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Identification of Ethiopian Yam (*Dioscorea* spp.) Collections and Their Phenotypic Diversity Study

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Abstract

Yam plant has a major role in Ethiopia particularly in densely populated areas of south, southwestern, and western parts of the country. It grows in a wide range of soils with an altitude range of 1140 to 2200 masl. This study was done to identify yam species collected from major producing areas of the country. The total of sixty yam accessions from ten different geographic origins of South and Oromiya region of Ethiopia were used. The collected samples were planted in complete randomized block design at two research sites of South Agricultural Research Institute. Forty-five qualitative morphological characterizations were used to characterize and identify *Dioscorea* species. Among these qualitative characters observed in the study presence and absence of spines on stems and roots, number of male and female inflorescence, stem length, twining direction, and flesh color were the major traits considered for species identification. The organoleptic properties evaluation was carried out using fifteen selected local farmers. Statistical analysis was done using Numerical Taxonomy and Multivariate Analysis System Version 2.02 NTSYpc software program and the data reduction function of SPSS for windows. Based on this study, sixty yam germplams of ten major growing areas of the country were identified into six *Dioscorea* species. These identified *Dioscorea* species were again subjected to qualitative morphological characterization and 33 morphological traits revealed variability. This implies presence of high diversity in yam (*Dioscorea* species) of Ethiopia. Most of the morphological variations among the yam genotypes were contributed by young petiole color, tendency of tuber to branch, and tuber flesh color. Hence, these morphological traits could be taken as useful traits for identification of yam cultivars.

Keywords

Yam, Species, Characterization, Morphology, Traits, Diversity, Organoleptic

1. Introduction

Yam is cultivated mainly for its tuber. It is a major source of carbohydrates and nutrient energy for many people in tropical countries including east and West Africa, the Carribean, South Africa, India and South East Asia [1] [2]. Ethiopia is the fifth largest yam producing country of Africa and its annual production is estimated at about 1,191,809 metric tons [3]. The crop plays a vital role in local livelihood particularly in densely populated areas of south, southwestern, and western parts of the country [4] [5]. About nine types of yam have been reported to grow in Ethiopia indicating the diversity of the species in the country [6].

Yams have become an important cash crop in most localities. Yams are also served during the traditional festival which coincides with the peak harvesting time thus allowing farmers to earn profit from the market. It grows in the altitude range of 1140 to 2200 and in a wide range of soils mainly in clay, clay loam, sandy and sandy loam types. It is planted in October (in most parts of South Ethiopia), November and December (in South Western and Western part of the country) [7]. The present work is to identify Ethiopian yam collections from major growing areas of the country into their *Dioscorea* species group and study their phenotypic diversity.

2. Materials and Methods

2.1. Morphological Characterization and Yam Landraces

Sixty yam accessions from ten different geographic origins of Southern Nations Nationalities and People's Regional State and Oromiya region of the country were used for this study. The sprouted tubers of some accessions were obtained from Research Centers whereas others were directly collected from farmers' fields during early March, 2010 as indicated in **Table 1**. The samples collected were planted on April 2010 in complete randomized block design with three replication at two research sites (namely at Hawassa and Wonago) which are found under South Agricultural Research Institute at the end of April 2010 as indicated in **Figure 1**. All important cultural practices such as staking, weeding and irrigation were done starting from planting till harvesting.

Among 45 morphological characters (**Table 3**) observed in the study presence and absence of spines on stems and roots, number of male and female inflorescence, stem length, twining direction, and flesh color were the major traits considered for species identification. The species identification was done through observing some earlier developed identification keys [7].

Table 1. Ethiopian yam germplasms with their origin site, vernacular name and respective altitudes used in the study.

