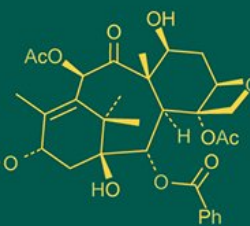


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Morphological and biochemical characterization of *Dioscorea alata* L. landraces from Northern Eastern region, India

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Abstract

Yam is an important monocotyledonous tuberous plant belonging to Dioscoreaceae family. It is a climate resilient food security crop widely cultivated in India and Africa. The genus *Dioscorea* contains about 644 species out of which 50 species are reported from India and 28 species and 25 cultivated varieties are reported from northeastern region of India. The most commonly edible *Dioscorea* species found in northeastern region is *Dioscorea alata* (*Dioscorea alata* L.) which provides a good source of dietary carbohydrates to the tribal section of the society. In the present study, 37 accessions of *Dioscorea alata* collected from different parts of northeastern region of India were characterized based on 38 qualitative and 13 quantitative traits including the major yield components and six biochemical characteristics. Among the 57 morphological and biochemical characters used in this study, 16 (28.07%) were the most discriminating characters for the *D. alata* accessions evaluated. Traits like tuber size, shape and skin colour, young stem and leaf colour, leaf number, crude fiber, ash content and sugar content were of great importance to distinguish *D. alata* accessions of North-Eastern region of India. These traits were considered for Principal Component Analysis (PCA) with a measure of Sample Adequacy greater than 0.6. The first six principal components of data accounted for 49.15 % of the total variance among accessions. Cluster analysis revealed that most of the accessions clustered randomly among two groups regardless of geographical locations and there were no duplicate accessions. Accessions were clustered mainly by stem height, emergence habit, petiole length and skin colour at tuber head.

Keywords: *Dioscorea alata*, greater yam, accessions, North-Eastern region, characterization, morphological, biochemical, principal component analysis, clustering

Introduction

The genus *Dioscorea* contains about 644 species that are distributed throughout the tropics out of which eight species are under cultivation (Govaerts *et al.*, 2007; Asiedu and Sartie, 2010) [16, 5]. Yams originated primarily from Africa and Asia then gradually spreading to other tropical or subtropical areas of America and Polynesia, where some *Dioscorea* species represent economically important tuber crops (Coursey, 1967). Now the crop is of major importance in the diet and economic life of more than 100 million people especially in West Africa, the Caribbean islands, parts of Asia, and Oceania (Ravindran and Wanasundera, 1992; Girardin *et al.*, 1998) [37, 15]. Yams are quite rich in starch, accounting for 60 to 89 per cent of yam carbohydrates (Degras, 1986) [10] as well as protein, vitamins, potassium, sodium, magnesium, copper and zinc (Baah *et al.*, 2009) [7]. Yam flour had higher levels of fibre than potato flour, refined wheat flour, maize and rice (Woolfe, 1987) [45]. Besides, it also has medicinal properties such as the steroidal sapogenins, used in the production of cortisone and synthetic steroid hormones, hence gaining popularity in industrial and medicinal sector.

Yam is the fourth most important tropical root and tuber crop after potato, cassava and sweet potato (Fu *et al.*, 2005) [14]. Over the decades, the area under yam production in India has increased from 1.15 million hectare in 1961 to 5.05 million hectare in 2013 with an increasing yield from 72.35 thousand metric tons in 1961 to 119.12 thousand metric tons in 2013 (FAO, 2014). As compared to other cultivated species of yam, *D. alata* is superior to

most edible yam species due to its high yield potential especially under low to average soil fertility, ease of propagation (production of bulbils and reliability of sprouting), early vigor for weed suppression and storability of tubers (Jyothy *et al*, 2017) [23]. Its tubers can be stored longer than other root and tuber crops, ensuring food security even at times of general scarcity. Numerous generations in many parts of northeastern region of India select and domesticate different varieties/land races of this species bearing several vernacular names that yield larger starch rich tubers for cultivation. Thus it is considered as one of the most important supplementary food sources in most of the tribal areas of northeastern region including Assam. The development of *D. alata* varieties with improved food quality and resistance to pests and diseases would encourage its widespread cultivation and significant increase in production. Genetic improvement programs are necessary for developing high yielding greater yam varieties with resistance to pests and diseases to meet farmers' requirements. However, accurate information on genetic diversity is critical to the success of such development programmes.

Although yam is an important crop in northeastern region, there is a lack of knowledge regarding the existing level of

diversity among various species of yam or varieties within the species. Moreover, no systemic studies have been carried out in *D. alata* in this region with respect to morpho-biochemical characters. The objectives of present study were to determine the relationships between the accessions, and to identify duplicates and groupings of genotypes collected from different districts of North-East India. In this study, the multivariate techniques of principal components and cluster analyses were used to determine the levels of morphological diversity in 37 *Dioscorea alata* accessions. The exploitation of the genetic diversity so determined serves to facilitate the development of better varieties through combination and marker assisted breeding program.

Materials and Methods

Dioscorea alata cultivars were collected from different parts of northeastern region of India with a view to obtain potential diversity among the cultivars (Table.1). *Dioscorea* tubers were collected from farmer's field including all possible diversity in morphological characters to avoid collection of identical or closely related cultivars. One cultivar was also collected from Central Tuber Crop Research Institute, Thiruvananthapuram, Kerala and was used as check variety for this experiment.

Table 1: Place of collection of *Dioscorea alata* cultivars

Sl. No.	Germplasm	States	Districts
1	CV1	Assam	Jorhat
2	CV 2	Assam	Morigaon
3	CV 3	Assam	Nagaon
4	CV 4	Assam	Darrang
5	CV 5	Assam	Bongaigaon1
6	CV 6	Assam	Bongaigaon2
7	CV7	Assam	Dhubri
8	CV8	Assam	Kamrup
9	CV9	Assam	Chirang1
10	CV10	Assam	Chirang2
11	CV11	Assam	Tezpur1
12	CV12	Assam	Tezpur2
13	CV13	Assam	Borpeta
14	CV14	Assam	Goalpara1
15	CV15	Assam	Goalpara2
16	CV16	Arunachal Pradesh1	West Kameng
17	CV17	Manipur	Imphal
18	CV18	Arunachal Pradesh2	Longding
19	CV19	Arunachal Pradesh3	Papum Pare
20	CV20	Arunachal Pradesh4	Changlang
21	CV21	Nagaland	Mokokchung
22	CV22	Mizoram	Aizawal
23	CV23	Meghalaya	Ri-Bhoi
24	CV24	Arunachal Pradesh5	Siang
25	CV25	Arunachal Pradesh6	West Kameng
26	CV26	Assam	Nalbari
27	CV27	Arunachal Pradesh7	Namphai
28	CV28	Assam	Karbi Anglong
29	CV29	Assam	Sibsagor
30	CV30	Assam	Baksa
31	CV31	Assam	Tinsukia1
32	CV32	Assam	Golaghat
33	CV33	Assam	Udalguri
34	CV34	Assam	Tinsukia2
35	CV35	Assam	Dibrugarh
36	CV36	Assam	Cachar
37	CV37	Kerala	CTCRI-Thiruvananthapuram

Table 2: Percentage distribution of qualitative traits in *D. alata* germplasm

Sl. No.	Characters	Traits	Percentage of germplasm (%)
1.	Young stem colour	Purplish green	40.54
		Green	59.46
2.	Presence/absence of wings	Present	86.49
		Absent	13.51
3.	Wing colour	Green	13.51
		Green with purple edges	24.32
		Purple	48.65
4.	Presence/absence of spines	Dense spine	64.86
		Very few spines	10.81
5.	Stem height	2-10m	72.97
		>10m	27.03
6.	Mature stem colour	Purplish green	57.76
		Green	42.24
7.	Young leaf colour	Yellowish	5.41
		Pale green	40.54
		Dark green	24.32
		Purplish green	27.03
		Purple	2.70
8.	Young leaf margin colour	Green	86.49
		Purple	13.51
9.	Young leaf vein colour	Green	70.27
		Pale purple	13.51
		Purple	13.51
		Yellowish	2.70
		Green with purple at both ends	62.16
10.	Young leaf Petiole colour	Green with purple at leaf juncture	21.62
		Green with purple at base	10.81
		Green	5.41
		Purple	59.46
11.	Young leaf Petiole wing colour	Green with purple edges	21.62
		Green	18.92
		Yellowish	24.32
12.	Mature leaf colour	Pale green	37.84
		Dark green	37.84
		Intermediate	78.38
13.	Distance between lobes	No measurable distance	31.51
		Very distant	9.89
		Green	67.57
14.	Leaf vein colour	Purple	13.51
		Pale purple	13.51
		Yellowish	5.41
		Green	67.57
15.	Mature leaf Petiole wing colour	Green with purple edge	24.32
		Purple	8.11
		Cordate	62.16
16.	Leaf shape	Cordate narrow	13.51
		Cordate broad	13.51
		Sagitate narrow	8.11
		Sagitate broad	2.70
		Acute	86.49
17.	Leaf tip shape	Obtuse	13.57
		Green	86.49
18.	Leaf margin colour	Purple	13.51
		Flowering	62.16
19.	Flowering habit	Non-flowering	13.84
		Spike	37.51
20.	Type of inflorescence	Raceme	28.57
		Panicle	35.71
		Present	70.27
21.	Aerial tuber	Absent	29.73
		Irregular	27.27
22.	Shape of tuber	Round	18.18
		Elongated	9.09
		Light brown	45.45
23.	Skin colour	Dark brown	36.38
		Greenish	18.18

