative traits grown in 4 year environments.

Variables	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
DFW	0.009	-0.289	-0.056	0.241	-0.237	0.357	-0.174	0.397
DDG	-0.133	0.075	0.109	-0.302	0.544	0.109	-0.217	-0.104
PLH	-0.014	-0.148	0.308	0.378	0.249	0.088	-0.249	0.247
NBH	0.086	0.039	0.221	0.462	-0.029	-0.236	0.296	-0.166
NSB	0.087	-0.016	0.189	0.306	0.124	-0.366	-0.500	0.082
DDM	0.014	-0.327	0.207	-0.232	0.012	0.277	0.079	0.272
% var. prop	23.240	10.900	9.300	8.630	6.220	5.510	5.040	4.220
Cummu var Proportion	23.200	34.140	43.020	51.640	57.730	63.270	68.210	72.500
Eigen value of r	4.874	2.281	1.879	1.800	1.292	1.146	1.054	0.888

Note: NDF= Number of Days to Flowering; PLH= Plant Height; NBH= Number of Primary branches; NSB= Number Of Secondary Branches, DDG= Days To Maturity, %var.prop= Percentage Variance Proportion, Cummu. Var. prop.= Cummulative Variance Proportion, r.= Correlation

Table A7. Variance analysis description using principal component analysis on AYB yield traits grown in 4 year environments.

Variables	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
NPD	0.35	-0.21	0.01	-0.04	0.16	0.07	-0.11	-0.14
PP	0.28	-0.22	-0.08	0.07	0.11	0.16	0.14	-0.26
PLG	0.25	-0.23	0.09	-0.11	-0.09	-0.02	0.23	0.24
FPP	0.37	0.06	-0.01	-0.03	-0.04	0.08	0.13	0.12
PPP	0.40	-0.09	-0.08	-0.01	-0.13	-0.10	-0.04	-0.04
SP	0.35	0.13	0.14	-0.08	0.00	0.10	0.12	0.06
SYP	0.22	0.52	0.07	0.06	0.08	0.22	-0.02	0.15
NYP	-0.07	-0.03	-0.53	0.19	0.19	0.12	0.10	0.12
TY	-0.15	-0.12	0.33	0.03	0.36	0.22	0.25	0.09
SYH	0.22	0.52	0.07	0.06	0.08	0.22	-0.02	0.15
PCA	-0.03	0.04	-0.38	0.06	-0.05	0.37	-0.37	-0.07
OC	0.02	-0.02	0.37	-0.23	-0.31	0.27	-0.27	-0.43
% var. prop	23.24	10.90	9.30	8.63	6.22	5.51	5.04	4.22
Cummu var Prop.	23.20	34.14	43.02	51.64	57.73	63.27	68.21	72.50
Eigen value of r	4.87	2.28	1.88	1.80	1.29	1.15	1.05	0.89

Note: NPD= Number of Peduncle/ plant; PP= number of pods/peduncle, PLG= pod length, FPP = filled pod/ plant, PPP= Number of Pods/ Plant, SP= Number of Seeds/pod, SYP= Seed Yield/Plant, NYP= Nodule Yield/Plant, TY= Tuber Yield/ plant, Sy/ha= Seed Yield/Hectare, PCA= Crude Protein Content, OC%= Oil Content in Percentage. %var.prop= Percentage Variance Proportion, Cummu. Var. prop.= Cummulative Variance Proportion, r.= Correlation

Table A8. Mean value of the vegetative traits and six identified cluster groups using ward's clustering analysis.

Variables	Trait Genotypic Mean	CL I	CL II	CL III	CL IV	CL V	CL VI	CL VII
DFW	100.77	*93.47*	**100.01**	110.17	**110.39***	*94.53*	121.03	96.42
DDG	9.92	8.76	*7.49*	**10.37**	**9.97**	8.24	8.37	**9.76**
PLH	125.09	*125.97***	*126.71*	126.56	**128.31**	**128.87**	126.61	**128.97**
NBH	3.11	3.1	*3.34*	2.46	**3.62**	4.01	**3.82**	**3.17**
NSB	7.27	6.55	***7.74***	7.08	6.11	5.87	7.5	7.09
DDM	159.97	**149.21**	155.86	150.18	*150.38*	165.32	*161.11*	152.94
Number of landraces	23	7	4	4	3	2	2	1

NDF= Number of Days to Flowering; PLH= Plant Height; NBH= Number of Primary branches; NSB= Number of Secondary Branches, DDG= Days To Maturity.
* Group mean maximum value (**bold**) ; ** Group mean minimum value (*italics*)

Table A9. Mean value of the yield and quality traits and six identified cluster groups using ward's clustering analysis.

