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Assessment of Phenotypic Diversity in Morphological and Agronomic Traits of Aerial Yam (*Dioscorea Bulbifera* L.)

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Abstract

Aerial yam (*Dioscorea bulbifera* L.) is an underutilized crop of significant economic importance and a potential contributor to food security in developing countries. Understanding its genetic diversity is crucial for effective breeding and crop improvement. A two-year field experiment was conducted at the National Root Crops Research Institute (NRCRI), Umudike, Nigeria, using 94 aerial yam accessions sourced from the National Root Crops Research Institute (NRCRI), Umudike and the International Institute of Tropical Agriculture (IITA), Ibadan. The study aimed to characterize and assess the extent of genetic diversity among these accessions based on phenotypic traits. The accessions were evaluated in a randomized complete block design (RCBD) with three replications. Data on morphological and agronomic traits, including bulbil yield, were collected and pooled across the two years. Frequency distributions for qualitative traits revealed substantial variation in stem colour, leaf colour, leaf type, bulbil shape, and bulbil skin texture. Combined analysis of variance showed highly significant genotypic differences ($p < 0.001$) for most traits. Principal component analysis identified four components with eigenvalues >1, explaining 52.9% of total variation. The first component (34.5%) was associated with vine length, number of branches, stem count, and total bulbils per plot, while the second was strongly linked to bulbil weight and yield. The FAI-BLUP index effectively identified superior genotypes, with accessions YC2, YBI, YB5, YD4, YA5, YA3, YB4, YA1, and YC3 emerging as promising candidates for simultaneous improvement of key agronomic traits in D. bulbifera breeding programs.

Keywords: Aerial yam**,** *Dioscorea bulbifera*, agro-morphological diversity, bulbil yield; PCA; FAI-BLUP.

INTRODUCTION

Yam (*Dioscorea* spp.) is a clonally propagated tuber crop belonging to the genus *Dioscorea* in the *Dioscoreaceae* family. It comprises > 600 species, of which 10 are economically important and widely cultivated species (Darkwa *et al*., 2020). Roots and tubers like yam rank next in importance to cereal grains providing daily caloric needs of people in the tropics and sub-tropics. Its value chain sustains ~5 million people's livelihood, including the rural farming households, traders, transporters and processors (Mignouna *et al*., 2020). *Dioscorea bulbifera* is native to Africa and Asia, but it is widely cultivated across several regions, including Central and South America, Nepal, China, the Americas, the West Indies, Pacific Islands, Southeast Asia, and even parts of Australia (Coursey, 1967; Guan *et al*., 2017; Kundu *et al.,* 2021; Bhat, 2022). This species is characterized by a twining stem with a sleek surface and alternately arranged vibrant green leaves in a broadly cordate shape (Burkill, 1960). *Dioscorea bulbifera* has the potential to improve nutrition, boost food security and foster rural development. It is a rich source of primary metabolites, encompassing carbohydrates, proteins, lipids, vitamins, minerals, and fibers (Abara *et al*., 2011). Its tubers and bulbils offer versatile culinary possibilities as food sources, especially during famine, while providing active pharmacological compounds in traditional medicine (Xu *et al.* 2008, Fan *et al.* 2020). Significantly, the presence of essential amino acids, such as threonine and phenylalanine, coupled with significant mineral content, notably iron, enhances its nutritional importance (Ezeocha *et al*., 2014; Otegbayo *et al*., 2018). Beyond its nutritional richness, *D. bulbifera* holds a profound place in traditional medicine serving as a purgative, anthelmintic, antidiuretic, rejuvenating tonic, and exhibiting aphrodisiac qualities (Kumar *et al.,* 2017). The vast nutritional and medicinal benefits of *D. bulbifera* have triggered substantial characterization and genetic variability analyses in diverse regions like Brazil (Silva *et al*., 2016), Ethiopia (Beyene, 2013; Mulualem and Weldemichel, 2013), Nigeria (Jayeola and Oyebola, 2013), Uganda (Ikiriza *et al*., 2023), and West Africa (Osuagwu *et al*., 2020). These investigations have significantly propelled the advancement of breeding techniques aimed at enhancing its desirable traits for both food and medicinal purposes in these areas (Osuagwu *et al*., 2020*).*

D. bulbifera germplasm has been maintained as landraces, which are often phenotypically and genetically diverse (Nokuthula Hlanga *et al*., 2022). Landraces with different historical origins, distinct identities, values, and adaptations constitute the dominant parts of the cultivated variability exhibited by aerial yams in West Africa (Akakpo *et al*., 2017). All cultivated aerial yams genotypes are from farmers' mass selection from landraces that have evolved directly from their wild relatives, and which have adapted to the natural environments (Akakpo *et al*., 2017; Mohammad *et al*.,2020). The tradition of continued domestication from the wild relatives by African farmers contributes to the high level of varietal and genetic diversity (Mignouna and Dansi, 2003; Dumont *et al*., 2006; Scarcelli *et al*., 2006; Agre *et al*., 2021a; Adewumi *et al*., 2022).

D. bulbifera landraces can be systematically exploited in breeding programmes through a dedicated pre-breeding programme. Morphological characterization is vital for the initial identification of aerial yam species, followed by further in-depth characterization using protein and or/DNA markers. Diversity assessment is done using morphological markers such as size, form, bulbil formation, presence of spines on the stem, twining direction, leaf shape, etc. (Girma *et al*., 2014; Loko *et al*., 2017; Ude *et al*., 2019; Darkwa *et al*., 2020a). This study provided more estimation of morphological diversity in aerial yam as well as traits that are considerable for further evaluation to improve the crop. Hence, this research assessed agronomic variability of 94 accessions of *D. bulbifera* by means of quantitative and qualitative agro-morphological traits. Agronomic variability assessment of accessions is the first pre-breeding step toward breeding programme establishment as such reveals the potentials of the studied genetic resources for favourable selection. Therefore, the present study seeks to uphold the status of the different agro-morphological traits capable of distinguishing *D. bulbifera* germplasm, to identify promising genetic resources for food security and hence their effective incorporation in *D. bulbifera* breeding programme in Nigeria.

