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Morphological Characterization of Some Water Yam (*Dioscorea alata* L.) Germplasm in Ghana

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Abstract: The Asiatic *Dioscorea alata* yam species is an important food crop, especially in Cote d'Ivoire. It has high yield and stores longer than *Dioscorea cayenensis/rotundata* yam and therefore fills the hunger gap created when other yam types are not available. However, very little research has been done on it. Several cultivars are susceptible to pests and diseases and lack the aesthetic values of smooth skin and elegant tuber shape of *Dioscorea rotundata* that appeal to consumers in the market. This study therefore sought to establish the genetic variability and relationships among 35 accessions of Ghanaian *Dioscorea alata* together with 14 accessions introduced from International Institute of Tropical Agriculture in Nigeria. Morphological variation was studied to establish genetic relationship among 49 accessions assembled as *Dioscorea alata* in Ghana. Principal component analysis (PCA) indicated that the first two principal components accounted for 25.27% of total variation from accessions with PCA1 and PCA2, contributing 13.92% and 11.35%, respectively. Cluster analysis performed clearly separated the 49 accessions into three main groupings using unweighted neighbour-joining method. Morphological descriptors were able to group the accessions into distinct clusters independent of place of collection.

Key words: *Dioscorea alata*, germplasm, characterization, morphological, Ghana.

1. Introduction

Of all yam species, *Dioscorea alata* and the *Dioscorea cayenensis/rotundata* complex are the most widely cultivated and have real economic significance in Africa [1]. Yam is cultivated in all the ecological zones of the country [2-6]. The yams are largely grown in the Guinea Savannah zone where *Dioscorea rotundata* thrives well but is grown in the forest and Sudan Savannah zones. *Dioscorea alata*, *Dioscorea cayenensis*, *Dioscorea dumentorum* and *Dioscorea praehensilis* are mostly grown in the forest zone. In terms of utilization as food, *Dioscorea rotundata* is the most popular yam in Ghana followed by *Dioscorea alata*, *Dioscorea cayenensis*, *Dioscorea dumetorom*, *Dioscorea esculenta* and *Dioscorea praehensilis.* Although cultivated in most tropical countries, yam has been produced over 95% of the world's output alone in West Africa [7], serving as the staple carbohydrate source for millions of people [8, 9].

The Asiatic *Dioscorea alata* Linn, introduced to West Africa some hundred years ago, is fairly widely grown [10]. Very few varieties of the species are used for major food products in West Africa, or further processed. This is attributable to its perceived unimpressive food quality traits such as its less suitability for the preferred cohesive and elastic dough in "fufu" or pounded yam. Several cultivars are also susceptible to pests and diseases and lack aesthetic values of smooth skin and elegant tuber shape appealing to consumers in the market [11]. Even though *Dioscorea alata* is also eaten as boiled, it is less preferred to *Dioscorea rotundata* varieties in most West African countries except Cote d'Ivoire where it

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is most widely grown and preferred. This difference in preference is mainly due to the food forms of the individual country. Breeders are keen to improve the food quality of the species as good agronomic flexibility and productive potential [11]. The traditional cultivars have not been adequately characterized hindering the breeding and selection of *Dioscorea alata* cultivars with novel or improved characteristics. This also makes reference to varieties ambiguous unreliable and impossible to determine the true genetic variation in *Dioscorea alata* [12].

Additionally, although guidelines exist for the safe movement of yams [13], there has been little official sharing of germplasm between countries. The informal nature of the yam trade and exchange of planting materials among farmers, have also led to duplication of planting materials whose ethnic or local names have changed in different localities. Thus, the same material may be called differently in another region [12]. In order to exploit *Dioscorea alata* for diversity, it has to be well characterized for further investigation so as to influence usage of the crop.

Plant breeders over the years have relied heavily on phenotypic markers for cultivation [14, 15]. These markers are still used in Africa because it is readily available for use, particularly where the capacity to use molecular markers is not yet fully developed to carry out *in situ*, and it is relatively inexpensive and easy to carry out [16]. For instance, many released cultivars in Ghana were developed based on morphological descriptors [17]. Morphological characterization is a highly recommended the first step that should be made before more in-depth biochemical or molecular studies are attempted. The general objective of this study therefore was to conduct preliminary investigation into *Dioscorea alata* in Ghana to facilitate further studies. Specifically, the study was designed to investigate genetic diversity and relationships among some Ghanaian *Dioscorea alata* germplasm based on morphological traits in order to facilitate future molecular characterization as well as research and development of *Dioscorea alata* germplasm.

2. Materials and Methods

Forty-nine accessions of *Dioscorea alata* were used to assess the differences in morphological traits. Among these accessions, 35 of them were obtained from Council for Scientific and Industrial Research (CSIR)-Crops Research Institute (CRI) at Fumesua in the Ashanti region of Ghana, while other 14 cultivars were collected directly from International Institute of Tropical Agriculture (IITA) in Nigeria (Table 1). The study was conducted in the major cropping season of 2011 at the CSIR- CRI at Fumesua, Ghana. The land, which had been previously cropped was slashed, ploughed, harrowed and manually ridged. The experimental design used was augmented randomized complete block design (RCBD) with three blocks. Each block was divided into rows of 10 m in length and 1.0 m between rows. Each row had 8-10 stands of each accession. The checks, Matches and TDa 01/0004 from CSIR-CRI and IITA respectively were replicated in all the blocks, with inter-block spacing of 2 m. Tuber setts were sown directly in the field on mounds (35-40 cm high) at a spacing of 1 m × 1 m under rain-fed condition. An estimated total of 490 plants were cultivated. Standard agronomic practices such as weeding and staking were adopted. No chemical amendments were applied to the soil. Data were collected using a standardized crop descriptor for yam [18]. A total of 107 characters were scored on binary basis for distinguishing the accessions.

All of 107 morphological descriptors (not shown) were converted to binary form by converting all classes of a characteristic and clustering it using GenStat Discovery Edition 3 statistical software (Jaccard’s similarity coefficient approach) in classifying the accessions. Cluster analysis was used to estimate pairwise genetic similarity or dissimilarity values among accessions.

Further, selected traits were subjected to principal component analysis (PCA) to examine the percentage contribution of each trait to total genetic variation, or

Table 1 "Water yam" accessions collected and used in the study.