Variables	Trait Genotypic Mean	CL I	CL II	CL III	CL IV	CL V	CL VI	CL VII
NPD	23.33	20.18	23.04	*19.17*	**24.88***	20.09	21.52	22.74
PP	5.18	**5.87**	4.38	4.02	*3.72***	5.04	5.11	4.89
PLG	19.44	19.02	19.96	*17.22*	18.18	17.64	19.19	**20.85**
FPP	12.59	**14.01**	10.43	12.54	13.87	13.01	11.2	*10.02*
PPP	38.77	36.56	**39.87**	27.41	*20.36*	37.02	39.55	21.02
SP	12.08	**14.08**	13.79	11.03	11.79	13.02	12.41	*10.22*
SYP(g)	19.06	17.28	17.03	15.37	**21.04**	16.19	15.29	*14.79*
NYP(g)	34.56	*30.08*	31.22	32.49	34.19	30.87	**38.04**	34
TY(g)	46.08	31.77	*43.71*	45.33	46.17	44.85	**49.75**	40.92
SYH	481.11	**583.08**	487.19	494.01	481	*436.4*	480.15	480.84
PCA	19.61	**19.02**	18.2	18.19	**21.42**	**20.19**	**20.27**	18.02
OC	12.23	*10.25*	19.27	12.02	**16.66**	**15.08**	13.28	13.71
Number of landraces	23	7	5	3	3	2	1	2

: NPD= Number of Peduncle/ plant; PP= Number of Pods/Peduncle, PLG= Pod Length, FPP = Filled Pod/ Plant, PPP= Number of Pods/ Plant, SP= Number of Seeds/Pod, SYP= Seed Yield/Plant, NYP= Nodule Yield/Plant, TY= Tuber Yield/ Plant, Sy/ha= seed Yield/Hectare, PCA= Crude Protein Content, OC%= Oil Content in Percentage * group mean maximum value (**bold** * ; ** group mean minimum value (*italics*)

Table A10. Origin and demography of the 23 AYB landraces used for the experiment.

S/N	Genotype	Root Formation	Origin	Agronomic Information	Geographical Coordinate
G1	TSs118	Seed	Togo	Cultivated	8.61N - 1.10E
G2	Tss10	Tuber and seed	Cameroun	Cultivated	10.44N – 14.85E
G3	TSs12	Nodule and seed	Cameroun	Cultivated	10.44N – 14.85E
G4	TSs5	Nodule and seed	Cameroun	Cultivated	7.37N - 12.35E
G5	TSs109	Tuber and seed	Mali	Cultivated	13.88N – 8.10E
G6	TSs111	Nodule and seed	Mali	Cultivated	13.35N – 7.90E
G7	TSs 148	Nodule and seed	Mali	Cultivated	13.88N – 8.10E

(Table A10) Contd…

S/N	Genotype	Root Formation	Origin	Agronomic Information	Geographical Coordinate
G8	TS119	Seed	Mali	Landrace	17.00N - 8.00E
G9	TSs45	Nodule and seed	Zambia	Cultivated	13.08N- 31.21E
G10	TSs49	Nodule and seed	Zambia	Cultivated	15.07N – 25.39E
G11	TSs48	Nodule and seed	Zambia	Cultivated	14.41N – 30.70E
G12	TSs7	Seed	Zambia	Cultivated	14.41N – 30.70E
G13	TSs93	Tuber and seed	Malawi	Cultivated	13.25S - 34.30E
G14	TSs95	Tuber and seed	Tanzania	Cultivated	6.37S - 34.89E
G15	TSs96	Tuber and seed	Tanzania	Cultivated	6.37S - 34.89E
G16	TSs116	Nodule and seed	Tanzania	Cultivated	6.37S - 34.89E
G17	TSs57	Seed	Nigeria	Landrace	9.08N - 8.67E
G18	TSs58	Seed	Nigeria	Landrace	9.08N - 8.67E
G19	TSs60	Seed	Nigeria	Landrace	9.08N - 8.67E
G20	TSs61	Seed	Nigeria	Landrace	9.08N - 8.67E
G21	TSs69	Seed	Nigeria	Landrace	9.08N - 8.67E
G22	TSs79	Seed	Nigeria	Landrace	9.08N - 8.67E
G23	TSs82	Seed	Nigeria	Landrace	9.08N - 8.67E

REFERENCES

[1] Adama IJ, Asaleye AJ, Oye AJ, Ogunjobi OJ. Agricultural production in rural communities: Evidence from Nigeria. J Environ Manag Tour 2018; 27(3): 428-38.