MATERIALS AND METHODS

Experimental site

The study was conducted over two consecutive growing seasons at the research farm of the National Root Crops Research Institute (NRCRI), Umudike, Nigeria. The experimental site is located at 5°20′ N latitude and 7°33′ E longitude, at an elevation of 120 m above sea level. The area lies within the humid forest agro-ecological zone of southeast, Nigeria and is characterized by an annual rainfall ranging from 1,800 to 2,200 mm, with a mean annual temperature of 20.5 °C and an average relative humidity of 76.8%.

Planting Materials

A total of 94 accessions of aerial yam (Dioscorea bulbifera L.) were used in this study. These comprised: 64 accessions obtained from the genebank of the International Institute of Tropical Agriculture (IITA), Ibadan, originally collected from eight West and Central African countries, and 30 accessions collected from six south-eastern Nigerian states: Abia, Anambra, Imo, Enugu, Ebonyi, and Akwa Ibom. All planting materials were obtained through the Yam Breeding Programme of NRCRI and represent diverse germplasm adapted to the humid forest zone of Nigeria.

Field Establishment and Experimental Design

The field was manually cleared, ploughed, and harrowed before planting. The experiment was laid out in a randomized complete block design (RCBD) with three replications. Each accession was planted in a single-row plot, with each row measuring 7 m in length. A 1 m spacing was maintained both between rows and within rows to minimize inter-plant competition and ensure proper establishment. Planting was conducted at the onset of the rainy season. Each plant was supported with bamboo stakes to facilitate vertical growth and bulbil formation. Standard agronomic practices, including regular weeding and staking adjustments, were applied to maintain optimal growing conditions. For phenotypic evaluation, data were collected from the five central healthy plants in each plot to minimize border effects.

Phenotypic Evaluation

Data were recorded on 29 phenotypic traits, comprising 17 quantitative and 12 qualitative attributes related to leaf, stem, and bulbil morphology (Table 1). Measurements were based on the Yam Standard Operating Protocol developed by Asfaw (2016), with slight modifications to suit aerial yam characterization.

Table 1: Quantitative traits observed on *Dioscorea bulbifera* accessions

S/N	Traits	Measurement
1	Vine length	Measurement of the length of vines using ruler
2	Number of stems per plant	Counting of number of stem per plant of the selected plants
3	Number of branches on main stem	Counting of number of branches on the main stem per plant of the selected plants
4	Stem diameter	Average diameter of the stem of the selected plants using vernia caliper
5	Leaf number	Number of leaves counted per plant of the selected plants
6	Leaf length	Measured length of selected leaf in the selected plants
7	Leaf width	Measured width of selected leaf in the selected plants
8	Days to first bulbil appearance	Counting in days (appearance of first bulbil)

9	Bulbil diameter	Average diameter of 3 bulbils per plot
10	Bulbil length	Average length of 3 bulbils per plot
11	Bulbil number	Total number of bulbils counted per plot
12	Bulbil weight	Total weight of bulbils per plot

Source: Asfaw (2016)

Table2 : Descriptions of pathological traits of yam diseases

S/N	Trait	Nature of the Trait	Collection Period	Collection Method
1	YMV severity	Visual assessment of the grade of reaction of the plant to the virus infection, varying from mottle, mosaics until total leaf deformation, recording of the severity as a proportion or percentage of plant surface affected	2-6 MAP	Using a visual five ordinal scale (1–5 scale) where 1 = no visible symptoms; 2 = mosaic on few leaves, symptom recovery over time; 3 = mild symptoms on many leaves but no leaf distortion; 4 = severe mosaic on most leaves, leaf distortion; and 5 = severe mosaic (bleaching), severe leaf distortion and stunting
2	YAD Severity	Visual assessment of anthracnose severity by observing the relative or absolute area of plant tissue affected by yam anthracnose disease and recording of the severity as a proportion or percentage of plant surface affected	2-6 MAS	Using a visual 1–5 general scale where 1 = no visible symptoms of anthracnose disease, 2 = few anthracnose spots or symptoms on 1 to ~25% of the plant, 3 = anthracnose symptoms covering ~26 to ~50% of the plant, 4 = symptoms on >51% of the plant, and 5 = severe necrosis and death of the plant

Source: Asfaw (2016)

Data Analysis

Phenotypic data were analyzed using descriptive statistics to summarize trait variation among accessions. Quantitative traits were subjected to analysis of variance (ANOVA) using the Generalized Linear Model (GLM) procedure of SAS software version 9.1 (SAS Institute, 2002). Where significant differences were detected, means were separated using the Least Significant Difference (LSD) test at $p \leq 0.05$. Pearson's correlation coefficients were computed to evaluate the strength and direction of associations between bulbil yield and other agronomic traits. Cluster Analysis: Genetic relationships among the 94 accessions were visualized using a dendrogram constructed with the dendextend package (Galili and Dendextend, 2015) and enhanced using the circlize package (Gu et al., 2014) in R. Principal Component Analysis (PCA): Conducted following the method of Iezzoni and Pritts (1991) to identify traits contributing most to genetic divergence among accessions. The FAI-BLUP index was computed using the metan package (Olivoto *et al*., 2020) to rank accessions based on their simultaneous performance across multiple traits. A radar chart was generated using the fmsb package (Nakazawa *et al.,* 2018) to visualize the relative performance of top-performing genotypes. The predicted selection genetic gain (SG%) was estimated for each trait using the formula:

$$SG(\%) = \frac{(X_s - X_O)h^2}{X_O} \times 100$$

Where Xs is the mean of the selected genotypes, Xo is the mean of the original population and h^2 is the heritability