24.	Surface texture	Smooth	54.55
		Rough	27.27
		Wrinkled	18.19
25.	Underground tubers/hill	Few(2-5nos)	62.16
		Several(>5)	13.64
26.	Relationship of tubers	Completely separate and distant	45.95
		Fused at neck	32.49
		Completely separate but closed together	21.62
27.	Tuber shape	Cylindrical	40.34
		Oval oblong	24.32
		Digitate	13.51
		Irregular	13.51
		Oval	8.10
28.	Skin colour at head of tubers	Yellowish white	62.16
		Purple with white	15.22
		Purple	16.22
		Light purple	2.70
29.	Skin colour beneath the bark	Yellowish white	45.95
		Light purple	45.95
		Dark purple	5.41
		Cream	2.70
		White	51.35
30.	Tuber flesh colour	Yellow	27.03
		Light purple	13.51
		Yellowish white	8.10
31.	Flesh oxidation colour	Yellowish brown	43.27
		Light brown	29.73
		Light purple	18.92
		Brown	18.18
32.	Skin texture	Smooth	29.73
		Wrinkled	45.95
		Rough	24.32
33.	Roots on tuber surface	Few (0-15)	81.08
		Many (>15)	18.92
34.	Place of roots on tuber surface	Entire tuber	51.35
		Upper surface	48.65
		Lower surface	2.70
35.	Flesh texture	Smooth	35.14
		Grainy	48.65
		Very grainy	16.22
36.	Skin thickness	<1mm	40.52
		>1mm	59.46

Table 3: Percentage distribution of qualitative traits in *D. alata* germplasm

Sl. No.	Characters	Traits	Percentage of germplasm (%)
1.	Days to emergence	Early	35.13
		Late	68.87
2.	Leaf number	10-20 number	27.72
		20-30 number	15.46
		30-40 numbers	10.81
3.	Tuber length	Long	81.08
		Short	18.92
4.	Tuber girth	Broad	51.35
		Narrow	48.65

The experiment was laid out in the Horticultural Experimental Farm of Department of Horticulture, AAU, Jorhat in a Randomized Block Design (RBD) with three numbers of replications. The collected thirty seven numbers of accessions for conducting the experiment were considered as treatments which were replicated thrice for two years i.e. 2020-21 & 2021-22. The proper package of practices of yam crop recommended for Assam were followed to raise the crop.

The tubers of the collected accessions were planted in the field at the end of April for two successive years i.e. 2020 and 2021. Tuber cuttings weighing 250gm each were

planted on mounds prepared at a spacing of 1m×m by keeping buds facing upward and mulching with rice straw and soil heaped over it. The vines were supported on a stake of aboutm height. Harvesting was done manually in the month of February by digging out the tubers with digging hoe and then cleaned under tap water to make it free from soil and then kept in ventilated storage house till the next planting season.

The morphological as well as biochemical characterization and evaluation of 37 numbers of *Dioscorea alata* accessions were carried out by using International Plant Genetic Resources Institute's descriptor list for yam (IPGRI/ IITA,

1997) with slight modifications. Only those descriptors or traits that discriminated between genotypes were used in this study. Thus the collected accessions were evaluated for 36 qualitative and 18 quantitative traits including the major yield components and six biochemical characteristics. Performance of individual accession was recorded and composite sample from the three replications of each accessions were collected for further chemical analysis. The quantitative data were analyzed for analysis of variance (ANOVA) using RBD to identify genotypes that were significantly different from each other.

Principal component analysis (PCA) was done using R software using factorMinor package (Le *et al.*, 2002). The PCA data was used to generate eigenvalues, cumulative variability and load coefficient values. The principal component with eigenvalues >1.0 were selected and those traits that had load coefficients > 0.6 were considered relevant scores for the PC and considered as valuable traits for distinguishing between the genotypes (Jeffers, 1967) [22]. Cluster analysis was used to estimate pair-wise genetic similarity values based on qualitative traits among accessions using Jaccard's dissimilarity index. The similarity matrix based on Jaccard's coefficient of dissimilarity then used to construct a dendrogram using Ward's linkage method with IBM SPSS software.

Results and Discussion

Variation in qualitative traits assessed

The 37 *Dioscorea alata* germplasm under the study showed high level of significant variability for young stem characters. Based on time taken for emergence, germplasm were grouped into two categories *i.e.* early (13 germplasm) and late (24 germplasm). The range varied from 11.57 days in CV30 to 33.37 days in CV7. In respect to stem colour, two classes of variation were observed among the germplasm under the study. Most of the germplasm were found to have green stem colour (22 germplasm) and the remaining germplasm had purplish green stem colour. Based on the presence and absence of wings, majority of the germplasm (32 germplasm) exhibited wings except for five germplasm and based on intensity of wing colour, germplasm were categorized into purple (18 germplasm), green (5 germplasm) and green with purple edges (9 germplasm). Based on the presence or absence of spines, germplasm were grouped into three categories *i.e.* produced dense spine (9 germplasm), produced very few spines (4 germplasm) and produced no spines (24 germplasm) on young stem base. Regarding mature stem characters, all 37 germplasm twinned anticlockwise (twinning to right). Two distinct types were observed with respect to mature stem colour. These were green colour (16 germplasm) and purplish colour (21 germplasm). Regarding stem height, none of the germplasm was found dwarf. However, majority of the germplasm were grouped into medium height (27 germplasm) and germplasm were categorized under tall group according to the study.

Five distinct types of young leaf colours were observed among the germplasm *viz.*, yellowish (2 germplasm), pale green (15 germplasm), dark green (10 germplasm), purplish green (9 germplasm) and purple (1germplasm). Jothy *et al.* (2017) also reported 6 different colours of young leaves among 45 accessions conserved at ICAR-CTCRI, Kerala under study. These findings are in line with our study where majority of leaves *i.e.* 71.1 per cent exhibited pale green leaf

colour. Two types of young leaf margin colour was observed. Accessions with green leaf margin colour (32 germplasm) was predominated the other colour observed *i.e.* purple leaf margin (5 germplasm). These results are in confirmatory with the findings of Anokye *et al.* (2014) [3] where out of 49 *D. alata* accessions used for the study, 71.4 per cent had green leaf margin colour which was the majority over purple and yellow leaf margin colours. Regarding young leaf vein colour, accessions were divided into four groups *i.e.* green (26 germplasm), pale green (5 germplasm), purple (5 germplasm) and yellowish (1 germplasm). The basic colour of the petiole was extremely variable among the *D. alata* germplasm. Four main colours were observed at top, bottom and entire petiole. Majority of germplasm expressed green with purple at both ends (23 germplasm) which was followed by green with purple at leaf juncture (8 germplasm), green with purple at base (4 germplasm) and green coloured petiole (2 germplasm). In respect to petiole wing colour, three classes of variations were observed among the germplasm studied. 22 germplasm exhibited purple coloured petiole wing which was the majority, 8 germplasm possessed petiole wing which is green with purple edges and rest 7 germplasm manifested green coloured petiole wing.

Among mature leaf characters, position of leaf, leaf colour, leaf vein colour (upper surface), leaf number, leaf length, leaf breadth, petiole length, leaf shape, distance between lobes and leaf tip shape were considered as important characters for characterization of greater yam germplasm. No variation was observed among *Dioscorea alata* germplasm regarding position of leaves. Leaves were alternate at base and opposite above in all the germplasm. Matured leaf colour like yellowish (9 germplasm), pale green (14 germplasm) and dark green (14 germplasm) was identified from the germplasm under study. The findings of this study are consistent with the report of Rao *et al.* (2019) [36].

Four predominant mature leaf vein colours were found among the *Dioscorea alata* germplasm under investigation *i.e.* green (25 germplasm), pale purple (5 germplasm), purple (5 germplasm) and yellowish (2 germplasm). Most of the accessions had cordate leaf shape (23 germplasm) ranging between cordate broad (5 germplasm) and cordate narrow (5 germplasm). Few of the accessions have sagitate leaf shape ranging from sagitate broad (1 germplasm) and sagitate narrow (3 germplasm). Anokye *et al.* (2014) [3] and Munaweera *et al.* (2020) [31] both found comparable outcomes, indicating that the cordate leaf shape was the predominant shape observed during their examination of morphological variations in *Dioscorea* spp. in Ghana and Sri Lanka, respectively.

Regarding matured leaf margin colour, majority of the germplasm under study (32 germplasm) possessed green coloured leaf blade margin and only few (5 germplasm) had purple margin. The existence of two types of petiole wing colour *i.e.* purple and green had similarly been reported by Islam *et al.* (2011) [21] with purple petiole wing colour being the dominant in *D. alata* accessions. However, in our study, green petiole wing colour is the most dominant (25 germplasm) followed by green with purple edges (9 germplasm) and purple (3 germplasm). Our study is in line with the findings of Anokye *et al.* (2014) [3]. Majority of the germplasm (29 germplasm) under study exhibited intermediate distance between lobes followed by no

measurable distance between lobes (5 germplasm) and only three germplasm exhibited very distant distance between leaf lobes. With respect to leaf tip shape, the germplasm fell into two categories as acute (32 germplasm) which was the majority and obtuse (5 germplasm).

The flowering aspect is advantageous to breeders since genotypes that flower can produce seeds for sexual reproduction to enhance genetic improvements (Denadi *et al.*, 2020) [12]. In our study, only *D. alata* accessions flowered. Type of inflorescence among the germplasm were found to be male which further categorized under three groups *i.e.* spike (5 germplasm), raceme (4 germplasm) and panicle (5 germplasm). Wu-Wenqiang *et al.* (2019) [46] reported about 41.5 per cent flowering in *D. alata* genotypes in China. Sartie and Asiedu (2014) [39] observed that about 45 per cent of *D. alata* genotypes produced flowers with the male being 49 per cent and female 19.9 per cent. No variation was observed among the *Dioscorea alata* germplasm regarding colour of inflorescence. All the inflorescence bearing germplasm manifested yellow colour of inflorescences under investigation.