Accessions	Sources
AGA 97 023	CRI
TA 97 148	CRI
FA 89 026	CRI
AGA 97 136	CRI
SO 89 149	CRI
TA 97 106	CRI
TA 97 025	CRI
TA 97 116	CRI
FA 89 036	CRI
TA 97 121	CRI
82/318	CRI
82/526	CRI
SO 89 066	CRI
SO 89 100	CRI
SO 89 103	CRI
SO 89 028	CRI
TA 97 113	CRI
AGA 97 115	CRI
TA 97 065	CRI
SPR	CRI
AGA 97 224	CRI
TA 97 130	CRI
SO 89 039	CRI
FA 89 039	CRI
AGA 97 204	CRI
SO 89 120	CRI
GHA 89 107 (A)	CRI
TA 97 144	CRI
FA 89 019	CRI
AGA 97 066	CRI
TA 97 131	CRI
TA 97 143	CRI
TDa 00/0003	IITA
TDa 01/00046	IITA
TDa 98/01168	IITA
TDa 00/00045	IITA
TDa 98/01174	IITA
TDa 291	IITA
TDa 98/01176	IITA
TDa 02/00151	IITA
TDa 98/01166	IITA
TDa 00/00046	IITA
TDa 297	IITA
TDa 02/00012	IITA
TDa 01/0004 (A)	IITA
TDa 01/0004 (B)	IITA
Matches (A)	CRI
Matches (B)	CRI
Matches (C)	CRI

Note: the last five italicized accessions were checks.

the range of genotypic variability in the population using GenStat Discovery Edition 3. In the PCA analysis, eigenvalues of morphological data and variation percentage expressed by each PC and accumulated variability percentage were also generated. Dimensional scatter diagram of the PCs with variability > 10% was then plotted to observe the dispersion of the accessions on the two PCs.

3. Results and Discussion

3.1 Variation in Qualitative Traits Assessed

3.1.1 Tuber Flesh Colour

Fig. 1 shows the frequency of various types of tuber flesh colour among the 49 accessions of *Dioscorea alata*. The *Dioscorea alata* accessions examined phenotypically based on their tuber flesh colour at central transverse cross-section exhibited wide range of polymorphism (five types, namely, white, white with purple, yellowish white/off-white, orange and yellow flesh were observed).

In all, 22 (44.9%) had yellowish white/off-white flesh colour. Nine accessions had white and white with purple tuber flesh colour, representing 18.4%. The next predominant colour was orange tuber flesh where seven (14.3%) out of the total 49 materials had orange flesh. Only two (4.1%) of the collections had yellow flesh colour at central transverse cross-section.

3.1.2 Tuber Skin Colour beneath Bark

Three types of tuber skin colour beneath bark were observed. They are light maroon, dark maroon and greyish. A majority of 37 (75.5%) out of the total accessions had light maroon skin colour beneath bark while 10 (20.4%) had dark maroon colour (Fig. 2).

Accessions with greyish skin colour beneath bark were at very low frequency (4.1%) among the total accessions.

3.1.3 Texture of Tuber Flesh

Significant phenotypic variability was identified among the individual accessions with respect to texture of tuber flesh (Fig. 3). In all, 26 (53.1%) of the accessions had smooth tuber flesh when cut across, while 22 (44.9%) and one (2.0%) had grainy and very grainy tuber flesh, respectively.

3.1.4 Leaf Shape

Forty six (90.1%) accessions had cordate leaf shape varying from cordate long, broad and cordate recording the least relative frequency (23.5%). Few (5.1%) of the materials studied had sagittate leaf shape and ranged from sagittate long to broad (Fig. 4).

3.1.5 Leaf Margin Colour

The leaf margin colours present were green, purple and yellowish. The frequency of various leaf margin colours is presented in Fig. 5. Accessions with green

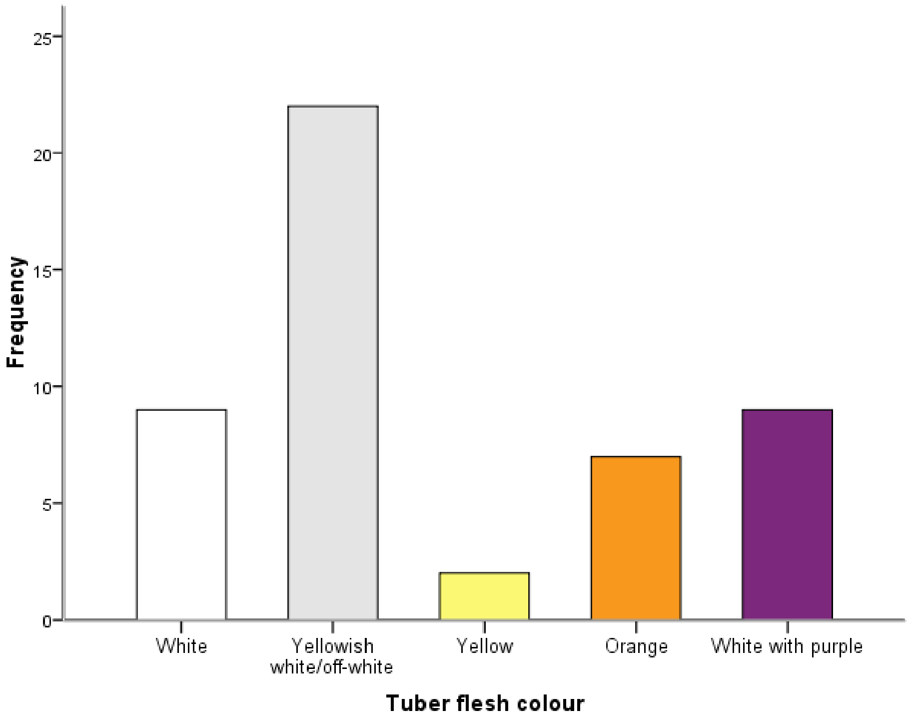

Fig. 1 Frequency of flesh colour at central transverse cross-section in *Dioscorea alata* germplasm.