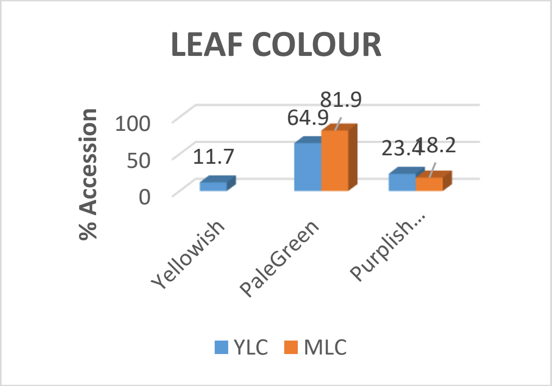
RESULTS

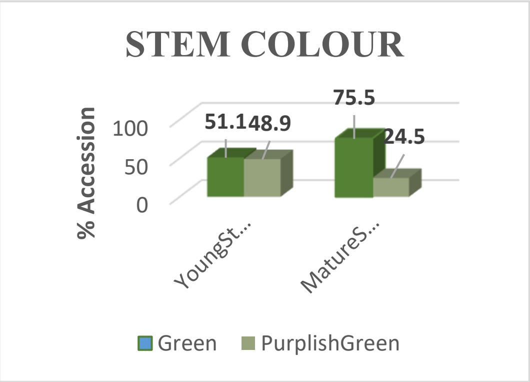
Results obtained from descriptive statistics using the distribution frequency on qualitative traits for the 94 accessions of *D. bulbifera* showed that there was a wide range of variations observed in leaves, stems, and aerial bulbils among the accessions (Table 3). These traits with recorded variations include leaf shape, young leaf colour, mature leaf colour, young stem colour, mature stem colour, leaf density, bulbil shape and bulbil skin texture. However, there were no variations observed for traits such as twinning direction, leaf type, leaf apex shape and young stem hairiness. The 94 aerial yam accessions had simple leaf structure. The analysis revealed that simple leaves were of two types, 73.4% of the accessions had cordate broad leaves and (26.6%) of the accessions had cordate long leaves. The accessions showed differences between the young and mature leaf colour. The young simple cordate leaves were of three types; 11.7% of the accessions were yellowish, 64.9% were pale green and 23.4% were purplish green. Furthermore, 81.9% of the matured leaves were greenish while 18.1% were purplish green (Figure 1). The analysis of leaf density showed that 46.8% of the accession had low leaf density, 12.8% had high leaf density and 40.4% had an intermediate leaf density (Figure 1).

The analysis of the young stems of aerial yam which were all soft and round, showed that 51.1% of the accession had green colour while 48.9% had a purplish green colour.

Table3: Distribution of *D. bulbifera* accessions among classes of qualitative morphological traits

Descriptors	Type	Number of Accession	Frequency
Leaf shape	Cordate broad	69	73.4%
	Cordate long	25	26.6%
Young Leaf colour	Yellowish	11	11.7%
	Pale green	61	64.9%
	Purplish green	22	23.4%
Mature leaf colour	Pale green	77	81.9%
	Purplish green	17	18.2%
Young stem colour	Green	48	51.1%
	Purplish green	46	48.9%
Mature stem colour	Green	71	75.5
	Purplish green	23	24.5%
Leaf density	Low	46	46.8
	High	11	12.8
	Intermediate	37	40.4
Bulbil shape	Round	7	7.5%
	Oval	33	35.1%
	Irregular	37	39.4%
	Elongated	17	18.1%
Skin texture	Smooth	6	6.4%
	Rough	62	66%
	Wrinkled	26	27.7%
Twinning direction	Clockwise	94	
Young stem hairiness	Absent	94	
Leaf type	Simple	94	





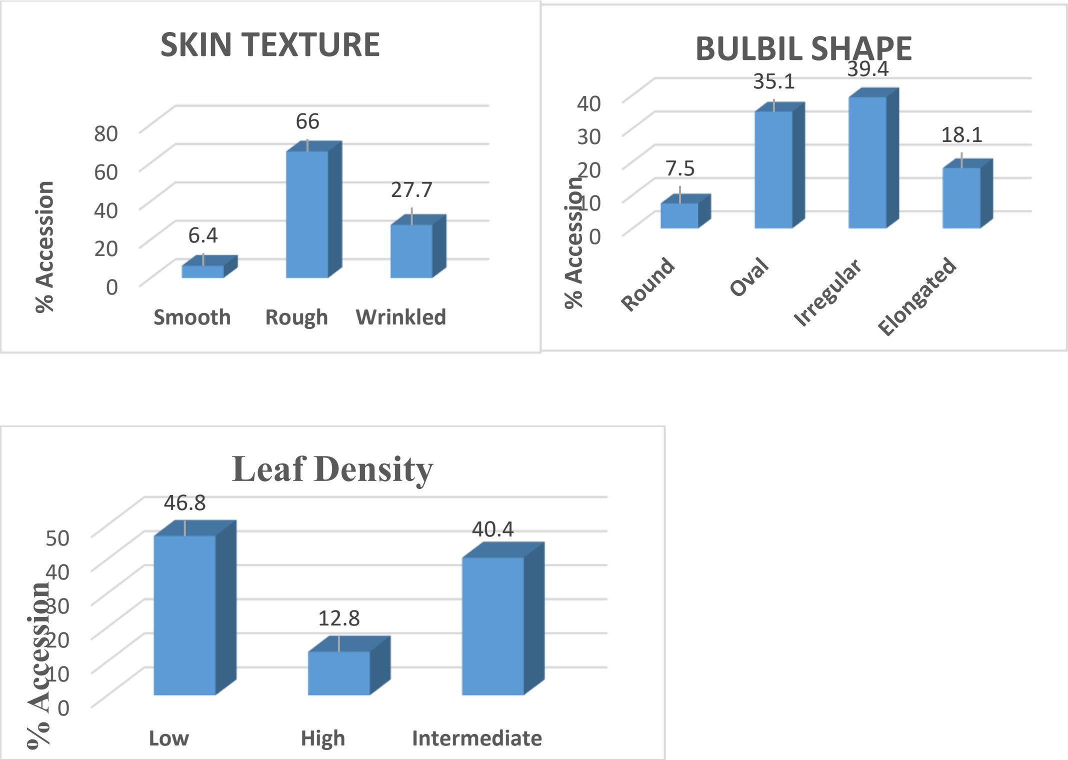


Figure1: Histogram distribution of some qualitative morphological traits on *D. bulbifera* as observed on the field green colour.

All the 94 *D. bulbifera* accessions produced aerial bulbils which displayed various shapes (Figure 1). The analysis showed that 7.5% of the accessions produced round aerial bulbils with dark and light brown outer skin colour, 35.1% had oval with dark-brown outer skin colour, .39.4% had irregular shape with light brown colour and 18.1% accessions had an elongated shape and greyish colour. Bulbil skin texture observed from the accession were smooth (6.4%), rough (66%) and wrinkled (27.7%).