SN	Accessions name	Place of collection		
		Zone	Woreda (local name)	Altitude (masl)
1	Aw/Ji/001	Jima	-	1780
2	Aw/Ge/004	Wonago	Dila	1940
3	Aw/Wo/011	Wolayita	-	1940
4	Aw/GG/001	Gamo Gofa	Bonke (Kemba)	1540
5	Aw/BD/065	Kefa	-	1600
6	Aw/BD055	Kefa	-	1600
7	Aw/GG/02	Gamo Gofa	Arbaminch (Hatiya-2)	1140
8	Aw/GG/003	Gamo Gofa	Breda (Bunne-2)	1655
9	Aw/ Ar/001	Wolita	Areka Research Center	1780
10	Aw/ Ar/005	Wolita	Areka Research Center	1780
11	Aw/Si/008	Sidama	-	
12	Aw/Wo/013	North Omo	Kedida Gamela (Gamlea)	1970
13	Aw/Ged/005	Gedio	Wonago	1770
14	Aw/Wo/012	North Omo	Alabana tembar	1630
15	Aw/Ged/06	Gedio	Wonago	1610
16	Aw/Wo/014	North Omo	Wancharo	
17	Aw/GG/04	Gamogofa	Gofa (Tolla)	1340
18	Aw/GG/005	Gamo Gofa	Arba minch (Bunne-1)	2070
19	Aw/GG/006	Gamo Gofa	Kucha (Bunne-3)	1500
20	Aw/Si/010	Sidama	-	
21	Aw/Si/001	Sidama	Dalle (Gellawcho)	1940
22	Aw/Ar/006	Wolita	Areka Research Center	1780
23	Aw/Ar/002	Woilita	Areka Research Center	1780
24	Aw/Ar/061	Wolita	Areka Research Center	1780
25	Aw/Ar/062	Wolita	Areka Research Center	1780
26	Aw/GG/007	Gamo Ggofa	Bonke (Arfa-01)	2070
27	Aw/Ar/027	Wolita	Areka Research Center	1780
28	Aw/Si/002	Sidama	Dale (Genticha)	1940
29	Aw/Si/003	Sidama	Dale (Midasho)	1940
30	Aw/Si/004	Sidama	Dale (Ouwisho)	1940
31	Aw/Si/005	Sidama	Dale (Adameado)	1940
32	Aw/Ji/046/87	Jim 04	Jima (JRC)	1780
33	Aw/Si/007	Sidama	Dale (Wnedu)	1940
34	Aw/Wo/001	Wolayita	Dwoyde (Oha)	1780
35	Aw/Wo/002	Wolayita	Dgalle (Arkiya)	2200

Continued

36	Aw/Wo/003	Wolayita	Dgalle (Gassa)	1950
37	Aw/Da/001	Dauro	Mareka (Dorsita)	1580
38	Aw/Da/002	Dauro	Konta (Gebiche)	1900
39	Aw/Wo/010	Wolayita	Areka (Gaffela)	1870
40	Aw/Ke/001	Kembata	Hadero (Makawa)	1140
41	Aw/Ge/007	Gedio	-	1590
42	Aw/GG/008	Gamogofa	Bonke (Afra-2)	1900
43	Aw/Wo/05	Wolayita	Dwoyde (Wiyacha)	1780
44	Aw/Wog/001	East Wolega	Sasiga (Gudina)	1750
45	Aw/Wog/002	East Wolega	Diga (Msreta)	1650
46	Aw/Wog/003	East Wolega	Sasiga (Haro)	1750
47	Aw/Wog/004	East Wolega	Diga (Lalo)	1650
48	Aw/Ji/002	Jima	-	1780
49	Aw/Ji/003	Jima	-	1780
50	Aw/Wog/004	East Wolega	Diga (Dhoknuma)	1650
51	Aw/Wog/005	East Wolega	Diga (Roba)	1650
52	Aw/Ji/004	Jima	-	1780
53	Aw/Wo/006	North Omo	Kokate (Cheyae, woncharo)	
54	Aw/Wo/07	North Omo	Sodo zuria (Oha 2)	1900
55	Aw/Wo/008	North Omo	Sodo zuria (Wdela 1)	1850
56	Aw/Wo/009	North Omo	Sodo zuria (Oha 1)	1860
57	Aw/Wo/010	North Omo	Sodo zuria Chocha	1850
58	Aw/Wo/063	-	Areka Research Center	1780
59	Aw/Ge/002	Gedio	Wonago (Ganticho)	1770
60	Aw/Wo/003	Gedio	Wonago (Nifo)	1770

Figure 1. General appearance of the field experiment of yam (*Dioscorea* spp.) at Hawassa Agricultural Research Center.

The identified *Dioscorea* species were subjected to qualitative morphological characterization. The qualitative morphological characterizations were carried out to determine the level of variability and the relationship among accessions using IPGRI/IITA descriptors [8]. Characters were observed for five different healthy plants per accession. The color aspect of the plant was recorded using Munsell color chart for plant tissues. The farmers perception were taken at the time of collection and sensory evaluation during harvesting for both boiled (eight characters) and un-boiled yam tubers.