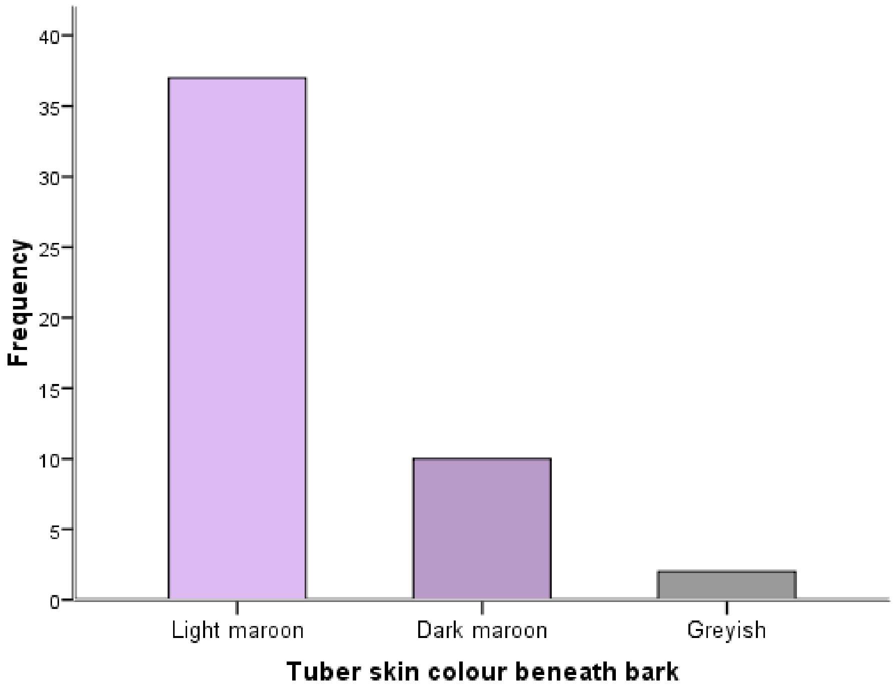

Fig. 2 Frequency of tuber skin colour beneath bark in *Dioscorea alata* germplasm.

Fig. 3 Frequency of tuber texture flesh in *Dioscorea alata* germplasm.

Fig. 4 Variation in leaf colour and shape among *Dioscorea alata* accessions: (a) saggitate long green leaves; (b) cordate broad dark green leaves; (c) cordate long green leaves; (d) saggitate broad light green leaves.

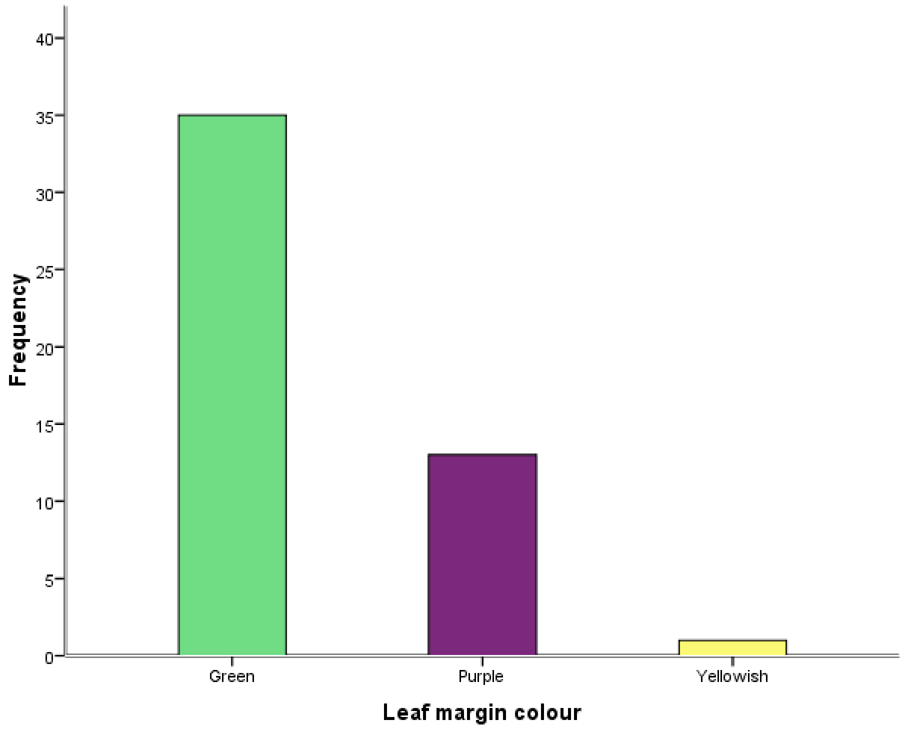

Fig. 5 Frequency of leaf margin colour in *Dioscorea alata* germplasm.

leaf margin colour predominated the other colours observed. Out of 49 *Dioscorea alata* accessions used for the study, 35 (71.4%) had green leaf margin colour, 13 (26.5%) had purple leaf margin with only one (2.0%) having yellowish margin colour.

3.1.6 Petiole Wing Colour

Three types of petiole wing colour were observed: green, green with purple edges and purple (Fig. 6). Among the total accessions evaluated, 32 (65.3%) had their petiole wing colour to be green. The second predominant colour observed was purple. This colour was recorded among nine accessions representing 18.4%. Eight (16.3%) out of the 49 accessions had green with purple edges as their petiole wing colour.

3.1.7 Spine Shape

Among the 49 accessions examined morphologically, only six (12.2%) had spines on the stem with varying shapes (Fig. 7). Out of the six accessions with spines, TDa 01/00046 and TDa 98/01176 had straight spines observed on the stem wings while TDa 02/00151, TDa 00/00046 and TDa 01/0004 had their spines curved downwards. All the collections that had spines were from IITA, and the spines were located on the wings of the stem.

3.1.8 Branching of Stem above Ground

Among the 49 *Dioscorea alata* accessions evaluated, 13 of them representing 26.5% of the accessions had no branches above ground level, whereas 36 (73.5%) recorded branching above ground (Fig. 8). Out of the 36 accessions where branching was noticed, there were varying number of branching that was observed for the different accessions. Twenty-six, eight and two representing 72.2%, 22.2% and 5.6% had one, two and three branches above ground, respectively.