Descriptive statistics including the minimum, maximum, grand mean values and the results of the analysis of variance of the accessions were summarized as obtained for both seasons for each of the traits evaluated in Table 4. In general, *D. bulbifera* accession differed significantly ($P<0.001$) for most of the attributes. The accessions showed a wide range of variability for most of the characters as all the traits exhibited broad ranges between the minimum, maximum and the mean values.

Results from analysis of variance for vine length indicated highly significant genotypic difference in vine length of the accessions ($P < 0.001$). The mean vine length of all the accession was 1.85m and it ranged from 0.87m to 3.47m. A length difference of over 2 m among the accession was observed. The accession TDb/3060 (3.47m) produced the tallest plant height followed by TDb/3087 (3.23m) and TDb/3045 (3.21m).

Stem diameter of *D. bulbifera* accessions ranged from 1.89 to 5.69 mm with a mean of 3.30mm. The accessions varied very highly significantly in their stem diameter ($P < 0.001$). The widest stem diameter was observed in TDb/3091 with a mean of 5.69 mm, followed by the accession YA4 and YF4 with means of 5.40 mm and 4.32 mm respectively. However, the matured stems of aerial yam showed that 75.5% had greenish colour while 24.5% had a purplish

Table 4: Descriptive and variance statistics of the 17 quantitative phenotypic traits employed for the diversity study of the 94 *D. bulbifera* accessions

Variables	Genotype mean square	Error mean square	Grand mean	Variance Ratio	Minimum	Maximum
PH	0.41	0.15	1.85	2.68***	0.87	3.47
Sdia	0.62	0.34	3.30	1.84***	1.89	5.69
NL	256.7	309.90	60.60	0.83ns	20.00	123.00
Llenght	6.77	3.12	12.63	2.17***	7..20	18.12
Lwidth	3.27	2.48	9.91	1.32ns	2.62	17.60
TFB	54.09	18.77	60.81	2.88***	47.00	69.00
Bdia	49.11	44.00	32.55	1.12ns	9.45	61.40
BWP	0.24	0.07	0.70	3.17***	0.02	2.33
TNB	1087.80	362.30	51.99	3.00***	9.00	131.00
SPP	2.79	1.34	6.00	2.08***	1.00	11.00
Bwidth	6.50	1.26	5.30	5.17***	1.48	9.64
Byield	0.55	0.25	1.27	2.23***	0.00	3.88
NBMS	37.33	4.34	8.74	8.60***	3.00	24.00
YMD	0.52	0.30	2.27	1.70**	1.00	4.00
YLB	0.42	0.11	1.30	3.75***	1.00	3.00
YLS	0.64	0.34	1.53	1.90***	1.00	3.00
YAD	0.22	0.14	1.26	1.53**	1.00	3.00

* PH=Vine lenght (m) ; Sdia= Stem diameter (mm); NL=Number of leaves; Llength=Leaf length (cm); Lwidth= Leaf width (cm); TFB=Time to first bulbils appearance; Bdia=Bulbils diameter (mm); BWP=Bulbils weight per plot (kg); TNB=Total number of bulbils per plot; SPP=Number of stem per plant; Bwidth=Bulbils width (cm); Byield=Bulbil yield (tonha^{-1}); NBMS=Number of branches on main stem; YMD=Yam mosaic virus(1-5); YLB=Yam leaf blight(1-5); YLS=Yam leaf spot(1-5); YAD=Yam anthracnose disease.

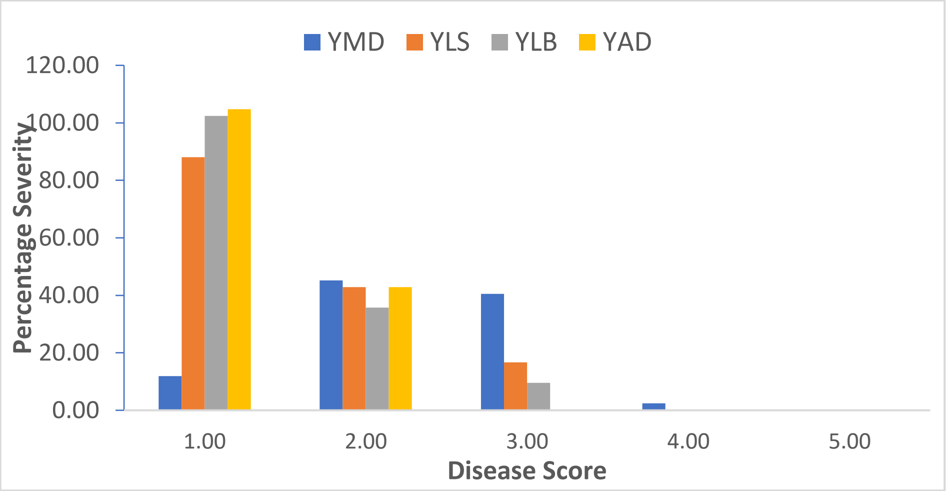
Result showed a very highly significant variation in the number of branches per plant among the accession ($P < 0.001$). The mean number of branches per plant varied between 3.00 branches per plant to 24 branches per plant with an overall mean of 8.74 The number of leaves per plant was not significantly different among the accession ($P > 0.05$). The mean number of leaves per plant for all the accession was 60.60 and it ranged from 20.00 to 123.00 leaves per plant. The highest number of leaves per plant was produced by the accession TDb/3060 (123) and followed by TDb/3087 (120).

With respect to productivity traits such as bulbil weight per plot, number of bulbils per plot and bulbil yield, there were big ranges between the lowest and the highest values obtained for both seasons. These traits are invaluable in varietal identification and the variations can play a significant role in the conservation, diversity analysis and genetic improvement of *D. bulbifera*.

Bulbil weight per plot (BWP) ranged from 0.02kg to 2.33 kg with an overall average of 0.70kg. There was a highly significant ($P < 0.001$) variation observed in the bulbil weight among the accessions of *D. bulbifera*. The highest weight was recorded in YC2 with a mean fresh bulbil weight of 2.33kg. Similarly, the total number of bulbils per plot obtained at harvest showed differences which were as high as 131 among the accessions in both years. Number of bulbil per plot varied between 9 to 131 bulbils per plot.