The formation of aerial bulbils in *D. alata* has been reported (Sanada *et al.*, 2018; Wu *et al.*, 2019) [38, 46]. In our study, majority of germplasm produced no areal tubers (26 germplasm) while only germplasm produced aerial tuber. Variation in the shape of aerial tubers was found among the germplasm under evaluation. Aerial tubers manifested most variable shapes *i.e.* round, oval, elongated and irregular. Jyothy *et al.* (2017) [23] also reported variations in aerial tubers among *D. alata* accessions from India in which oval, round, cylindrical and irregular tuber shapes were observed. Regarding skin colour of aerial tubers, three main colours were observed *viz.*, greyish, dark brown and light brown whereas, the study on the surface texture of aerial tubers revealed three predominant textures among the *Dioscorea alata* germplasm under investigation *i.e.* smooth (7 germplasm), rough (3 germplasm) and wrinkled (1 germplasm).

With respect to number of underground tubers per hill, the greater yam germplasm were grouped into two categories of which 24 germplasm were under few (2-5 numbers per hill) group and remaining 13 germplasm were categorized under several (>5 numbers per hill) group. Based on relationship of tubers, three types of variations were observed among the germplasm, of which 8 of them were completely separate but closed together, germplasm were fused at neck region and majority of germplasm (17 germplasm) were completely separate and distant. Three predominant places for roots were found on tuber surface among the *Dioscorea alata* germplasm under investigation *i.e.* entire tuber (19 germplasm), upper surface (17 germplasm) and lower surface (1 germplasm). Roots on tuber surface classified the germplasm into two groups *viz.*, few and many. Among them, majority of germplasm (30 germplasm) produced few roots on tuber surface while 7 germplasm produced many roots on tuber surface.

Tuber skin texture varied from wrinkled (20 germplasm), which was the majority, followed by smooth (11 germplasm) and rough (9 germplasm). Similar observations were reported by Jyothy *et al.* (2017) [23] regarding tuber skin texture where out of 45 accessions conserved in CTCRI, Kerala, majority of the germplasm had warty skin texture while others have moderately smooth and smooth skin texture of underground tubers of *D. alata*. Regarding

tuber shape, a wide range of morphological variation was observed among the accessions. The observed tuber shapes were oval, cylindrical, digitate, oval-oblong and irregular. In the diversity pattern study of *D. alata* in Brazil (Siqueria *et al.*, 2014) [41] three tuber shapes, namely irregular, oblong and round were found. But in the present study more than three shapes were found indicating more variability of this crop in India. Our observations are in line of research with Jyothy *et al.* (2017) in CTCRI, Kerala. Regarding tuber skin thickness, germplasm possessed skin thickness <1mm while 22 germplasm produced skin with >1mm thickness.

Wide variation existed among the germplasm pertaining to skin colour beneath the bark. There was an equal percentage of yellowish white (45.95%) and light purple (45.95%) which was followed by dark purple to cream colour. Anokey *et al.* (2014) reported that light maroon tuber skin colour beneath the bark were in the majority among the 49 accessions of *D. alata* studied in Ghana, followed by dark maroon with only few collections having greyish tuber skin colour beneath the bark. Regarding skin colour at head portion of the tubers, variation was observed under evaluation. Tubers manifested variable colours at head portion *i.e.* yellowish white was in majority (23 germplasm), followed by purple with white (6 germplasm), light purple (4 germplasm), purple (3 germplasm) and white (1 germplasm).

Four distinct flesh colours were observed among the germplasm under investigation. Majority of the germplasm (19 germplasm) exhibited white flesh colour, 10 germplasm produced yellow flesh colour, 5 germplasm expressed light purple flesh colour and remaining 3 germplasm manifested yellowish white flesh colour at central transverse cross section of underground tubers. Similar observations have been reported in the studies done by Demuyakor *et al.* (2013) [11] and Anokye *et al.* (2014) [3]. Among the genotypes evaluated, yellowish white / off-white emerged at the pre dominant character among the flesh colour of the accessions. The sequence that ensued was purple, purple with white and yellow having the least relative frequency. Jyothy *et al.* (2017) [23] observed that 86.7 per cent of yam accessions had off-white while 2.2 per cent were purple flesh colour. Cream and purple flesh colours were also dominant colours in *D. alata* reported by Trimanto and Hapsari (2015) [43].

Variations were observed regarding tuber flesh oxidation colour of the germplasm under study. Four main colours were observed *viz.*, yellowish brown, brown, light brown and light purple of which yellowish brown colour was the majority (17 germplasm), followed by light brown (10 germplasm), light purple (7 germplasm) and brown (3 germplasm). Regarding tuber flesh texture, majority of the germplasm had smooth texture (18 germplasm), followed by smooth (13 germplasm) and very grainy (6 germplasm). Accessing 49 *D. alata* accessions from Ghana, Anokye *et al.* (2014) [3] observed that majority of the accessions had smooth texture while others had grainy tuber flesh.

Variation in quantitative characters (Morphological characters) Several factors influence quantitative traits and hence are not stable as qualitative traits. Among the 37 *D. alata* accessions, data was recorded for eighteen quantitative characters and performed ANOVA (Analysis of Variance). The 37 *Dioscorea alata* germplasm under the study, germplasm were grouped into two categories based on days to emergence *i.e.* early (13 germplasm) and late (24

germplasm). The range varied from 11.57 days in CV30 to 33.37 days in CV7 (Table.4). Regarding stem height, none of the germplasm was found dwarf. However, majority of the germplasm were grouped into medium height (27 germplasm) and 10 germplasm were categorized under tall group according to the study. Regarding internode number and internode length, highest number of internode and highest internode length (Table.3) was recorded in CV25 and CV7 while lowest was recorded in CV 27 and CV20, respectively. The other germplasm were in between this range.

Some degree of polymorphism was observed in terms of leaf measurement of 37 *D. alata* germplasm under study (Table.5). The number of leaves of collected germplasm ranged between 36.42 and 15.66 with a mean of 26.04. Leaf length measured ranged between 27.46 cm and 16.45 cm with a mean of 21.96 cm while leaf breadth (Table.6) was ranged from 18.52 cm to 11.28 cm with a mean of 14.9 cm. Similar observations were recorded by Athira *et al.* (2017) with a mean leaf length of 21.16 cm and mean leaf breadth of 17.99 cm while studying 45 *D. alata* accessions conserved at National repository of tuber crops germplasm at ICAR-CTCRI, Kerala. Leaf petiole length ranged between 14.94 and 8.55 cm with a mean value of 11.75 cm. Wide variation existed among the germplasm pertaining to length of the tubers in present study; it varied from 65.38 cm to 29.0 cm (Table.6). Majority of the germplasm produced long tubers (81.08%) while remaining 18.92 per cent germplasm manifested short tuber length. Similarly, large variation with respect to tuber girth (Table.7) was obtained; it varied from 18.51 cm to 11.27 cm. On the basis of tuber girth, germplasm were grouped into narrow (48.65%) and broad (51.35%). While the germplasm exhibited a range of 3.20 kg to 8.84 kg for weight of the main tuber per plant. High phenotypic diversity among 59 *D. atata* accessions was reported from Bangladesh by Islam *et al.* (2011) [21]. Their study presented that the length of main tuber ranged between 5.4 to 66.4 cm and width was 2.5 to 15.5. The germplasm accessions exhibited 0.51 to 16.45 kg underground tuber per plant.

Based on the yield of underground tubers per ha, germplasm can be classified as low yielder, medium yielder and high yielder (Table.7). The range varied from 22.28 t/ha to 58.85 t/ha of tuber yield. In the low yielder group (20-35 t/ha) there were 19 germplasm (51.35%), in the medium yielder group (35-48 t/ha) there were germplasm (35.14%) and in the high yielder group (48-65 t/ha) there were 5 germplasm (13.51%).

Variation in quantitative characters (Biochemical characters)

Yam are primarily consume for its carbohydrate and secondarily for proteins, vitamins and other minerals (Baah *et al.*, 2009) [7]. A high level of significant variation was recorded among the *Dioscorea alata* germplasm concerning the nutritional profile. Dry matter content ranged between 24.26 to 34.51 per cent with a mean of 29.39 per cent (Table.8). CV34 had the lowest and CV7 had the highest value. It was found that among the highest yielding germplasm viz., CV7, CV16, CV17 and CV2, the germplasm CV7 contain the highest dry matter content which is desirable qualitative character. In their study, Bhandari *et al.* (2003) assessed the nutritional components of wild yam and discovered that the dry matter content varied between 19.8 and 30.5 per cent based on fresh

weight. A comparable range of 13.68 to 37.4 per cent dry matter content for *D. alata* varieties has been reported in the literature (Maziya-Dixon and Asiedu, 2003) [29]. Lebot *et al.* (2005) [25] observed that *D. alata* varieties with good eating quality are characterized by high dry matter, starch and amylase contents.

Starch is known to account for about 80 per cent on a dry weight basis of yam carbohydrate, which is also a dominant factor in determining the physicochemical, rheological and textural characteristics of yam food products (Moorthy, 1994) [30]. There is a significant range of starch content in white yam (*Dioscorea rotundata*), with values ranging from 33.9 to 75.7 per cent (Oladeji *et al.*, 2014) [34] and 93.67 per cent (Adegunwa *et al.*, 2011) [1]. On the other hand, *Dioscorea alata* has a starch content of 62.94 per cent (Adegunwa *et al.*, 2011) [1], which is comparable to the findings of Baah *et al.* (2009) [7] with a range of 16.3 to 74.4 per cent. Our results are also within the range (48.44 to 78.49%) of the previously published works. From this study CV27 (78.49%) and CV30 (76.27%) may be developed as high starch lines.

The total sugar content, also known as total soluble sugars, plays a crucial role in determining the sweetness of cooked yams (Lebot *et al.*, 2005) [25]. In present study, percentage of sugar content ranged between 4.48 per cent for CV and 11.60 per cent for CV with a mean of 8.04 per cent. A comparable range of 0.62 to 15.8 per cent sugar had been reported for *D. alata* varieties by Maziya-Dixon and Asiedu (2003) [29]. A wide range of soluble sugar in *D. alata* had also been detected earlier by Oladeji *et al.* (2004).