3.2 Variation in Quantitative Characters Assessed

Among the 49 *Dioscorea alata* accessions, the young stem length assessed at 20 d after plant emergence (mean of five plants per each accession) ranged from 6 cm to 98.9 cm with a mean of 44.1 cm and coefficient of variation (CV) of 58.2%. Length of internode recorded at 1 m height on average of five plants per each accession on mature stem ranged from 5 cm to 10 cm with a mean of 8.1 cm and a CV of 17.3% which is the least variation among the quantitative parameters measured. Of the 49 accessions, petiole length ranged between 2 cm and 3 cm with a mean of 2.2 cm and a CV of 18.9%. Five plants per each accession were selected randomly to record the matured leaf petiole length.

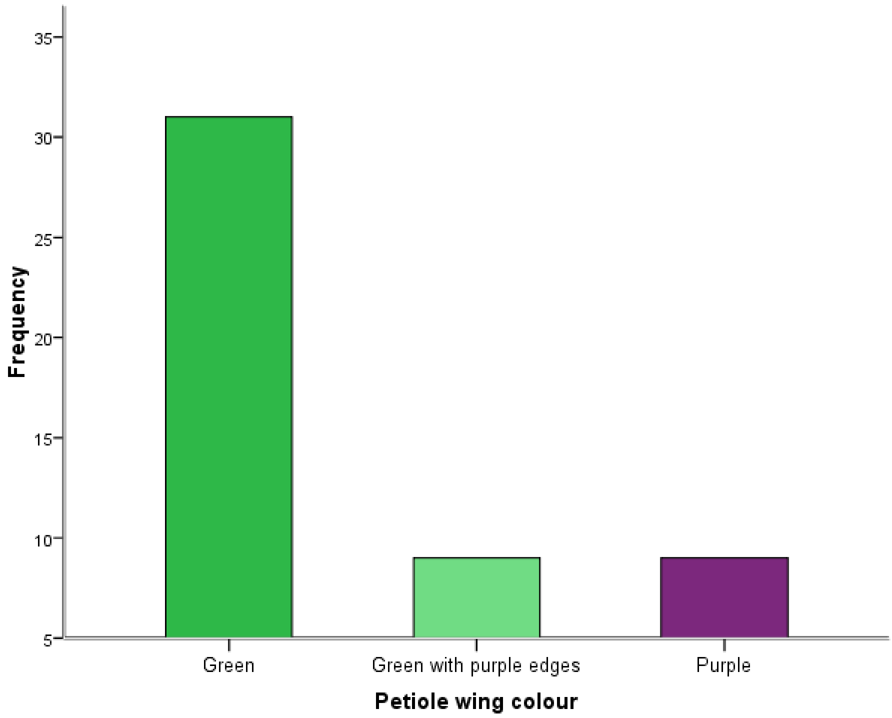

Fig. 6 Frequency of petiole wing colour in *Dioscorea alata* germplasm.

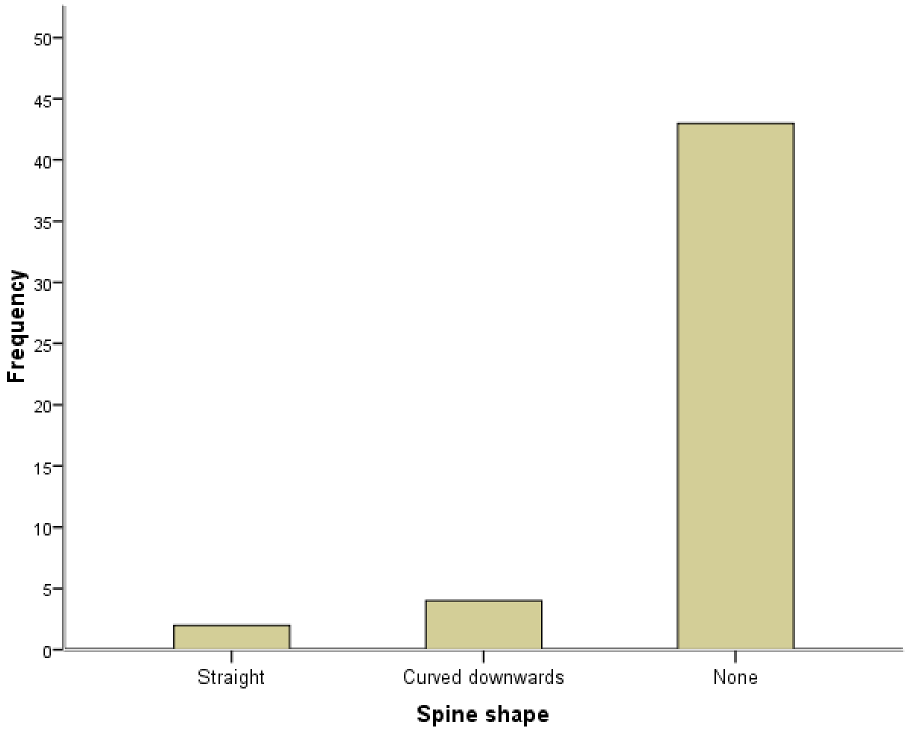

Fig. 7 Frequency of varying spine shape in *Dioscorea alata* germplasm.