The total forty five morphological characters were recorded at the time of young, flowering, maturity stage of the plant and at the time of harvesting using IPGR descriptor list [8] (**Table 2** and **Table 3**). The collected raw data were subjected to statistical analysis using computer software packages for the diversity and relatedness study among yams (*Dioscorea* spp.).

Table 2. The qualitative morphological characters and their score code of young and mature leaf, stem and tuber of yam (*Dioscorea* spp.) germplasms collected during field experiment.

Growth stage of the plant	Characters	Score code/Descriptor state
Young leaf	Leaf colour	1 Yellowish, 2 Pale green, 3 Dark green, 3 Purplish green, 4 Purple, 99 Other
	Leaf margin colour	1 Green, 2 Purple, 3 Other
	Vein colour	1 Yellowish, 2 Green, 3 Pale purple, 4 Purple, 99 Other
	Petiole colour	1 Green, 2 Green with purple edges, 3 Purple, 99 Others (specify in descriptor 7.7)
	Petiole wing colour	1 Green, 2 Green with purple edges, 3 Purple, 99 Others (specify in descriptor 7.7)
	Leaf hairiness upper/lower part position of widest part of leaf	1 Green, 2 Green with purple edges, 3 Purple, 1 Third upper, 2 Middle, 3 Third lower
Mature leaf	Absence and presence of waxiness	0 Absent, 1 Present
	Hairiness of petiole	3 Sparse, 5 Dense
	Petiole colour	1 All green with purple base, 2 All green with purple leaf junction, 3 All green with purple at both ends, 4 All purplish green with purple base, 5 All purplish green with purple leaf junction, 6 All purplish green with purple at both ends, 7 Green, 8 Purple 9 Brownish green, 10 Brown, 11 Dark brown 99 Other (specify in descriptor 7.7 Notes)

Continued

Mature leaf	Petiole wing colour	Green, Green with purple edge, Purple, Other
	Young stem colour after emergence	1 Green, 2 Purple green, 3 Brownish green, 4 Dark Brown, 5 Purple, 99 Other
	Absence or presence barky patches	0 Absent, 1 Present
	Absence or presence of spines	0 Absent, 1 Present
	Leaf density	3 Low, 5 Intermediate, 7 High
	Leaf type	1 Simple, 2 Compound
	Leatherness	0 No, 1 Yes
	Waxiness of upper/lower surface	1 Waxy upper surface, 2 Waxy lower surface, 3 Both
	Leaf apex shape	1 Obtuse, 2 Acute, 3 Emarginate, 99 Other
	Position of widest part of leaf	1 Third upper, 2 Middle, 3 Lower
	Distance b/n lobs	1 No measurable distance, 5 Intermediate, 9 Very distant
	Upward folding of leaf along main vein	3 Weak, 7 Strong
	Dawn ward folding of leaf along main vein	3 Few, 7 Many
Mature stem	Plant type	1 Dwarf, 2 Shrub like, 3 Climbing
	Twining habit	0 No, 1 Yes
	Twining direction	1 Clockwise (climbing to the left), 2 Antilock Wise (climbing to the right)
	Mature stem colour	1 Green, 2 Purplish green, 3 Brownish green, 4 Dark brown, 5 Purple, 99 Other
Underground Tubers	Corm size	3 Small, 5 Intermediate, 7 Large
	Absence or presence of underground tuber	0 no, 1 Yes
	Corm type	1 Regular, 2 Transversally elongated, 3 Branched
	Tendency of tuber to branch	3 Slightly branched, 5 Branched, 7 Highly branched
	ab/pr of cracks on tuber surface	3 Sparse, 7 Dense
	Spines of roots	3 Few, 7 Many
	Root on the tuber surface	0 No, 3 Few, 7 Many
	Place of root on the tuber	3 Few, 7 Many
	Uniformity of flesh colour	0 No, 1 Yes
	Maturity tuber after emergency	1 Up to 6 months, 2 7 - 8 months, 3 9 - 10 months

2.2. Characters Evaluated by Farmers

Fifteen farmers were selected from Gedio zone (Wonago district) near the research site. Following their consent an introduction was given to them by the researcher on the sensory parameters of interest. Yam tubers from each accession were taken washed and boiled by farmers as their method of preparation. The sensory values decided by farmers were recorded by the researcher as indicated in Table 3 using IPGRI descriptor list.