Germplasm like CV29 and CV were recorded with the highest ash content where as lowest ash content was found in germplasm CV23 (Table.9). The ash content serves as an indicator of the mineral status, despite the fact that contamination may suggest a high concentration in a given sample (Baah, 2009) [7]. Values ranged between 4.78 per cent to 2.53 per cent with a mean of 3.66 per cent. Comparable ash content (2.50 to 4.90%) had been reported for *D. alata* tubers (Labot *et al.*, 2005).

Crude fiber content ranged between [1].39 percent to 4.58 per cent with a mean of 2.99 per cent. The presence of crude fiber in our study was found to be significantly higher compared to previous reports in False Yam flour (*Ipomoea trichantha*) (1.06 to 1.51%) (Umoh and Iwe, 2014) [44], greater yam (Bhandari *et al.*, 2003) (0.6 to 1.5%), and elephant foot yam (Lenka and Nedunchezhiyan, 2013). Crude fiber plays a crucial role in preventing obesity by promoting food bowel movement and also contributes to the prevention of diabetes, colon cancer, and other gastrointestinal tract ailments (Topping and Clifton, 2001) [42]. Comparable range of 1.10 to 4.09 per cent crude fiber content for *Dioscorea alata* had been reported by Patel *et al.* (2019) [35]. In the present study, CV21, CV and CV32 genotypes with higher crude fiber content can be selected and cultivated specially for high crude fiber content.

The total phenol content in yam has been positively correlated with the rate of browning as browning is attributed to enzymatic oxidation of polyphenols in yam (Asemota *et al.*, 1992; Muzac-Tucker *et al.*, 1993) [4, 32]. In present study, total phenol content of *D. alata* germplasm ranged between 0.46 to 4.69 g/100g. Muzac-Tucker *et al.* (1993) [32] reported a range of 0.061 to 10.50 g/100g of total phenol on dry weight basis in *D. alata* germplasm while 0.023 to 0.034 g/100g was obtained for *D. rotundata* germplasm.

Table 4: Mean days to emergence, stem length and internode number of thirty-seven *D. alata* germplasm

Sl. No.	Germplasm	Days to emergence			Stem length (m)			Internode Number		
		2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
1	CV1	26.53	24.20	25.37	7.53	7.37	7.45	26.31	30.64	28.38
2	CV2	25.23	19.47	22.35	9.13	8.87	9.03	27.32	33.25	30.27
3	CV3	23.23	25.26	24.23	8.47	6.39	7.48	27.14	23.62	25.30
4	CV4	20.50	22.40	21.45	8.53	6.54	7.54	19.34	15.36	17.38
5	CV5	27.43	31.44	29.43	7.40	7.02	7.21	20.36	22.34	21.43
6	CV6	19.30	17.31	18.30	7.80	6.97	7.47	20.16	24.01	22.08
7	CV7	34.36	32.37	33.38	14.00	15.0	14.50	22.13	22.46	22.23
8	CV8	26.53	24.20	25.37	7.53	7.54	7.53	26.42	26.13	26.28
9	CV9	25.23	19.47	22.35	8.27	8.29	8.27	20.32	24.26	22.23
10	CV10	21.39	19.37	20.38	9.33	9.31	9.32	26.24	30.24	28.23
11	CV11	30.97	32.97	31.97	8.40	8.46	8.40	19.13	23.24	21.17
12	CV12	28.27	26.8	27.27	12.80	12.22	12.50	20.46	19.97	20.20
13	CV13	29.10	27.10	28.10	7.03	8.22	7.63	24.16	28.27	26.20
14	CV14	27.93	31.93	29.93	8.2	7.68	7.97	25.06	23.05	24.07
15	CV15	27.40	29.24	28.33	7.77	6.94	7.67	21.06	23.17	22.13
16	CV16	27.60	25.61	26.60	7.26	7.67	7.45	16.83	14.81	15.88
17	CV17	26.83	28.89	27.83	9.30	9.32	9.30	24.39	24.34	24.37
18	CV18	20.13	22.16	21.13	8.39	8.46	8.43	21.35	23.24	22.33
19	CV19	27.60	25.54	26.57	9.17	9.17	9.17	26.35	24.16	25.17
20	CV20	21.55	23.50	22.56	7.40	7.46	7.40	29.30	29.30	29.30
21	CV21	18.45	18.45	18.45	7.22	7.63	7.40	18.91	17.97	18.43
22	CV22	13.43	13.43	13.43	8.95	8.65	8.80	29.04	29.23	29.13
23	CV23	11.57	11.57	11.57	9.15	9.79	8.47	26.34	32.24	29.27
24	CV24	20.22	20.22	20.22	7.40	7.40	7.40	14.30	14.30	14.30
25	CV25	28.41	28.41	28.41	8.41	8.86	8.63	30.21	30.56	30.39
26	CV26	29.27	29.27	29.27	8.10	8.50	8.30	23.64	25.16	24.17
27	CV27	29.33	29.33	29.33	7.42	6.03	6.73	12.94	13.87	13.35
28	CV28	19.47	17.41	18.45	7.00	7.64	7.30	26.01	28.34	27.17
29	CV29	31.43	29.46	30.43	7.80	7.80	7.80	19.64	17.64	18.37
30	CV30	12.57	10.51	11.57	6.90	6.51	6.70	20.21	20.19	20.20
31	CV31	22.23	18.26	20.22	7.32	7.56	7.43	18.64	18.64	18.52
32	CV32	28.30	28.31	28.41	8.33	8.33	8.33	16.98	18.64	17.57
33	CV33	30.27	28.24	29.27	7.04	7.49	7.27	20.13	22.34	21.23
34	CV34	29.33	29.36	29.33	9.33	9.34	9.33	19.64	19.26	19.45
35	CV35	30.57	30.59	30.57	8.47	8.48	8.47	26.11	28.20	27.10
36	CV36	19.53	19.56	19.53	8.50	8.86	8.67	25.40	25.16	25.33
37	CV37	18.30	16.34	17.32	8.25	8.39	8.35	25.26	27.23	26.23
	CD (0.05%) Germplasm	4.32	4.31	3.04	0.43	0.52	0.34	3.19	4.42	2.70

Table 5: Mean internode length, leaf number and leaf length of thirty-seven *D. alata* germplasm

Sl. No.	Germplasm	Internode length (cm)			Leaf number			Leaf length (cm)		
		2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
1	CV1	24.31	27.94	26.50	15.40	15.40	15.40	18.56	18.56	18.56
2	CV2	30.56	30.32	30.36	32.25	30.67	31.45	20.17	20.17	20.17
3	CV3	30.84	30.26	30.55	21.88	21.11	21.49	19.67	19.67	19.67
4	CV4	33.76	35.74	35.75	20.32	18.64	19.48	15.51	15.51	15.51
5	CV5	32.01	34.39	33.20	19.34	21.53	20.44	27.30	27.30	27.30
6	CV6	30.61	28.11	29.36	25.31	25.31	25.31	27.43	27.43	27.43
7	CV7	37.77	39.49	38.47	35.31	37.51	36.41	26.50	26.50	26.50
8	CV8	34.37	30.56	32.20	30.50	31.97	31.24	18.23	18.23	18.23
9	CV9	35.43	35.93	35.68	30.36	28.24	29.30	20.69	20.69	20.69
10	CV10	34.39	36.21	35.30	19.31	19.31	19.31	22.45	22.45	22.45
11	CV11	31.89	33.90	32.90	22.32	22.32	22.32	19.38	19.38	19.38
12	CV12	32.80	34.30	33.55	20.39	20.39	20.39	16.41	16.41	16.41
13	CV13	29.50	29.80	29.65	18.35	18.35	18.35	21.45	21.45	21.45
14	CV14	27.47	29.47	28.47	18.26	14.59	16.43	21.55	21.55	21.55
15	CV15	31.40	31.40	31.40	17.89	17.24	17.57	19.39	19.39	19.39
16	CV16	34.80	36.95	35.88	33.20	33.29	33.25	24.36	24.36	24.36
17	CV17	33.63	33.26	33.45	18.56	20.43	19.50	25.49	25.49	25.49
18	CV18	34.17	35.23	34.70	28.60	28.60	28.60	20.48	20.48	20.48
19	CV19	34.97	34.75	34.86	18.34	18.34	18.34	24.37	24.37	24.37
20	CV20	25.40	25.40	25.40	24.26	24.26	24.26	20.42	20.42	20.42
21	CV21	25.40	25.40	25.40	22.29	26.16	24.23	20.42	20.42	20.42
22	CV22	34.90	34.90	34.90	19.56	19.49	19.50	24.53	24.53	24.53

23	CV23	30.93	30.93	30.93	18.00	19.51	18.76	16.71	16.71	16.71
24	CV24	33.23	33.23	33.23	20.35	20.35	20.35	25.27	25.27	25.27
25	CV25	30.40	30.40	30.40	20.58	22.64	21.61	17.55	17.55	17.55
26	CV26	27.45	27.45	27.45	20.51	20.29	20.40	21.44	21.44	21.44
27	CV27	34.20	34.20	34.20	21.54	23.16	22.35	18.37	18.37	18.37
28	CV28	35.73	35.73	35.73	20.26	20.61	20.44	20.47	20.47	20.47
29	CV29	33.60	35.21	34.41	25.00	26.16	25.58	23.57	23.57	23.57
30	CV30	37.70	37.91	37.81	23.73	23.73	23.73	22.53	22.53	22.53
31	CV31	33.23	33.56	33.40	20.46	20.46	20.46	20.48	20.48	20.48
32	CV32	32.48	34.61	33.54	20.37	20.19	20.28	23.49	23.49	23.49
33	CV33	35.64	35.57	35.61	21.20	21.20	21.20	19.43	19.43	19.43
34	CV34	33.90	33.90	33.90	17.37	17.37	17.37	17.28	17.28	17.28
35	CV35	35.26	35.83	35.55	20.55	20.55	20.55	21.52	21.52	21.52
36	CV36	30.97	30.68	30.83	20.13	20.92	20.55	20.37	20.37	20.37
37	CV37	31.13	31.13	31.13	21.39	19.51	20.45	22.29	22.29	22.29
	CD (0.05%) Germplasm	2.05	2.04	1.43	2.53	2.58	1.80	2.44	2.66	1.79
	Environment	-	-	NS	-	-	NS	-	-	NS
	Interaction	-	-	2.03	-	-	2.54	-	-	2.53