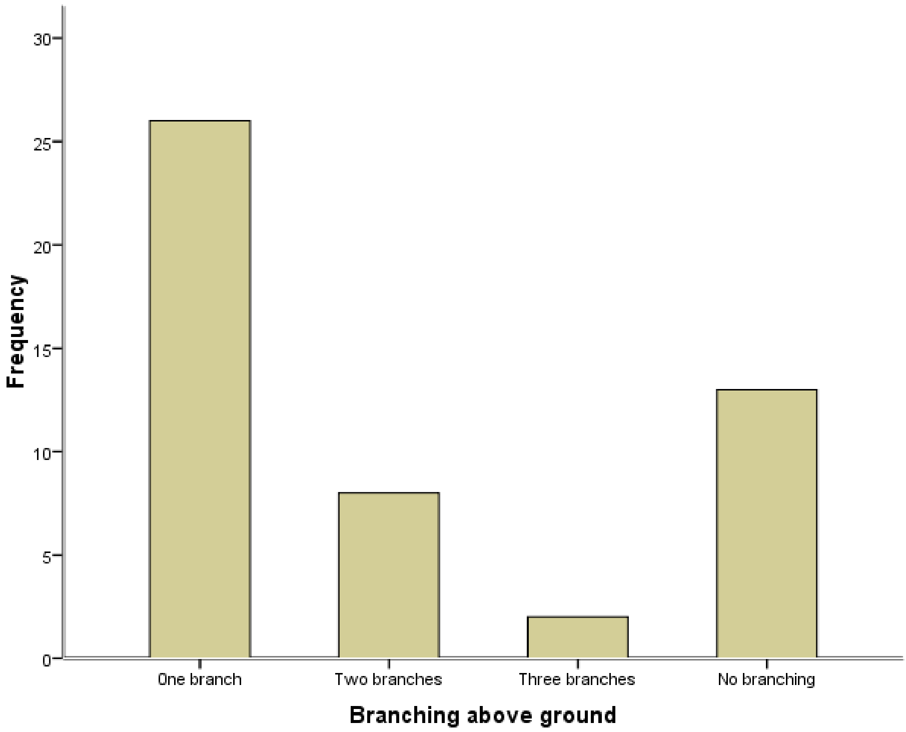

Fig. 8 Frequency of above ground branching in *Dioscorea alata* germplasm.

The number of leaves counted 30 d (assessed on five young plants randomly selected) after plant emergence for the individual accessions ranged between 6 and 17 with a mean of 11.1 and a CV of 26.2%. Mature stem diameter recorded at 15 cm from the base of the plant (average of five plants per each accession) ranged from 0.4 cm to 1 cm with a mean of 0.5 cm and a CV of 19.9%. Some degree of polymorphism was also observed in terms of number of days between planting and emergence. Days to plant emergence after planting ranged from 11 d to 44 d with a mean of 23.4 d and a CV of 34.4%.

Leaf measurement observed on 20 adult leaves for each of the accessions (average of five plants per each accession) had some variations in terms of plant height and width. Leaf length measured ranged from 5.3 cm to 13.5 cm with a mean of 9.6 cm and a CV of 20.2%. Measurement on the leaf width also ranged from 5.2 cm to 11.9 cm with a mean of 8.3 cm with CV of 19.9%. The underground tuber width also ranged from 2 cm to 13 cm with a mean of 5.8 cm and a CV of 32.7%. The underground tuber yield had the highest CV of 84.8% with a mean of 0.92 kg per mound and ranged from 0.08 kg to 2.8 kg (Table 2).

3.3 Diversity Assessment Using Cluster Analysis

Results of the morphological analysis confirmed that the *Dioscorea alata* accessions were genetically diverse for the 107 morphological traits assessed. Factorial analysis using PCA evealed 15 principal components with eigenvalues greater than 1.00 explaining 75.92% of the total variance in the samples assessed (data not shown). However, the scree test, disclosed first two PCAs were the most important accounting for 25.27% of variation (Table 3). Thus, assessment was based on the first two principal component axes.

Tuber characteristics such as texture of flesh, roots on the tuber surface, flesh oxidation colour, wrinkles on tuber surface, skin colour at head of tuber, and tuber flesh colour together with spine characteristics such as spine shape, spine position on the stem, spine length accounted for most of the observed variation in PCA1. Traits, mostly leaf characteristics, showed

Table 2 The mean, range and CV of quantitative traits.

Parameters measured	Mean ± s. e	Range	CV (%)
Stem length (cm)	44.1 ± 3.7	6-98.9	58.2
Stem diameter (cm)	0.5 ± 0.0	0.4-1	19.9
Internode length (cm)	8.1 ± 0.2	5-10	17.3
Number of leaves	11.1 ± 0.4	6-17	26.2
Petiole length (cm)	2.2 ± 0.1	2-3	18.9
Tuber width (cm)	5.8 ± 0.3	2-13	32.7
Days to emergence	23.4 ± 1.1	11-44	34.4
Internode number	8.2 ± 0.4	3-16	36.3
Leaf length	9.6 ± 0.3	5.3-13.5	20.2
Leaf width	8.3 ± 0.2	5.2-11.9	19.9
Tuber yield (kg/mound)	0.92 ± 0.12	0.08-2.8	84.8

Table 3 Eigenvalues of morphological data and percent variation explained by the first two principal component axes from factorial analysis.

PC	Eigenvalue	Percent variance	Cumulative variability (%)
1	10.860	13.92	13.92
2	8.850	11.35	25.27

more variation among the accessions found in PCA2. For instance, characters such as mature leaf vein colour, distance between leaf lobes, young leaf colour, petiole wing colour, young leaf vein colour and leaf margin colour contributed to much of the variation.

The PCA analysis, using Jaccard's similarity matrix confirmed generally that, the accessions were grouped into four clusters corresponding to the four quadrants (Fig. 8). Quadrant I had 15 accessions including two checks (TDa 01/0004) from IITA collections. It can be established from this quadrant that, the two checks grouped together, while accessions TDa 00/00046, TDa 98/01176 and TDa 02/00151 also grouped as another entity with accession TDa 01/00046 being the distinct member of this group. The remaining members of this quadrant were also found grouped together with accessions AGA 97 136 and TA 97 116 being close to the midpoint. Majority of the accessions in quadrant I are IITA collections. Quadrant II had eight accessions with accessions TDa 02/00012, 82/526 and FA 89 039 being the most distinct members of this group. Similarly, quadrant III also had eight accessions with accessions TA 97 131 and SO 89 039 separated from other members of the group. The rest of the 16 accessions were grouped in quadrant IV. Generally, with the exception of quadrant I, the large number of the accessions in quadrant II, III and IV are local collections from CSIR-CRI. Quadrant IV had the largest number of accessions compared to other quadrants.

Moreover, it can be observed that, accessions TA 97 116 and SO 89 149 were located directly on the vertical line separating quadrant I and IV. Unlike accession SO 89 149 which was further away from the origin, accession TA 97 116 was closer to the midpoint of the axes (Fig. 9).

Results from further clustering of the morphological data with tree analysis concept based on Jaccard's index genetic similarity matrix also revealed that the *Dioscorea alata* accessions exhibited greater degree of genetic variation for the 107 different morphological traits observed (Fig. 10). The similarity coefficient ranged from 0.5 to 1.00. The 49 *Dioscorea alata* accessions were grouped into two clusters (major and minor cluster, respectively) at a similarity level of 0.5, however, at a similarity coefficient of 0.55, they were further divided into three clusters. Among these different clusters, the cluster size varied from one for cluster I to 30 for cluster II. Cluster III had 18 members.