Bulbil yield showed a highly significant ($P < 0.001$) variation from the analysis of variance. Overall mean of bulbil yield of all accessions was 1.27 ton/ha with a maximum yield of 3.88 ton/ha. The result of the evaluation showed that there was high variation among the accession for each of the traits in both years. The accessions exhibited significant variability for most of the traits assessed over the two years. Traits assessed over the years included; vine length (m), stem diameter (mm), number of leaves, leaf length (cm), leaf width (cm), time to first bulbils appearance, bulbils diameter (mm), bulbils weight per plot (kg), total number of bulbils per plot, number of stem per plant, bulbils width (cm), bulbil yield (tonha^{-1}), number of branches on main stem. Other traits include severity of diseases and pest such as yam mosaic virus (YMV), yam leaf spot (YLS), yam leaf blight (YLB), and yam anthracnose disease. (YAD). The results from the analysis of variance showed that the 94 accessions of *D.bulbifera* tested were significantly ($P<0.001$) affected by the different diseases studied across the years (Table 4). However, disease severity across all the accessions were generally low, which may be due to the genetic make-up relating to disease resistance developed by the tested accessions. The tested accessions showed a range of score between 1 and 3 across the different diseases. Evaluation of plants for yam mosaic disease, yam leaf spot, yam leaf blight and yam anthracnose disease revealed that 11.90% of the accessions were resistant to YMV, 88.10% were highly resistant to YLS while 9% were susceptible to YMV. (Figure 2).

The patterns of variation and the relative importance of each descriptor in explaining the observed variability were assessed for 94 *D. bulbifera* accessions studied using principal component analysis (PCA). The results of the accession by trait biplot explained 52.9% of the total variation (Figure 3). Based on PC1 and PC2, total number of bulbils per plot, number of branches on main stem, number of stems per plant, vine length, bulbil weight per plot, bulbils yield, bulbil width and bulbil diameter had relatively long vectors, suggesting that there was relatively large variation among the accessions. The influence of the traits on the principal components and the levels of correlation among them were observed on traits like vine length (PH), number of branches on main stem (NBMS), number of stem per plant (SPP), total number of bulbil per plot (TNB) which were found to be positively correlated on the X-axis as well as bulbil weight per plot (BWP), bulbil yield (Byield) were positively correlated on the y axis.



YMV – Yam mosaic virus,, YLB - yam leaf blight, YLS - yam leaf spot () and YAD - yam anthracnose disease ().

Figure 2: Histogram distribution of aerial yam diseases on the field

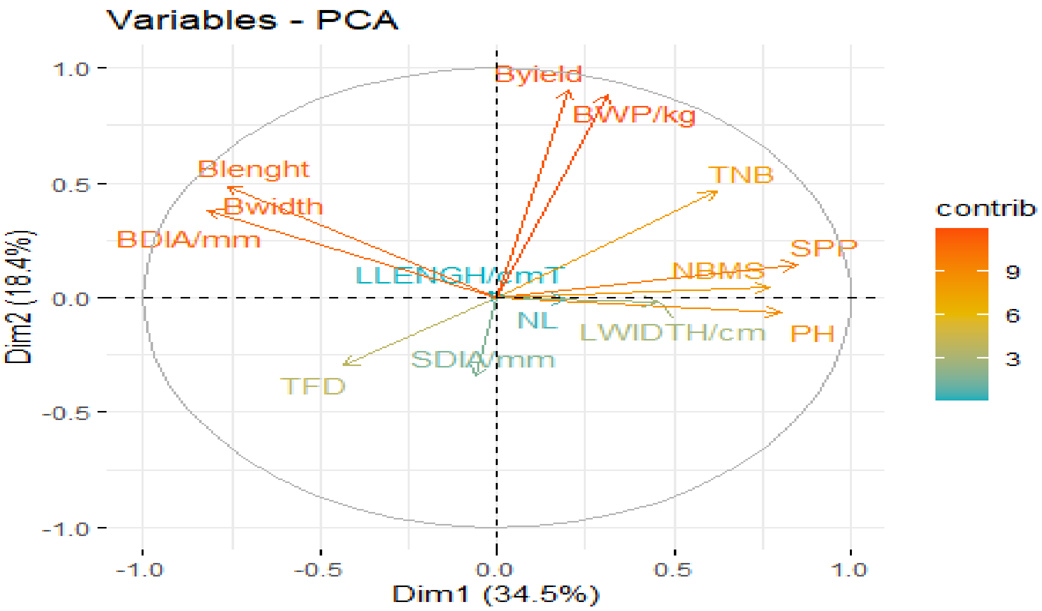


Figure 3: Plots showing the contributions of traits to variability in aerial yam accessions

Blength= Bulbil length; Bwidth= Bulbil width; BDIA= Bulbil diameter; LLength= leaf length; SPP= number of stem per plant; SDIA= stem diameter; TNB= Total number of bulbils per plot; Byield= Bulbil yield; BWP/kg:=Bulbil weight per plot; NL= Number of leaves; Lwidth= Leaf width; PH=Vine Length; NBMS= Number of branches on main stem.

The hierarchical clustering analysis employed for the grouping of aerial yam accessions were based on the evaluated quantitative agronomic characters and these differentiated the 94 *Dioscorea bulbifera* accessions into two major clusters (Figure 4) with sub-clusters within the main clusters. Cluster one (1) was the largest cluster and was accounting for 68 accessions which consisted of a mixture of accession with its members widely distributed across the different yam agro-ecologies. Cluster one was characterized by accessions with increased tolerance and resistance to the pathological effects of YMV, YLS and YLB severities, also having high bulbil length but moderate bulbil yield, leaf length, and low bulbil weight per plot with a low number of bulbils per plant. Cluster two (2) consisted of twenty-six (26) accession sourced mostly from different states in south eastern Nigeria, including one accession from Togo (TDb/3096). Cluster two consisted of accessions that were characterized by a significant high yield, high bulbil weight per plot, high number of bulbils per plot, tolerance to different pathological effects and also having high number of stems per plant.