Table 6: Variation in mean leaf width, tuber length and petiole length of thirty-seven *D. alata* germplasm

Sl. No.	Germplasm	Leaf breadth (cm)			Tuber length (cm)			Petiole length (cm)		
		2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
1	CV1	13.34	13.34	13.34	43.36	43.36	43.36	8.91	8.91	8.91
2	CV2	11.54	11.54	11.54	52.22	52.22	52.22	9.36	9.36	9.36
3	CV3	13.31	13.31	13.31	30.58	30.58	30.58	9.22	9.22	9.22
4	CV4	12.39	12.39	12.39	33.53	33.53	33.53	8.56	8.56	8.56
5	CV5	14.54	14.54	14.54	51.49	51.49	51.49	9.65	9.65	9.65
6	CV6	13.35	13.35	13.35	50.39	50.39	50.39	9.74	9.74	9.74
7	CV7	13.54	13.54	13.54	51.24	51.24	51.24	10.54	10.54	10.54
8	CV8	12.48	12.48	12.48	57.41	57.41	57.41	8.91	8.91	8.91
9	CV9	14.49	14.49	14.49	54.95	54.95	54.95	9.35	9.35	9.35
10	CV10	16.39	16.39	16.39	58.64	58.64	58.64	10.36	10.36	10.36
11	CV11	11.29	11.29	11.29	31.49	31.49	31.49	9.95	9.95	9.95
12	CV12	12.57	12.57	12.57	49.46	49.46	49.46	9.93	9.93	9.93
13	CV13	12.38	12.38	12.38	65.38	65.38	65.38	14.78	14.78	14.78
14	CV14	16.62	16.62	16.62	38.83	38.83	38.83	14.89	14.89	14.89
15	CV15	14.42	14.42	14.42	40.50	40.50	40.50	14.56	14.56	14.56
16	CV16	18.52	18.52	18.52	34.45	34.45	34.45	14.63	14.63	14.63
17	CV17	12.52	12.52	12.52	51.56	51.56	51.56	9.51	9.51	9.51
18	CV18	11.41	11.41	11.41	52.56	52.56	52.56	10.65	10.65	10.65
19	CV19	12.35	12.35	12.35	49.69	49.69	49.69	10.34	10.34	10.34
20	CV20	15.4	15.4	15.4	43.36	43.36	46.73	11.45	11.45	11.45
21	CV21	14.38	14.38	14.38	30.58	30.58	48.54	11.12	11.12	11.12
22	CV22	15.64	15.64	15.64	33.53	33.53	56.65	10.96	10.96	10.96
23	CV23	12.40	12.40	12.40	51.49	51.49	50.64	10.46	10.46	10.46
24	CV24	14.40	14.40	14.40	50.39	50.39	49.48	10.94	10.94	10.94
25	CV25	16.45	16.45	16.45	51.24	51.24	54.73	9.54	9.54	9.54
26	CV26	11.55	11.55	11.55	57.41	57.41	47.43	9.15	9.15	9.15
27	CV27	14.30	14.30	14.30	54.95	54.95	43.46	9.63	9.63	9.63
28	CV28	16.76	16.76	16.76	58.64	58.64	39.60	9.64	9.64	9.64
29	CV29	15.08	15.08	15.08	31.49	31.49	48.54	14.98	14.98	14.98
30	CV30	14.47	14.47	14.47	49.46	49.46	51.58	8.96	8.96	8.96
31	CV31	15.54	15.54	15.54	65.38	65.38	49.58	9.12	9.12	9.12
32	CV32	14.37	14.37	14.37	38.83	38.83	53.41	10.78	10.78	10.78
33	CV33	13.10	13.10	13.10	40.50	40.50	49.63	11.95	11.95	11.95
34	CV34	13.74	13.74	13.74	34.45	34.45	48.69	9.56	9.56	9.56
35	CV35	13.54	13.54	13.54	51.56	51.56	42.55	14.16	14.16	14.16
36	CV36	14.37	14.37	14.37	28.96	28.99	28.98	10.42	10.42	10.42
37	CV37	11.40	11.40	11.40	49.69	51.69	50.45	12.59	12.59	12.59
	CD (0.05%) Germplasm	1.57	1.78	1.18	6.25	6.29	4.41	1.47	1.68	1.18
	Environment	-	-	NS	-	-	NS	-	-	NS
	Interaction	-	-	1.67	-	-	6.24	-	-	1.56

Table 7: Variation in mean tuber girth, tuber weight and tuber yield of thirty-seven *D. alata* germplasm

Sl. No.	Germplasm	Tuber girth (cm)			Tuber weight (kg)			Tuber yield (t/ha)		
		2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
1	CV1	13.34	13.34	13.34	3.24	3.24	13.34	22.42	22.25	22.34
2	CV2	11.52	11.52	11.52	7.43	7.43	11.52	51.63	51.63	51.63
3	CV3	13.31	13.31	13.31	5.53	5.53	13.31	34.58	34.58	34.58
4	CV4	12.39	12.39	12.39	3.50	3.50	12.39	24.24	24.24	24.24
5	CV5	14.52	14.52	14.52	5.10	5.10	14.52	34.87	34.99	34.93
6	CV6	13.35	13.35	13.35	5.93	5.93	13.35	29.19	29.19	29.19
7	CV7	13.54	13.54	13.54	4.30	6.31	13.54	62.47	62.47	62.47
8	CV8	12.48	12.48	12.48	7.03	7.03	12.48	34.70	34.70	34.70
9	CV9	14.49	14.49	14.49	5.20	5.20	14.49	35.10	35.10	35.99
10	CV10	16.39	16.39	16.39	3.20	3.20	16.39	24.94	25.62	25.28
11	CV11	11.29	11.29	11.29	5.57	5.57	11.29	40.50	40.50	40.50
12	CV12	12.57	12.57	12.57	4.73	4.73	4.73	33.17	33.17	33.17
13	CV13	12.38	12.38	12.38	3.46	3.46	3.46	23.95	23.95	23.95
14	CV14	16.62	16.62	16.62	3.40	3.40	3.40	23.54	23.54	23.54
15	CV15	14.42	14.42	14.42	3.32	3.32	3.32	22.96	22.80	22.88
16	CV16	18.52	18.52	18.52	8.50	8.50	8.75	35.8	35.84	35.84
17	CV17	12.52	12.52	12.52	8.10	8.10	8.10	52.09	52.09	52.09
18	CV18	11.41	11.41	11.41	4.23	4.23	4.23	29.13	29.38	29.26
19	CV19	12.35	12.35	12.35	3.46	3.46	3.46	23.97	23.97	23.97
20	CV20	15.34	15.34	15.34	5.80	5.80	5.80	40.15	40.15	40.15
21	CV22	14.38	14.38	14.38	3.51	3.51	3.51	24.27	24.27	24.27
22	CV22	15.64	15.64	15.64	3.41	3.41	3.41	23.63	23.63	23.63
23	CV23	12.4	12.4	12.4	5.50	5.50	5.50	38.05	38.21	38.13
24	CV24	14.4	14.4	14.4	5.50	5.50	5.50	37.40	37.40	37.40
25	CV25	16.45	16.45	16.45	3.75	3.75	8.75	26.30	26.30	26.30
26	CV26	11.55	11.55	11.55	3.74	3.74	3.74	25.87	25.87	25.87
27	CV27	14.30	14.30	14.30	3.94	3.94	3.94	27.27	27.27	27.27
28	CV28	16.76	16.76	16.76	3.60	3.60	3.60	31.92	31.92	31.92
29	CV29	15.08	15.08	15.08	3.93	3.93	3.93	27.20	27.20	27.20
30	CV30	14.47	14.47	14.47	7.70	9.70	8.70	27.61	25.61	25.61
31	CV31	15.54	15.54	15.54	3.90	3.90	3.90	26.10	27.21	27.10
32	CV32	13.37	13.37	13.37	3.64	3.64	3.64	25.22	25.22	25.22
33	CV33	13.10	13.10	13.10	3.50	3.50	3.50	23.12	23.12	23.12
34	CV34	13.74	13.74	13.74	6.17	6.17	6.17	43.35	43.35	43.35
35	CV35	13.54	13.54	13.54	4.57	4.57	4.57	32.35	32.35	32.35
36	CV36	14.37	14.37	14.37	4.43	4.43	4.43	31.58	31.58	31.58
37	CV37	11.40	11.40	11.40	4.77	4.77	4.77	34.52	34.91	34.52
	CD (0.05%) Germplasm	0.50	0.36	0.31	9.35	9.34	6.57	9.35	9.34	6.57
	Environment	-	-	NS	-	-	NS	-	-	NS
	Interaction	-	-	0.43	-	-	9.30	-	-	9.30

Table 8: Variation in mean dry matter, sugar and starch content of thirty-seven *D. alata* germplasm