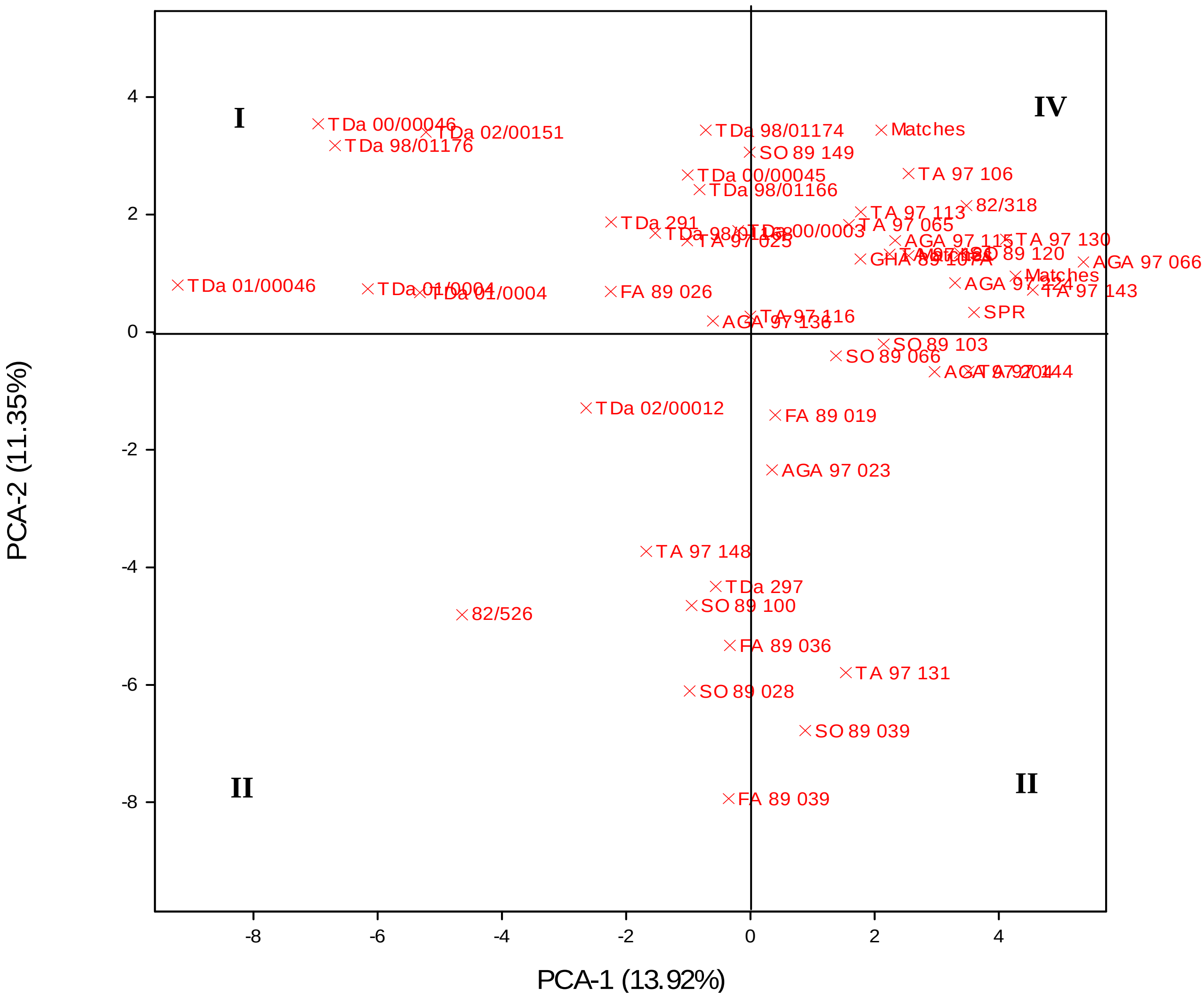

Fig. 9 PCA showing genetic relationship among 49 accessions of *Dioscorea alata* including checks revealed by morphological data.

Accession 82/318 stood alone as distinct cluster. Cluster II had two checks (TDa 01/0004) from IITA collections while the rest of the checks (Matches) from CSIR-CRI collections clustered with other accessions in cluster III. Again, it is revealed from the dendrogram that, cluster II had accessions from local collections by CSIR-CRI as well as collections from IITA. With the exception of TDa 291, all the germplasm in cluster III are local collections (Fig. 10).

Knowledge of genetic diversity of *Dioscorea alata* germplasm is key for efficient conservation and utilization of these all-important species.

In Ghana, for instance, wild yam diversity of *Dioscorea praehensilis* was reported being endangered by uncontrolled harvest from their natural environment (forest). The need therefore to use both qualitative and quantitative approaches to study the variation to enhance its conservation and utilization cannot be over-emphasized.

The use of qualitative traits in the classification of crops is very essential due to their relative stability over quantitative traits. Wide range of polymorphism was observed in some of the various qualitative characters used in the differentiation of the accessions namely, tuber skin colours beneath bark, tuber flesh colour at central transverse cross-section, texture of