The combined correlation analysis was among different yield traits and yam disease as shown in Table 5. There was significant correlation between the traits in the accession across the two cropping seasons. Bulbil yield, which reflects economic productivity showed a positive and significant relationship with bulbils weight per plot (r= 0.979***) and total number of bulbils (r= 0.454**) however, bulbils yield relationship with yam mosaic virus, yam leaf spot, yam leaf blight and yam anthracnose disease where insignificant weak negative and positive. Relationship with bulbils yield correlated strongly and positively with non- marketable (r = 0.349*) and marketable (r = 0.38*). Result show that bulbils weight per plot exhibited a strong and positive correlation with total number of bulbils (r=0.507**), 20bulbils weight (r= 0.359*), number of non-marketable bulbils (r= 0.425*), the number

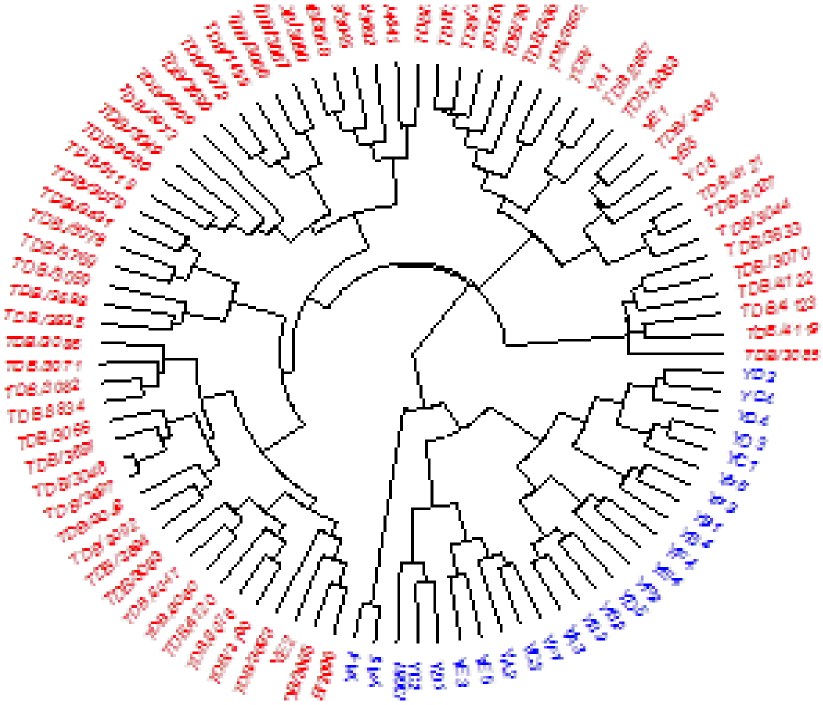


Figure 4: Clustering showing the grouping patterns of the 94 *D. bulbifera* accessions into two main clusters using 16 quantitative agronomic traits based on the Gower genetic dissimilarity matrix.

Cluster 1—Red, Cluster 2—Blue,

Table 5: Pearson's correlation coefficients between quantitative yield traits and aerial yam disease scores

Variables	TNB	20BWT	BL	BW	BYIELD	YMD	YLS	YLB	YAD	NMAKT	MAKT
BWP[a]	0.507**	0.359*	0.153	0.084	0.979***	0.006	0.084	0.036	0.033	0.425*	0.474**
TNB[b]		0.121	-0.13	-0.103	0.454**	0.104	0.069	-0.015	-0.04	0.687**	0.46**
20BWT[c]			-0.117	-0.196	0.258**	-0.014	-0.011	-0.086	-0.146	0.303*	0.691**
BLENGTH[d]				0.70	0.217**	-0.143	-0.047	0.200*	0.093	-0.284*	-0.196
BWIDTH[e]					0.157	-0.081	0.067	0.149	0.130	-0.227*	-0.23*
BYIELD[f]						-0.021	0.098	0.108	0.019	0.349*	0.38*
YMD[g]							0.085	-0.119	-0.098	0.137*	0.044
YLS[h]								0.115	0.241*	0.003	-0.027
YLB[i]									0.244*	-0.113	-0.051
YAD[j]										-0.112	-0.130
NMKTABLE[k]											0.496*

[a]Bulbils weight (kg); [b]Total number of bulbils; [c]20 Bulbils weight (kg); [d]Bulbils Length (cm); [e]Bulbils width (cm); [f]Bulbil yield (tons ha^{-1}); [g]Yam mosaic virus (1-5); [h]Yam leaf spot (1-5); [i]Yam leaf blight (1-5); [j]Yam anthracnose disease (1-5); [k]Non-marketable sized bulbils; [l]Marketable sized bulbils*p0.05; **p0.01.

marketable bulbils (r= 0.474**) and bulbils length (0.153). Total number of bulbils had strong positive and significant correlation with number of marketable bulbils (r = 0.687**) and number of non-marketable bulbils (r =0.46*). 20 bulbils weight positively correlated with number marketable bulbils (r = 0.691**), number of non-marketable bulbils (r=0.303*) but negatively correlated with bulbils weight per plot (r=-0.196) and bulbils length (r=-0.117). All the disease variables correlated with each other and with all the yield related variables. However, yam mosaic virus had a negative and significant correlation with bulbils length (r=-0.143) and a positive significant correlation with number of non-marketable bulbils (r=0.137). Yam leaf spot was positively and significantly correlated with yam anthracnose disease (r=0.241*) while yam leaf blight was positive and significantly correlated with bulbils length (r=0.200*), bulbils width (r=0.149) and yam anthracnose disease. Marketable and non- marketable yield positively correlated with each other (r=0.496*), however non-marketable yield negatively and significantly correlated with bulbils length (r=-0.284*) and bulbils width (r=-0.227*). Marketable yield was also negatively correlated with bulbils length (r=-0.196) and bulbils weight (r=-0.23).

The exploratory factor analysis identified the first two factors (FA) (Eigenvalue >1) that explained 81.8% of the total variation among the traits as most discriminative. The communality after the varimax rotation of each trait's variance explained by the two factors ranged from 0.708 for stem diameter to 0.950 for bulbil yield. The eight traits were grouped into two based on their highest genetic correlations for the first two factors. Factor analysis (FA) 1 was associated with stem diameter(mm), number of leaves, time to first bulbil appearance, bulbil weight per plot/kg and Bulbil yield (ton ha^{-1}); whereas Factor analysis (FA) 2 was associated with leaf length(cm), leaf width and total number of bulbils (Table 6). The average communality and specificity accounted for 81.77%and 18.38% of all the genetic variability in the dataset respectively.