Sl. No.	Germplasm	Dry matter (%)			Sugar (%)			Starch (%)		
		2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
1	CV1	28.37	26.19	27.28	6.57	6.36	6.46	69.47	67.5	68.49
2	CV2	25.43	23.42	24.43	6.47	6.49	6.47	71.35	69.35	70.35
3	CV3	29.70	27.72	28.60	4.53	4.43	4.48	68.46	66.46	67.46
4	CV4	27.47	25.43	27.47	4.71	4.79	4.71	67.32	65.32	66.32
5	CV5	32.41	30.28	31.34	5.34	5.36	5.34	69.12	68.93	69.03
6	CV6	33.45	31.49	32.42	5.77	5.71	5.77	70.10	68.10	69.10
7	CV7	35.49	33.50	34.51	6.26	6.32	6.29	74.34	72.34	73.34
8	CV8	26.52	30.54	28.52	6.61	6.64	6.61	72.49	70.49	71.49
9	CV9	27.76	23.54	25.66	7.32	7.35	7.32	71.38	69.38	70.38
10	CV10	28.51	24.52	26.51	7.64	7.62	7.64	72.39	70.35	71.37
11	CV11	26.65	22.64	24.63	8.48	8.56	8.53	69.49	67.49	68.49
12	CV12	26.68	28.68	27.68	9.55	9.56	9.55	69.68	66.68	64.68
13	CV13	29.70	25.72	27.70	4.30	4.34	4.32	70.08	68.08	69.08
14	CV14	36.47	32.45	34.47	5.54	5.56	5.54	72.48	70.48	71.48
15	CV15	25.16	23.39	24.50	9.45	9.42	9.43	69.60	67.42	68.51
16	CV16	26.52	24.51	25.51	4.49	4.79	11.48	68.23	68.23	68.23
17	CV17	33.35	27.36	30.35	10.84	10.82	10.84	67.61	65.61	66.61
18	CV18	32.36	30.35	31.35	9.40	9.43	9.40	66.37	64.37	65.37
19	CV19	28.58	29.18	28.88	4.51	4.57	4.51	66.68	67.68	67.68
20	CV20	26.49	29.46	27.49	7.35	7.31	7.35	65.50	63.50	64.50

21	CV21	30.56	27.55	29.56	6.57	6.51	6.57	67.54	65.43	66.48
22	CV22	30.54	28.54	29.54	6.62	6.68	6.62	66.50	64.59	65.59
23	CV23	31.60	29.66	30.60	6.48	6.41	6.48	69.37	67.37	68.37
24	CV24	31.43	31.38	31.41	8.42	8.53	8.48	69.60	65.12	67.36
25	CV25	29.62	27.40	28.40	8.04	8.09	8.04	72.55	74.55	73.55
26	CV26	32.26	31.27	32.28	6.61	6.69	6.61	71.55	69.55	70.55
27	CV27	26.67	24.64	25.65	8.71	8.73	8.71	79.49	77.49	78.49
28	CV28	28.57	26.59	27.59	5.58	5.59	5.58	70.43	68.43	69.43
29	CV29	33.73	27.71	30.72	5.81	5.86	5.81	74.26	70.33	72.29
30	CV30	26.54	24.58	25.54	6.57	6.52	6.57	77.27	75.27	76.27
31	CV31	25.71	23.70	24.73	8.43	8.25	7.44	71.39	69.40	70.39
32	CV32	35.49	33.48	34.33	7.35	7.32	7.35	49.48	46.48	48.4
33	CV33	32.55	30.54	31.54	6.58	6.56	6.57	70.51	68.51	69.51
34	CV34	26.23	22.26	24.26	10.31	10.34	10.31	73.39	71.39	72.39
35	CV35	28.72	26.76	27.72	6.32	6.39	6.32	71.43	69.29	70.36
36	CV36	29.47	23.46	26.57	7.39	7.47	7.43	68.43	66.73	67.73
37	CV37	31.49	29.40	30.45	6.76	6.35	6.55	70.37	68.99	69.68
	CD (0.05%) Germplasm	3.28	3.38	2.35	0.70	0.66	0.48	3.43	3.39	2.39
	Environment	-	-	NS	-	-	NS	-	-	NS
	Interaction	-	-	3.32	-	-	0.68	-	-	3.39

Table 9: Variation in mean ash content, crude fibre and total phenol content of thirty-seven *D. alata* germplasm

Sl. No.	Germplasm	Ash (%)			Crude fibre (%)			Total phenol (g/100 g)		
		2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
1	CV1	3.50	3.60	3.55	14.31	10.35	12.31	2.37	2.56	2.47
2	CV2	4.62	4.04	4.43	11.69	9.69	11.69	2.30	2.30	2.30
3	CV3	3.08	3.38	3.18	10.49	10.51	10.50	0.63	0.68	0.6
4	CV4	3.18	3.46	3.28	10.23	13.41	11.51	3.34	3.34	3.34
5	CV5	2.52	2.79	2.63	8.57	10.57	9.57	0.64	0.64	0.64
6	CV6	4.17	4.44	4.27	12.40	12.55	12.40	0.77	0.77	0.77
7	CV7	4.64	4.48	4.54	12.72	10.12	11.62	2.18	2.38	2.28
8	CV8	3.67	3.52	3.59	9.84	12.54	10.44	2.19	2.19	2.19
9	CV9	4.16	4.24	4.20	10.72	12.82	11.72	1.41	1.41	1.41
10	CV10	3.82	3.66	3.72	10.46	8.66	9.46	4.49	4.48	4.49
11	CV11	3.60	3.54	3.57	12.38	10.48	11.58	0.8	0.91	0.85
12	CV12	2.97	2.74	2.87	9.26	9.50	9.39	4.87	4.69	4.70
13	CV13	4.34	4.16	4.24	11.36	13.98	12.68	0.63	0.53	0.58
14	CV14	4.75	4.58	4.65	12.43	10.93	11.53	0.2	0.66	0.66
15	CV15	3.80	3.65	3.71	12.31	10.45	11.32	1.70	1.69	1.70
16	CV16	2.73	2.56	2.63	10.75	11.34	10.57	0.95	0.95	0.95
17	CV17	3.67	3.49	3.57	12.66	10.56	11.26	1.04	1.09	1.07
18	CV18	3.51	3.39	3.45	11.44	9.86	10.54	0.76	0.76	0.76
19	CV19	4.42	4.22	4.24	10.90	8.69	9.62	0.94	0.95	0.94
20	CV20	3.74	3.77	3.76	10.45	8.51	9.84	0.46	0.47	0.47
21	CV22	3.63	3.61	3.62	11.48	16.63	13.58	2.53	2.53	2.53
22	CV22	3.32	3.36	3.32	11.82	9.78	10.87	2.64	2.52	2.58
23	CV23	2.53	2.51	2.53	12.14	10.37	11.64	1.76	1.70	1.73
24	CV24	4.34	4.36	4.34	10.21	1.69	10.46	1.63	1.63	1.63
25	CV25	3.66	3.67	3.66	12.45	10.21	11.51	1.85	1.85	1.85
26	CV26	3.72	3.76	3.72	12.36	12.90	12.79	2.12	2.32	2.22
27	CV27	4.23	4.36	4.30	10.39	8.69	9.99	1.56	1.56	1.56
28	CV28	2.56	2.54	2.56	11.24	9.92	10.62	0.66	0.72	0.69
29	CV29	4.79	4.76	4.79	11.98	11.46	11.67	0.46	0.46	0.46
30	CV30	3.67	3.64	3.67	12.31	10.56	11.21	0.95	0.9	0.95
31	CV31	4.38	4.56	4.47	12.42	10.12	11.49	2.29	2.29	2.29
32	CV32	3.32	3.31	4.31	12.32	12.71	12.59	0.65	0.68	0.67
33	CV33	3.64	3.65	3.65	10.01	10.80	10.41	0.76	0.76	0.76
34	CV34	4.59	4.53	4.54	10.63	8.48	9.53	1.17	1.33	1.25
35	CV35	3.67	3.63	3.63	11.32	10.89	11.03	2.40	2.44	2.40
36	CV36	3.75	3.70	3.70	9.94	9.21	9.54	3.69	3.69	3.69
37	CV37	4.36	4.40	4.36	10.23	12.33	11.56	2.65	2.55	2.60
	CD (0.05%) Germplasm	0.40	0.42	0.29	NS	NS	2.42	0.26	0.39	0.23
	Environment	-	-	NS	-	-	NS	-	-	NS
	Interaction	-	-	0.41	-	-	3.43	-	-	0.33

Principal component analysis

Principal Component Analysis (PCA) conducted on thirty seven *Dioscorea alata* germplasm based on eighteen quantitative characters and thirty six qualitative characters (Table.10 and Table.11) revealed the existence of diversity among the germplasm. Ordination among the germplasm revealed principal components exhibits eigen vector greater than one and cumulatively accounted for 81.10 per cent of the total observed variability. The Eigen vectors of fourteen

principal components were interpreted as relative weight of variables in each component. The variables causing variations are those which have high positive value i.e. > 0.6. These finding are in complementary with the findings of Jyothy *et al.* (2017) [23]. Haydar *et al.* (2007) [18] also stated that diversity among genetic materials were contributed by the traits that have the greatest value and positive feature vector.