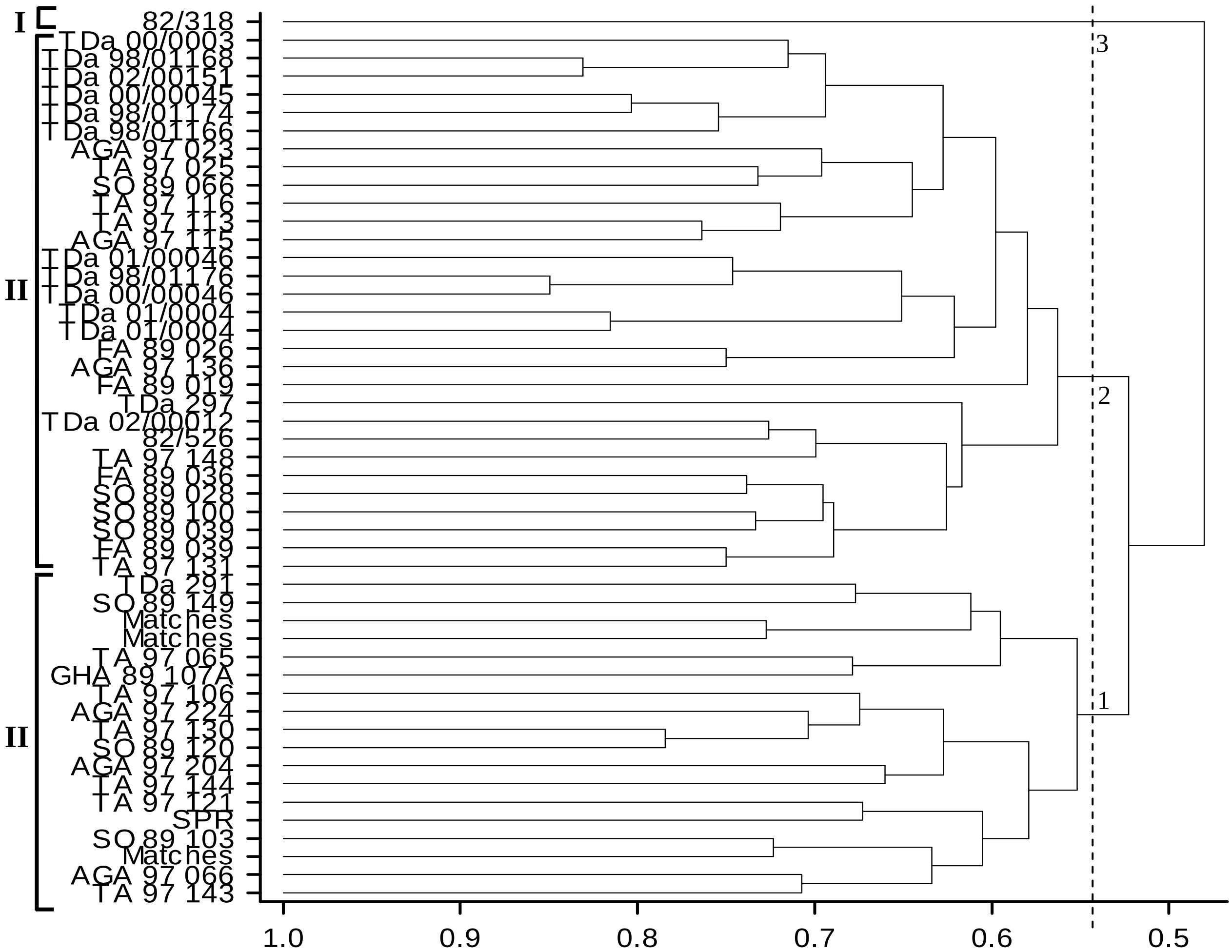

Fig. 10 Genetic diversity tree of 49 *Dioscorea alata* accessions based on Jaccard's index genetic similarity matrix among morphotypes using GenStat Discovery Edition 3 statistical packages.
Similarity matrix is based on presence or absence of 107 morphological traits.

tuber flesh, leaf margin colour, leaf shape, petiole wing colour, spine shape on stem and branching of stem above ground. Similar observations have been reported [19].

Within the total accessions, yellowish white/off-white emerged as the most predominant character among flesh colour at central transverse cross-section. It was followed by white with purple, white, orange with yellow being the character with lowest relative frequency. Assessing 59 *Dioscorea alata* accessions from Bangladesh [20] observed the following tuber flesh colours: white, yellow, yellowish white, red, purple and yellow-orange. Similarly, while studying morphological variations in *Dioscorea alata* landraces [21] also observed that white, purple and yellow coloured flesh of tubers exist. In this study, white, yellow and purple coloured tuber flesh observed were in agreement with Ref. [21], while red types were absent as reported by Ref. [20]. Light maroon tuber skin colours beneath bark were in the majority among the accessions studied followed by dark maroon with only few collections having greyish tuber skin colour beneath bark. Regarding texture of flesh, majority of the germplasm had smooth texture while others had grainy tuber flesh.

For other qualitative traits, wide variation was observed in terms of the shape of the leaves. Most of the materials had cordate leaf shape ranging between cordate broad and cordate long. Few of the accessions had sagitate leaf shape. Also, most of the accessions showed green leaf margin colour followed by purple and yellowish being the least. The existence of two types of *Dioscorea alata* petiole wing colour (purple and green) had similarly been reported by Ref. [20], with purple petiole wing colour being the domination in *Dioscorea alata* accessions. However, in this study, green petiole wing colour is the most dominant in the total materials studied together with green with purple edges and purple. Generally, majority of the materials evaluated had no spines on their stems. Those accessions with spines had varying shapes, ranging from spines that are curved downwards to straight ones. Comparatively, materials with spines curved downwards were more than those with straight spines on the stem. Majority of the materials studied showed some level of stem branching above ground varying from one, two and three branches above ground.

Rhodes and Martin [22] used 100 characters to study the variation in 30 *Dioscorea alata* cultivars, concluding that only 28% of the characters used were useful for the classification of the cultivars. This compares favourably with this study because among 107 morphological traits scored to differentiate the accessions, majority of the characters were common to all the accessions studied. Hasan et al. [23] used 47 morphological traits to assess 70 *Dioscorea alata* accessions collected throughout Malaysia. The results obtained from the PCA indicated that the characters that most contributed to the species variability were those related to shape, size, texture and flesh colour of underground tubers, vein colour of the leaves and petiole colour. This assertion is in agreement with this study because among the qualitative traits assessed on the 49 *Dioscorea alata* accessions, tuber flesh colour, texture of flesh, petiole colour and colour of leaf margin also contributed to the materials variability. Mahalakshmi [24] reported the use of morphological traits to obtain a core collection for *Dioscorea alata*, evaluating a total of 772 accessions. The study identified 72 accessions to be part of the core collection using 77 qualitative traits and 11 quantitative traits. Similarly, both the qualitative and quantitative traits also facilitated the selection of core collections.