[2] Oloni E, Asaleye A, Abiodun F, Adeyemi O. Inclusive growth, agriculture and employment in Nigeria. J Environ Manag Tour 2017; 8(1): 183-94.

[3] Thiyagu D, Rafii MY, Mahmud TMM, Latif MA. Stability analysis of Sweet potato (*Ipomoea batatas* Lam). Shoot tips yield for leafy vegetable across agro-ecologies using AMMI. Aust J Crop Sci 2012; 6(11): 1522-6.

[4] Nnamani CV, Ajayi SA, Oselebe HO, Atkinson CJ, Igboabuchi AN, Ezigbo EC. *Sphenostylis stenocarpa* (ex. A. Rich.) Harms. A fading genetic resource in a changing climate: Prerequisite for conservation and sustainability. Plants (Basel) 2017; 6(3): E30.

[5] Sood S, Kumar N, Chandel KS, Sharma P. Determination of genetic variation for morphological and yield traits in bell pepper (Capsicum annum var grossum). Indian J Agric Sci 2011; 81(7): 590-4.

[6] Massawe FJ, Azam-Ali SN, Roberts J. A The impact of temperature on Bambara groundnut. Crop Sci 2003; 43: 1375-9.

[7] Aiboni VU. Characteristics and classification of soils of a representative topographic location of the University of Agriculture, Abeokuta. Asset Series 2001; A 1: 51-62.

[8] Ella MM, Singh A. Bambara groundnut (*Vigna subterranean* L.Verdc) yield as influenced by phosphorus and cultivars in the semi-arid savanna of Nigeria. J Plant Sci 2008; 3: 176-81.

[9] Hillocks I, Bennet C, Mponda OM. Bambaranut: A review of utilization, market potential and crop improvement. Afr Crop Sci J 2012; 20(1): 1-16.

[10] Adewale BD, Kehinde OB, Odu BO, Dumet DJ. The potential of African yam bean (*Sphenostylis stenocarpa* Hochst. Ex. A. Rich). Harms in Nigeria: Character distribution and genetic diversity. In: Smart J, Haq N, Eds. New Crops and uses: Their role in a rapidly changing world. Centre for Underutilized Crops 2008; 1(1): pp. 265-76.

[11] Yadava DK, Gin SCM, Vignesh M, Vasuder S, Yadar AK. Genetic variability and trait association studies in Indian mustard (*Brassica juncea*). Indian J Agric Sci 2011; 81: 712-6.

[12] Holtsford TP, Ellstrand NC. Genetic and environmental variation in floral traits affecting the outcrossing rate in *Clarkia tembloriensis* (Onagraceae). Evolution 1992; 46(1): 216-25.

[13] Ariyo OJ, Ayo-Vaughan MA. Analysis of genotype and environment interaction of okro (*Abelmoschus esculentus* (L) moench. J Genet 2000; 54: 35-40.

[14] Yan W, Manjit S. Kang, Baoluo Ma, Sheila Woods, Paul L. Cornelius. GGE Biplot *vs*. AMMI Analysis of genotype-by-environment data. Crop Sci 2007; 47: 643-53.

[15] Sinebo W. The trade-off between yield increase and yield stability in three decades of barley breeding in a tropical highland environment. Field Crops Res 2005; 92: 35-52.

[16] Adeniyan ON, Akande SR, Balogun MO, Saka JO. Evaluation of crop yield of african yam bean, maize and kenaf under intercropping systems. Am-Eurasian J Agric Environ Sci 2007; 2: 99-102.

[17] Alake CO, Alake OO. Genetic diversity for agro-nutritional traits in African landraces of Vina Subterranean germplasm. J Crop Improv 2016; 30(4): 378-98.

[18] Kush GS. Variability between local and exotics Bambara groundnut landraces in Botswana. Afr Crop Sci J 2000; 8: 1-8.

[19] Baye T. Genotypic and phenotypic variability in *Vernonia galemensis* var Ethiopia germplasm collected from Eastern Ethiopia. J Agric Sci 2002; 139: 161-8.

[20] Daniel AB, Celestina ON. A review on genetic resources, diversity and agronomy of African yam bean (*Sphenostylis stenocarpa* (Hochst.Ex A. Rich) Harms): A potential future food crop. Sustain Agric Res 2013; 2(1): 32-43.