Table 10: Eigen values, variance, cumulative variance and component scores of the first seven principal components for qualitative traits in thirty-seven *Dioscorea alata* germplasm

Principal Component	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Eigen values	4.39	3.49	3.43	2.77	2.59	2.49	2.05
%Variation	11.26	8.96	8.78	7.10	6.65	6.39	5.25
Cumulative Variation	11.26	20.23	29.01	36.11	46.75	49.15	54.90
Dry matter	.422	.316	.184	-.362	-.242	.044	.312
Sugar	.155	.117	-.048	-.008	.051	.191	-.128
Starch	-.109	-.047	-.189	.314	.141	-.179	-.135
Ash content	.095	-.041	.142	-.065	.029	.021	.117
Crude fibre	.023	-.131	.059	-.109	.148	-.048	.143
Total phenol	.088	.361	-.136	.139	.178	-.094	-.708
days to emergence	.007	.058	.092	-.030	-.162	-.086	.018
Stem length	-.023	-.225	.023	-.028	.150	-.064	.121
Internode number	.141	.036	.196	-.052	.169	-.838	-.024
Internode length	.015	.103	-.048	-.032	.130	.832	-.041
Leaf number	.090	.096	-.018	.046	.043	.073	.058
Leaf length	.153	.113	-.292	.030	.426	.059	.169
Leaf width	.012	-.282	-.695	-.016	-.165	.010	.046
Petiole length	-.168	-.363	-.217	-.233	.231	-.032	.235
Tuber width	.951	.065	.036	.082	.036	-.035	-.047
Tuber length	.952	.046	.026	.070	.030	-.068	-.056
Tuber yield	-.049	.124	.106	-.053	.196	.038	-.002
Stem colour	.007	.231	.203	-.099	-.032	-.458	.138
Wing colour	.001	-.064	-.036	.365	-.276	.235	-.102
Stem height	-.104	-.142	.679	.265	-.162	-.160	.052
Stem colour	-.093	.170	-.023	.156	-.117	.062	-.090
Wing colour	-.445	.164	.062	.096	-.008	.047	.288
Young leaf colour	.205	-.281	-.108	-.077	-.473	.104	.052
YL margin colour	.212	-.077	-.017	.800	-.091	-.020	-.022
YL vein colour	-.042	.013	.042	.816	-.283	.022	.144
YL petiole colour	.074	-.037	.138	-.228	.689	.186	-.265
YL petiole wing colour	-.007	-.034	.177	.251	-.793	.174	-.121
Distance between lobes	.018	.080	.794	-.305	-.018	-.118	.017
Leaf shape	.016	-.183	-.067	-.083	.223	-.172	-.042
Leaf tip shape	.195	.243	.659	.120	-.004	-.091	-.176
Tubers per hill	.106	.152	-.042	.111	.132	-.286	.197
Tuber shape	.007	.085	-.152	.153	.019	-.118	.872
Tuber Skin colour	-.117	.867	.075	-.125	.088	-.031	-.260
Tuber skin texture	-.057	-.814	-.038	-.041	.136	.039	-.152
Tuber cortex colour	-.298	-.297	.207	.443	.212	.182	.428
Tuber flesh colour	-.581	.424	.244	.079	-.009	-.021	-.155

Table 11: Eigen values, variance, cumulative variance and component scores of the last seven principal components for qualitative traits in thirty-seven *Dioscorea alata* germplasm

Principal Components	PC8	PC9	PC10	PC11	PC12	PC13	PC14
Eigen values	1.20	1.79	1.64	1.50	1.27	1.19	1.04
%Variation	5.11	4.56	4.22	3.84	3.26	3.06	2.66
Cumulative Variation	59.50	64.06	68.28	72.11	75.38	78.43	81.10
Dry matter	.129	-.125	.179	.006	-.352	.019	-.079
Sugar	.154	-.031	-.085	.064	.842	-.068	.145
Starch	-.023	.208	-.171	.556	.027	.075	-.284
Ash content	-.047	.058	.097	.846	.053	-.144	.092
Crude fibre	-.066	-.056	.826	.015	-.148	-.057	-.054
Total phenol	.021	-.190	-.079	.019	.069	-.018	.267
days to emergence	.823	.085	.011	-.016	.090	.031	.046
Stem length	-.182	.029	-.547	-.216	-.058	.193	.501

Internode number	-.076	-.100	-.135	-.096	-.025	.186	.092
Internode length	-.170	.061	-.102	-.176	-.043	.055	-.084
Leaf number	-.067	.910	.047	.069	-.025	-.064	.128
Leaf length	-.371	.045	-.079	-.043	-.090	.381	-.344
Leaf width	-.077	.057	-.228	.053	-.072	.312	-.150
Petiole length	.572	-.154	.095	.008	-.216	.118	-.004
Tuber width	-.081	.018	.005	.046	.135	-.022	-.015
Tuber length	-.080	.019	-.003	.042	.138	-.022	-.030
Tuber yield	.149	.815	-.051	.015	.064	.096	-.041
Stem colour	-.021	.317	-.086	-.498	-.049	-.189	.113
Wing colour	.436	.159	.307	-.427	.090	-.146	.015
Stem height	.036	.101	-.094	-.042	.018	.248	.003
Stem colour	.111	.066	.715	-.030	.026	.274	.170
Wing colour	-.346	-.199	.013	.165	.298	.496	.227
Young leaf colour	-.344	-.229	.046	-.375	.309	-.020	-.022
YL margin colour	-.064	.111	.165	.020	.052	-.040	.166
YL vein colour	-.042	-.140	-.115	.054	-.027	-.011	-.056
YL petiole colour	-.257	.032	-.025	.037	-.021	.017	.084
YL petiole wing colour	.006	-.288	-.054	-.143	-.029	-.149	.051
Distance between lobes	.088	.088	.082	.085	-.111	.069	.254
Leaf shape	.140	.072	.130	-.065	-.098	.786	.173
Leaf tip shape	-.209	-.008	-.200	.075	.202	-.306	-.163
Tubers per hill	.133	.075	.114	.449	.157	-.497	.308
Tuber shape	.036	.001	-.027	.074	-.049	-.017	.060
Tuber Skin colour	-.071	.045	.066	-.034	-.037	-.130	.098
Tuber skin texture	.052	-.265	.035	.038	-.127	.000	.121
Tuber cortex colour	.314	-.162	-.015	-.007	-.078	-.101	.027
Tuber flesh colour	-.282	.010	.320	.081	-.181	-.029	.130

The first thirteen principal components viz., PC1, PC2, PC3, PC4, PC5, PC6, PC7, PC8, PC9, PC10, PC11, PC12 and PC13 together explained 78.43 per cent of cumulative variation among the germplasm. Hence, the morphological characters like tuber width, tuber length, tuber skin colour, stem height, distance between lobes, leaf tip shape, young leaf margin colour, young leaf vein colour, young leaf petiole colour, internodal length, tuber shape, days to emergence, leaf number, tuber yield, stem colour and biochemical characters like crude fiber content, ash content and sugar content are useful characters to distinguish between *Dioscorea alata* germplasm and can be used as minimum descriptors for morpho-biochemical characterization of *Dioscorea alata* germplasm specially in North-Eastern region. In this study, tuber, leaf and stem characters revealed significant differences among the different genotypes sourced from different geographical origins which were consistent with the studies by Yalindu *et al.* (2018), Bekele and Bekele (2020) [8]. The first six principal components contributed 49.15 per cent of the total variation and the results are in line with the work done by Jyothy *et al.* (2017) [23] with 50.12 per cent and was slightly lower than variations observed by Norman *et al.* (2011) [33] and Agre *et al.* (2019) [2] with 74.3 per cent and 71.44 per cent of the total variation, respectively.

Among the 57 morphological and biochemical characters used in this study, 16 (28.07%) were the most discriminating characters for the *D. alata* for the yam genotypes evaluated. Our results are in confirmatory with the findings of Anokye *et al.* (2014) [3] who reported 23 characters (21.5%) out of the 107 characters as the most discriminating traits. In another study, Hasan *et al.* (2008) [17] reported 25 characters (53.2%) out of 47 characters were the most discriminating. Despite using many characters, only a few characters might be necessary to discriminate among genotypes of different yam species. Our study revealed that, the most discriminating characters such as

underground tuber size, shape and skin colour, young stem and leaf colour, leaf number, crude fiber, ash content and sugar content can be used by the farmers and breeders to preliminarily identify and distinguish *D. alata* genotypes of North-Eastern region of India.

Cluster analysis

Cluster analysis of thirty seven *Dioscorea alata* germplasm generated a dendrogram which divided the germplasm into two main clusters viz., cluster I (CL-I) and cluster II (CL-II). The first cluster CL-I was further divided into four sub-clusters viz., CL-IA, CL-IB, CL-IC and CL-ID. Sub cluster CL-IA consists of two germplasm from Tinsukia, Assam viz., CV34 and CV31 and two germplasm viz. CV24 and CV27 from Arunachal Pradesh (Table.10 and Fig. 1). Two germplasm from Arunachal Pradesh (CV19 & CV20) and one from Udalguri, Assam (CV33) clustered under sub-cluster CL-IB. Sub-cluster CL-IC consists of two germplasm from Assam viz., Sibsaigor (CV29) and Goalpara (CV14) while sub-cluster CL-ID contained three germplasm from Assam viz., Dhubri (CV7), Bongaigaon (CV6) and Morigaon (CV2) and one germplasm from Kerala (CV37). Second main cluster CL-II is a big cluster which is further divided into seven sub-clusters viz., CL-IIA, CL-IIB, CL-IIC, CL-IIID, CL-IIIE, CL-IIIF and CL-IIIG. Sub cluster CL-IIA contains five germplasm from Tezpur (CV11), Golaghat (CV32), Manipur (CV17), Arunachal Pradesh (CV18) and Meghalaya (CV23). Three germplasm from Assam viz., Nagaon (CV3), Karbi Anglong (CV28) and Bongaigaon (CV5) and one germplasm from Arunachal Pradesh (CV 16) were grouped under sub-cluster CL-IIB. Sub-cluster CL-IIC contains two germplasm from Cachar (CV36) and Chirang (CV10) while sub-cluster CL-IIID contains three germplasm from Assam viz., Kamrup (CV8), Tezpur (CV12), Dibrugarh (CV35) and one germplasm from Mizoram (CV22). Again fifth sub-cluster CL-IIIE consists of two germplasm from Nalbari (CV26) and Borpeta (CV13)

whereas three germplasm from Assam viz., Baksa (CV30), Chirang (CV9), Goalpara (CV15) and one germplasm from Arunachal Pradesh (CV25) grouped under sub-cluster CL-IIF. Seventh sub-cluster CL-IIG consists of three germplasm from Assam viz., Jorhat (CV1), Darang (CV4) and one germplasm CV21 from Nagaland (Table 4.23 and Fig. 4.19).