Table 6: Factorial loadings, communalities, specificities and predicted genetic gains based on the factor analysis and ideotype-design (FAI-BLUP) index

Variables	FA1	FA2	Communality	Specificity
Stem diameter(mm)	-0.73	0.48	0.76	0.24
Number of leaves	-0.93	0.1	0.87	0.13
Leaf length(cm)	0.03	-0.98	0.96	0.04
Leaf width(cm)	0.18	-0.88	0.8	0.2
Time to first bulbil appearance	-0.69	0.04	0.48	0.52
Bulbil weight per plot(kg)	0.96	-0.03	0.92	0.08
Total number of bulbils	0	-0.91	0.82	0.18
Bulbil yield (ton ha^{-1})	0.96	-0.02	0.92	0.08
Average			0.82	0.18

F1, and F2, = factors 1 and 2, respectively. The bold represent the traits with high (>0.5) contribution to each factor.

The analysis of FAI-BLUP index ranged from 2.76 to 8.11**.** Of the 94 *Dioscorea bulbifera* accessions evaluated, the factor analysis and ideotype-design (FAI-BLUP) index identified nine (9) accessions as high-performing accessions for multiple traits with < 3.5FAI-BLUP index values (Figure 5). These accessions (YC2, YBI, YB5, YD4, YA5, YA3, YB4, YA1, YC3) show the greatest potential for the simultaneous improvement of the measured traits in aerial yam (*Dioscorea bulbifera*) breeding programs. Crosses involving these accessions are expected to increase the frequency of favorable alleles in the resulting progenies while maximizing genetic variability and heterosis.

DISCUSSION

The use of an appropriate descriptors is very essential for diversity expression. The descriptor list for *Dioscorea* spp. according to Asfaw, (2016) was found to be a useful tool in assessing the available genetic variation among *D. bulbifera* accessions from southeast Nigeria and other selected regions in West Africa. The data which have been collected and analysed in the present study have shown significant variability in the accessions tested, providing large scope for management, conservation and breeding of new varieties with novel traits. Tewodros and Gatechew (2013) also used morphological descriptors and reported the existence of important genetic variation among D. bulbifera accessions from different locations and agro-ecological in Ethiopia.

Generally, the 25 traits contributed significantly to phenotypic variability indicating a high degree of morphological polymorphism within the accessions of D. bulbifera used in the current study. Similar observation was made by

(Norman *et al*., 2011; Adjei *et al*., 2022), who reported that observed variations are likely due to sexual recombination and possible mutation.

Identified in this study, was the cordate leaf shape which was a dominant shape observed among the accessions of *D. bulbifera*. Similar results were obtained by Anokye *et al*. (2014) and Munaweera *et al*. (2020) while studying the morphological variations of *Dioscorea* spp. in Ghana and Sri Lanka, respectively. Aerial bulbils of *D. bulbifera* accessions had either round, irregular or wrinkled shapes with dark-brown and light-brown outer skin colour, this is similar to the findings of Islam *et al.* (2011) and Mulualem and Weldemichel (2013). Results observed showed variations in shapes of aerial bulbils which are very important in the selection of preferred genotypes by farmers and breeders for cultivation and genetic improvements, respectively. These results indicate that there is a large and readily exploitable genetic variability among the aerial yam accessions studied here.

The highly significant differences observed on the quantitative traits indicated the presence of genetic variation among the accessions studied. Kouam *et al.,* (2018), Bekele and Bekele (2020) and Adjei *et al*. (2022) reported morphological variations of the quantitative and qualitative traits of accessions studied. This significant variability among the 94 *D. bulbifera* accessions was expected, since the study was carried out on accessions sourced from different backgrounds. Similar observations have been reported for other *Dioscorea* species such as *D. alata* (Bressan *et al.* 2011) and *D. dumetorum* (Adeigbe *et al*. 2015) as well as other root and tuberous species such as *Manihot esculenta Crantz* (Kosh-Komba *et al.* 2017).

(The selected accessions are shown in red and the unselected in black circles. The circle represents the cut-off point according to the selection pressure).

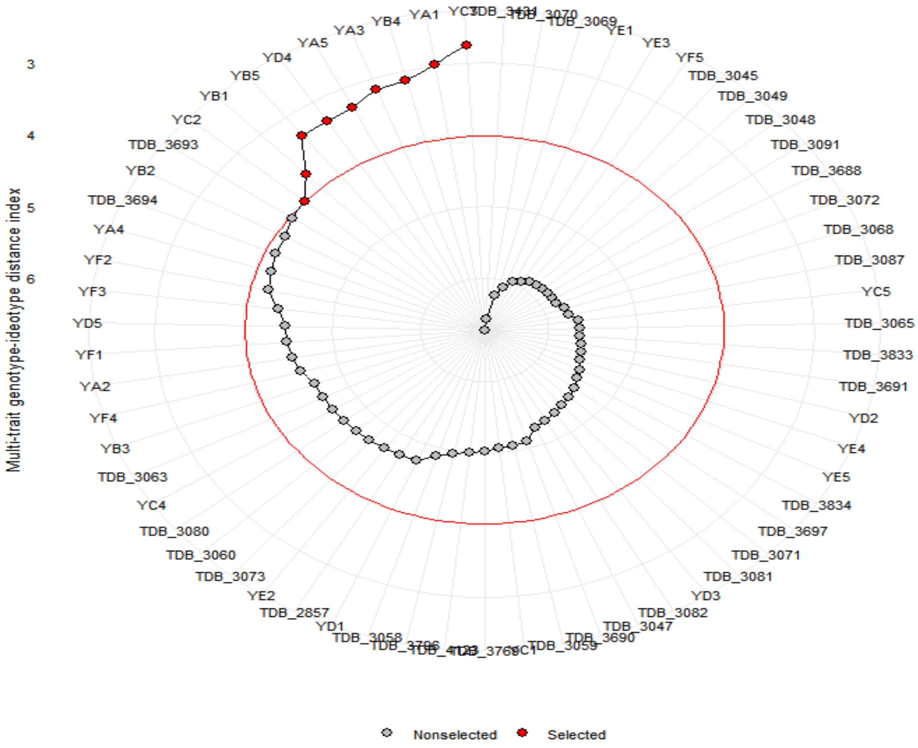


Figure 5: Aerial yam accession ranking and accessions selected using the factor analysis and ideotype-design (FAI-BLUP) index.