[21] Bhargava A, Shukla S, Ohri D. Genetic variability and interrelationship among various morphological and quality traits in quinoa (*Chenopodium quinoa* Wild). Field crop Res 2007; 101: 104-16.

[22] Adeniji OT, Wammanda DT. Variability and genetic correlations for yield and yield characters in some Bambara groundnut cultivars. Int J Agri Bio 2010; 12: 303-7.

[23] Amadou HI, Bebeli PJ, Kaltssikes PJ. Genetic diversity in Bambara groundnut germplasm revealed by RAPD markers. Genome 2001; 44: 995-9.

[24] Alake CO, Ayo-Vaughan MA, Ariyo OJ. Selection criteria for grain yield and stability in Bambara groundnut landraces. Acta Agric Scand Section B-Soil Plant Sci 2015; 65(5): 433-47.

[25] Okoye FI. Genetic variability and correlation studies in African yam bean. Nigerian J Botany 1992; 5: 75-83.

[26] Adewale BD, Kehinde OB, Popoola JO, Aremu CO. Seed metrics for genetic and shape determinations in African yam bean [Fabaceae] (*Sphenostylis stenocarpa* Hochst. Ex. A. Rich) harm. Afr J Plant Sci 2010; 4(4): 107-15.
[27] Adewale D, Dumet D. 2011.
[28] Ikhajiagbe B, Joseph KM. Genetic assessment of three colour variants of African yam bean [*Sphenostylis stenocarpa*] commonly grown in the Midwestern region of Nigeria. Int J Modern Bot 2012; 2(2): 13-8.
[29] Asaleye AJ, Popoola O, Lawal AI, Ogundipe A, Ezenwoke O. The credit channels of monetary policy transmission: Implications on output and employment in Nigeria. Banks Bank Syst 2018; 13(4): 103-18.
[30] Asaleye AJ, Adama JI, Ogunjobi JO. Financial sector and manufacturing sector performance: Evidence from Nigeria. Investment Management and Financial Innovations 2018; 15(3): 35-48.
[31] Asaleye AJ, Isoha LA, Asamu F, Inegbedion H, Arisukwu O, Popoola O. Financial development, manufacturing sector and sustainability: Evidence from Nigeria. J Soc Sci Res 2018; 12(4): 539-46.
[32] Aremu CO, Alhassan EA, Asaleye AJ, Alori E, Ige S, Nayan G. Effect of varietal and tillage methods on agronomic and yield characters of rice (*Oryla Sativa* L). Int J Civil Engin Technol 2018; 9(13): 590-600.
[33] Steel RGD, Torrie JH, Dickey D. Principles and Procedures of Statistics 1996.
[34] Lynch JM, Barbano DM. Kjeldahl nitrogen analysis as a reference method for protein determination in dairy products. J AOAC Int 1999; 82(6): 1389-98.
[35] Ward JH. Hierarchical grouping to optimize an objective function. J Am Stat Assoc 1963; 58: 236-44.
[36] Aremu CO. Genetic diversity: A review for need and measurement for interspecies crop improvement. J Microbiol Biotechnol Res 2011; 1: 80-5.
[37] Upadhyay P, Singh VK, Neeraja CN. Identification of genotype-specific alleles and molecular diversity assessment of popular rice (*Oriza Sativa* L) varieties of India. Int J Plant Breed Genet 2011; 5: 130-40.
[38] Aremu CO, Ibirinde AO. Bio-diversity studies on accessions of African yam bean (*Sphenostylis stenocarpa*). Int J Agric Res 2012; 7(2): 78-85.
[39] Adewale BD, Aremu CO, Amazue UE. Intra-specific variability and diversity analysis of African yam bean by seed size parameters. J Agric Biol Sci 2012; 7(6): 454-61.
[40] Rahim MA, Mia AA, Mahmud F, Zeba N, Afrin KS. Genetic variability, character association and genetic divergence in Mungbean (*Vigna radiate* L. Wilczek). Pant Omic J 2010; 3: 1-6.
[41] Soetan KO. Preliminary studies on the nutritional and anti-nutritional constituents of six accessions of African yam bean (*Sphenostylis stenocarpa*), an underutilized legume. Ann Food Sci Technol (Valahia Univ Târgoviste) 2017; 18(4): 625-31.
[42] Food and Agriculture Organization of the United Nation (FAO). The State of Agricultural Commodity Market; Agricultural, Trade, Climate Change and Food Security 2018; Rome.