Dendrogram using ward linkage

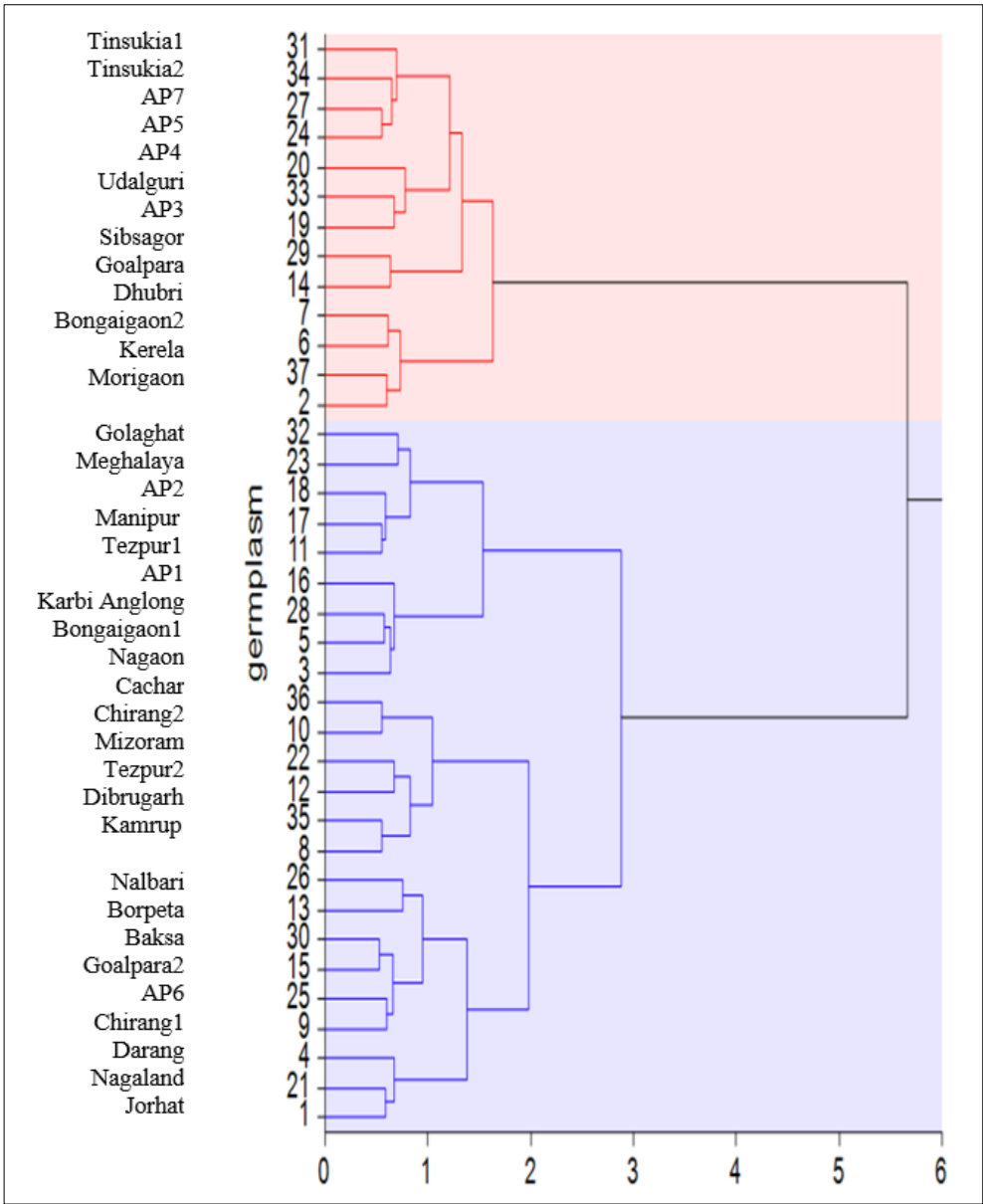


Fig 1: Hierarchical clustering of thirty-seven *Dioscorea alata* germplasm based on morphological and biochemical characterization using the ward’s linkage

Table 10: List of clustered germplasm using ward’s linkage method based on morphological and bio-chemical relationship among thirty-seven *dioscorea alata* germplasm

Cluster	Sub-cluster	No. of germplasm	Germplasm
I	CL-IA	4	Tinsukia 2 (CV34), Tinsukia 1 (CV31), Arunachal Pradesh 7 (CV27), Arunachal Pradesh 5 (CV24)
	CL-IB	3	Udalguri (CV33), Arunachal Pradesh 4 (CV20), Arunachal Pradesh 3 (CV19)
	CL-IC	2	Sibsagor (CV29), Goalpara 1 (CV14)
	CL-ID	4	Dhubri (CV7), Bongaigaon 2 (CV6), Morigaon (CV2), Kerala (CV37)
II	CL-IIA	5	Tezpur 1 (CV11), Golaghat (CV32), Manipur (CV17), Arunachal Pradesh 2 (CV18), Meghalaya (CV23)
	CL-IIB	4	Nagaon (CV3), Karbi Anglong (CV28), Bongaigaon 1 (CV5), Arunachal Pradesh 1 (CV16)
	CL-IIC	2	Cachar (CV36), Chirang 2 (CV10)
	CL-IID	4	Kamrup (CV8), Tezpur 2 (CV12), Dibrugarh (CV35), Mizoram (CV22)
	CL-IIE	2	Nalbari (CV26), Borpeta (CV13)
	CL-IIF	4	Baksa (CV30), Chirang 1 (CV9), Goalpara 2 (CV15), Arunachal Pradesh 6 (CV25)
	CL-IIG	3	Jorhat (CV1), Nagaland (CV21), Darang (CV4)

Observations recorded for the morphological and biochemical characters of *D. alata* were used for clustering with hierarchical clustering using the ward's linkage. It revealed that the *D. alata* germplasm exhibited greater degree of variation for the 57 different morphological and biochemical traits observed and germplasm were clustered mainly by stem height, emergence habit, petiole length and skin colour at tuber head. The germplasm having skin colour white with purple at tuber head, light maroon cortex colour and light purple flesh oxidation colour (CV7, CV6, CV37, and CV2) were found to be highly divergent from other germplasm and grouped as a separate sub cluster under study. Similar results were also observed by Sheela *et al.* (2016) [40] and Jyothy *et al.* (2017) [23] where germplasm with purple flesh colour were found to be highly divergent from other germplasm. Mahalakshmi *et al.* (2007) [27] also reported the use of morphological traits to obtain a core collection for *D. alata* by evaluating a total of 772 accessions.

In the dendrogram, most of the germplasm clustered randomly among two groups regardless of geographical locations. It was also observed that geographically closer germplasm were grouped under different clusters. Germplasm like CV37 (check) from Kerala were grouped with the germplasm from Arunachal Pradesh and Assam in cluster I. These results suggested that geographical origin of the *D. alata* germplasm does not bear any relationship with morphological and biochemical characterization. This is confirmatory with other reports based on morphological analysis by Massawe and Temu (2022) [28], Jyothy *et al.* (2017) [23] and Anokye *et al.* (2014) [3]. The informal nature of yam trade and exchange of planting materials among farmers and states leads to duplication of planting materials and majority of the germplasm were most likely clones of a common source (Anokye *et al.*, 2014) [3]. Furthermore, lack of breeding and conservation programmes could have contributed to the similarity of yam genotypes between the region (Massawe and Temu, 2022) [28]. Atieno *et al.* (2020) [6] also noted this phenomenon, where yam genotypes from various regions of Kenya were classified together, regardless of their geographical origins.

Conclusion

In the present study, 37 germplasm of greater yam collected were morphologically and biochemically analyzed using the descriptors of yam. According to the present study, there were no duplicate germplasm identified and it can be maintained as core collection because it depicts wide spectrum of variability and also represent landraces representing different yams growing regions of the North-Eastern states. Moreover, out of 37 germplasm studied, 10 germplasm viz. G7 (Dhubri), G16 (West Kameng), G5 (Bongaigaon2), G29 (Sivasagar), G13 (Barpeta), G14 (Goalpara1), G3 (Nagaon), G27 (Namp hai), G2 (Mokochung) and G12 (Tezpur2) showed highest values for desirable characteristics. Among these 10 germplasm, G7 (Dhubri) showed highest values for maximum 5 desirable characters followed by G16 (West Kameng1) for 4 desirable characters. Therefore these germplasm can be further evaluated and used in breeding programmes. Principal component analysis showed that the eigen values of the first six principal components of data accounted for 49.15% of the total variance among germplasm. Morphological traits like tuber width, tuber length, tuber

skin colour, stem height, distance between lobes, leaf tip shape, young leaf margin colour, young leaf vein colour, young leaf petiole colour, internodal length, tuber shape, days to emergence, leaf number, tuber yield, stem colour and biochemical characters like crude fiber content, ash content and sugar content were all found to be of great importance in distinguishing the germplasm in greater yam. The 37 greater yam germplasm were grouped into two major clusters with Cluster I having maximum number of germplasm (13) and Cluster II with 24 germplasm. The cluster dendrogram based on morphological and biochemical data revealed that the *D. alata* germplasm exhibited very high level of variation and no duplicate accessions were observed among the genotypes studied. So, conservation of these genotypes and inclusion in food chain as an additional tuber crop next to potato, cassava and sweet potato will help to curb malnutrition & lower incidence of other diet related diseases particularly in weaker section of the society. This will broaden the range of uses for this underutilized tuber beyond its current utilization in the North-Eastern region of India.

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