This study revealed variations in the response of the accession to yam mosaic virus, yam leaf spot, yam leaf blight and yam anthracnose disease. Most of the accessions had acceptable yam mosaic virus tolerance and other pathological disease resistance/ tolerance level (1 or 2). This indicates high heritability of YMV resistance; however, this yam species is not known for regular cultivation, as it is regarded as forest/wild species (Kundu *et al*. 2021: Ikiriza *et al*.2019). The identification of the genetic potential and gene reservoir for genetic improvement from the existing genetic pool of landraces for high resistance/tolerance to pathological diseases could offer a potential hope for consideration of *D. bulbifera* bulbil improvement.

The 94 aerial yam accessions exhibited significant variations in morphological and agronomic variables such as vine length, stem diameter, total number of bulbils per plot and number of branches on main stem, bulbil weight per plot (kg), bulbil diameter, bulbil width (cm) and bulbil yield (tonha^{-1}) in both years and combined analysis. These variables, which were good indicators of growth and yield showed considerable agronomic characteristics of the aerial yam accessions evaluated in the study and the findings were in consonance with previous studies by Lenis *et al.* (2006), Ojulong*, et al*. (2007), Ojulong, *et al.* (2010), El-Sharkawy (2012), and Odedina *et al.* (2015) who submitted that these variables exact strong influence on bulbil yield of aerial yam. These traits are valuable in varietal identification and the variations can play a significant role in the conservation, diversity analysis and genetic improvement of *D. bulbifera* as earlier explained by Beyene, (2013). Such variations among aerial yam specie might be related to their genetic origin, genetics of the specie and geographical variation sources where they are grown. These results of morphological variations in aerial yam specie were also consistent with the previous report of Odisha by Behera *et al*. (2009) and yams of Sierra Leone (Norman *et al.* 2011) who reported morphological diversity among 52 yam genotypes from Sierra Leone with shoot traits (shoot growth rate, position, size and density) contributing significantly to variations. Jayeola and Oyebola (2013) reported significant variations in petiole length, leaf number and stem length and internode number among populations of *D. bulbifera* studied. Beyene (2013) also noted significant variations in stem length among *D. bulbifera* accessions in regions of Ethiopia.

The knowledge of existing variability and the degrees of association among quantitative traits are paramount for selecting superior accessions for breeding programs. The very highly significant variations that were observed in some of the quantitative traits, especially the yield component traits, indicated a huge and readily available genetic differentiation in the accessions of *D. bulbifera.* Kouam et al. (2018) reported highly significant variations for bulbil yield components in a study conducted on *D. bulbifera* accessions. Similar observations of high genetic variability using quantitative traits have been reported in other yam species such as *D. alata* (Hazel, 1943), *D. rotundata* (Asfaw *et al.* 2016), and *D. dumetorum* (Adeigbe, *et al*. 2015; Siadjeu, *et al*. 2015). These high variations in quantitative traits are an indication that these traits could be used as the basis for the selection of accessions with high genetic merit.

The key agronomic traits that best discriminated the 94 accessions of *D. bulbifera* were those which resolved on PC1. These traits, including bulbil yield, bulbil weight, vine length, number of branches on main stem, number of stems per plant, and number of bulbils could be utilized in evaluating genetic diversity among related *Dioscorea* spp. Agre *et al.* (2019 and 2021) and Siadjeu *et al.* (2015) had reported the significant contribution of these traits in discriminating among yam accessions.

The hierarchical clustering in this study revealed similarities among accessions that were grouped in the same cluster. Hierarchical clustering revealed that Cluster 2 was the most promising group for superior bulbil yield attributes, high resistance to YMV severity, and also having high number of stems per plant. Cluster 1 had some promising accessions for resistance to YMV severity. Hybridization within each cluster may result in less genetic gain due to the close relatedness of the accessions within each cluster (Maranna, *et al*. 2021). Similarly, hybridization between accessions belonging to different clusters will result in the generation of different breeding materials.

Breeders frequently attempt to blend numerous desirable features into a new genotype in order to create high performance and increased variability. It is frequently difficult to choose a genotype from the ideotype when assessing many attributes. The FAI-BLUP index was used to rank *D. bulbifera* accessions based on the data from the multiple traits that were measured. The FAI-BLUP index selected nine accessions (YC2, YBI, YB5, YD4, YA5, YA3, YB4, YA1, YC3) as promising *D. bulbifera* accessions for a yam improvement program. The FAI-BLUP model has also been used to assess ideal yield and yield-related variables in white Guinea yam genotypes (Norman *et al*. 2022), wheat genotypes (Meier *et al.,* 2021), and eggplant genotypes (Uddin *et al.* 2021). Multiple trait selection using the FAI-BLUP index was found to be beneficial in identifying high performing aerial yam accessions and also in estimating the expected genetic gains of the selected accessions for the qualities studied. This supports the notion that the FAI-BLUP is a potentially useful strategy for simultaneously improving many attributes using projected genetic influences (Rocha *et al.,* 2018).

CONCLUSION

This study concluded that morphological variability existed among accessions of *D. bulbifera* and that such variation existed in vine length, stem diameter, number of stems per plant, total number of bulbils per plot, bulbil width, and bulbil weight per plot and are important traits that should be given attention in making effective selection for parents in aerial yam (*D. bulbifera*) breeding. This study confirmed that positive correlation existed among yield contributing traits and yield per hectare. Furthermore, the dendrogram showed that the selected population was divided into two primary clusters based on the observed quantitative traits. Accessions YC2, YBI, YB5, YD4, YA5, YA3, YB4, YA1, YC3 had the best in terms of yield and yield components based on yield data in this study, and should be given attention in future breeding programmes in other ecological zones in Nigeria.

Competing interests:

The authors report there are no competing interests to declare.

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