3.4 Variation in Quantitative Characters

Several factors influence quantitative traits and hence are not stable as qualitative traits. In order to achieve maximum yield in any crop improvement programme, knowledge of genetic variability of several traits and their contribution to yield are imperative. Thus, knowledge of parameters such as mean, range and CV are vital in the genetic improvement of a crop. The coefficient of CV revealed large difference among the traits studied. The CV ranged between 17.3% and 84.8%. Internode length, petiole length, stem diameter, leaf width, leaf length, and number of leaves recorded low CV of 17.3%, 18.9%, 19.9%, 19.9%, 20.2% and 26.2%, respectively (Table 4). This indicates that these traits showed limited variability, among which internode length showed the least. The stem diameter and leaf width recorded the same CV of 19.9% generally, the less variation among the collections for the characters suggest that there is less potential for improving these traits, especially internode length, as breeders/researchers would have less diversity to do their selection.

Stem length and underground tuber yield, on the other hand, showed high CV of 58.2% and 84.8%, respectively. This observation also implies that there was wide range of polymorphism among the accessions with respect to stem length and tuber yield signifying a better scope of selection for this character in breeding programmes. It also implies that the accessions can be classified based on the aforementioned parameters (stem length and tuber yield). Similarly, Otoo [12] recorded high diversity index for stem length and tuber yield when they examined morphological variability in *Dioscorea rotundata* cvr Pona complex accessions in Ghana.

3.5 Morphological Characterization Based on Multivariate Methods

Morphological analysis based on aerial and underground organs has shown significant diversity within cultivated yams such as *Dioscorea cayenensis/rotundata* complex and *Dioscorea alata* [25]. Application of morphological parameters is useful for preliminary evaluation, because they offer a fast and easy approach for assessing the extent of diversity [17]. The estimation of descriptive statistics of 107 morphological parameters used in the differentiation of the accessions in this study revealed the existence of morphological diversity among the *Dioscorea alata* accessions, providing room for improvement through hybridization and selection.

Factor analysis was performed in order to reduce a set of morphological traits to a more meaningful smaller set of traits and to identify the traits contributing to maximum variability, since it provides an exact picture of variability contributed by each trait of the accessions. Based on the factor loading of the 107 morphological traits, the first two factors accounting for much variability among the accessions studied were selected for the principal component analysis. Using the traits (which contributed to maximum variation in the factor analysis), tuber characteristics in the PCA, namely, hardness of tuber, texture of flesh, prickly appearance of the tuber, total number of harvested tubers, total weight of harvested tubers, flesh oxidation colour, wrinkles on tuber surface, roots on the tuber surface, skin colour at head of tuber, flesh colour at central transverse cross section, tuber skin colour (beneath bark), and uniformity of flesh colour in cross section recorded much of the variation in the morphological traits. This was followed by characteristics of the leaves such as downward arching of leaf along main vein, downward arching of leaf lobe, position of leaves, leaf vein colour (upper and lower surface), numbers of leaves, upward folding of leaf lobes to form a cup, leaf margin colour, petiole wing colour, and leaf tip colour. Other traits include spine characteristics such as shape, and position of spine on the stem. This observation confirms the assertion by Ref. [25] that in yams, general appearances of the plant and the tuber are of great importance in identification of cultivars. The study also compares favourably with results obtained from a previous study [12], where 91 accessions of “Pona” yam complex in Ghana using morphological traits of the various accessions, recorded maximum variation in tuber, leaf and spine characteristics.

In addition, from the factorial analysis, within quadrants I, II and III (Fig. 8), the observed position of some accessions suggested that there could be a sub group each for the three quadrants. For example, accessions 82/526, TDa 02/00012 and FA 89 039 in quadrant II were further away from other members in the quadrant. They all stood alone as distinct accessions. Similarly, accessions TA 97 131 and SO 89 039 in quadrant III were also found grouped together as distinct members from other members in the group indicating a possible sub group.

Further clustering of the morphological data with the tree analysis concept and tree construction using Jaccard’s similarity matrix approach gave three main clusters. The Jaccard’s similarity matrix was used based on morphological markers. The similarity coefficient ranged from 0.5 to 1.00. The 49 *Dioscorea alata* accessions were grouped into two clusters (major and minor cluster, respectively) at a similarity level of 0.5. However, at a similarity coefficient of 0.55, they were further divided into three clusters. Among these different clusters, the cluster size varied from one cluster to another. Cluster I had one member and Cluster II 30. Cluster III had 18 members (Fig. 9). It can be realized generally from the analysis that, even though collections of CSIR-CRI and IITA were from different locations, they were grouped in similar clusters signifying that they were similar accessions.

This observation might be due to the fact that identical materials may have different names in different collections and areas due to numerous vernacular names. It can also be inferred that some of the materials in the CSIR-CRI (Ghana) collections might have originated from IITA (Nigeria) or vice versa due to exchange of planting materials between these two countries. Lebot et al. [13] reported that although guidelines exist for the safe movement of yams, there has been little official sharing of germplasm between countries. The informal nature of the yam trade and exchange of planting materials among farmers and countries can also lead to duplication of planting materials whose ethnic or local names have changed in different localities. Thus, the same material may be called differently in another region. Majority of the accessions were most likely clones of a common source.

However, germplasm of vegetatively propagated species such as *Dioscorea alata* often contains accessions which, may be morphologically similar yet may have different genetic origins and vice versa [26]. They also reported that because somatic mutations occur frequently and are retained, collections, which appear similar in morphology, might be quite different genetically, and vice versa.

The checks (TDa 01/0004 and Matches) were closely related to each at a similarity level of 0.83 and 0.73 in cluster II and III, respectively, confirming their similarity (Fig. 9). Accession 82/318 from CSIR-CRI stood alone as a unique accession statistically different from other clusters. This observation reveals that, morphologically, this particular accession is distinct from other accessions in cluster II and III (Fig. 9).

4. Conclusions

The 49 *Dioscorea alata* accessions used in the study were genetically variable and therefore clustered in groups based on their close relationships or associations.

The descriptors for yam were efficient in discriminating the 49 *Dioscorea alata* accessions into three clusters.

There were several duplicate accessions identified based on the morphological classification. These duplicates will be removed from the collection if molecular analysis confirm them as duplicates.

Morphological traits like tuber flesh colour, tuber flesh texture, tuber skin beneath bark, leaf shape, leaf margin colour and petiole wing colour were all found to be of great importance in distinguishing the accessions.

Morphological characterisation provided an inexpensive means of quickly evaluating the “water yam” accessions.

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