Table 3. Characters assessed by farmers.

	Character	Score code/Descriptor state
Cooked tuber	Stickiness of cooked tuber	1 Not sticky 2 Sticky, 3 Very sticky
	Flavor of cooked tuber	0 Not acceptable, 1 Acceptable, 2 Very acceptable
	Absence/presence moisture on cooked tuber	0 Absent , 1 Present
	Bitterness of cooked tuber	0 Not bitter, 1 Bitter, 2 Very bitter
	Sweetness of cooked tuber	0 Not sweet, 1 Sweet, 2 Very sweet
	Appearance of tuber after cooking	2 Poor, 5 Fair , 7 Good
	Color of tuber after cooking	1 White not colored, 9 Highly colored
	Overall assessment of cooked tuber	3 Low , 5 Intermediate, 7 High

2.3. Statistical Analysis for Morphological Characterization

Statistical analysis was done using Numerical Taxonomy and Multivariate Analysis System Version 2.02 NTSYpc software program [9] and the data reduction function of SPSS for windows (version 12.0, 2003). The standardized data for qualitative characters were subjected to multivariate analysis and principal component analysis to identify the most discriminating morphological characters. The matrix of similarity was generated based on distance coeficents. The distance matrix was subjected to hierarchical cluster analysis using Shan through an un-weighted pair group method average (UPGMA) [10]. Cophenetic value (ultrametric) matrix was used to compute the cophenetic correlation as a measure of goodness of fit.

3. Results

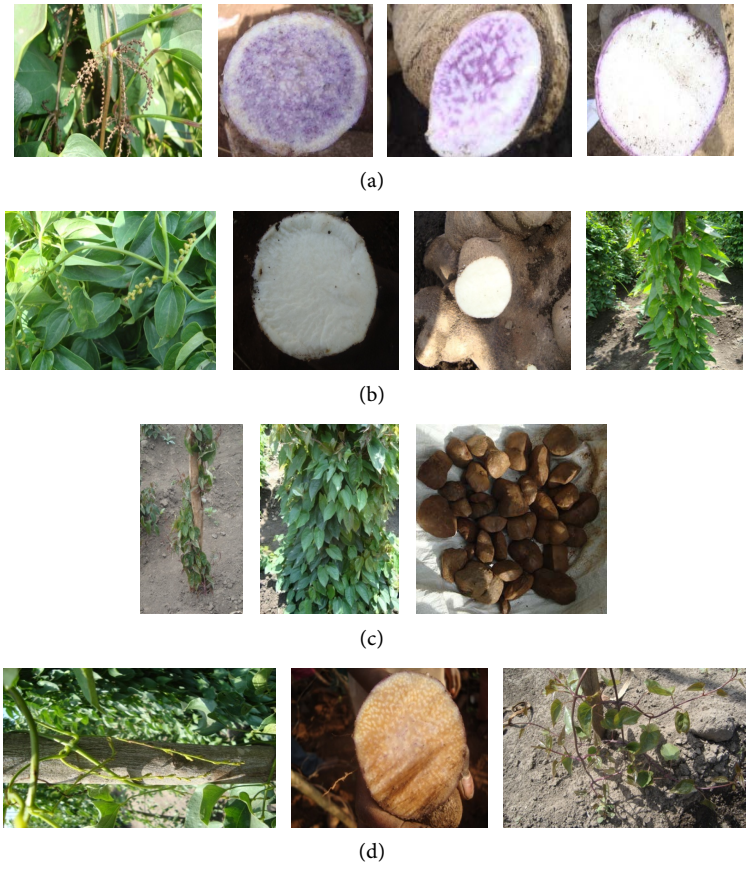
3.1. Morphological Variability Based Species Identification

Based on presence and absence of spines on stems and roots, number of male and female inflorescence, stem length, twining direction, and flesh color sixty yam germplams from ten major growing areas of the country were grouped into six species namely *D. alata*, *D. bulbifera*, *D. abyssinica*, *D. praehensilis*, *D. rotundata* and *D. cayenensis*. The two species *D. rotundata* and *D. cayenensis* were observed to have 1 - 3 male inflorescences per spike and after cutting revealed

white and yelowish flesh color. During this study the yellowish colour was grouped to *D. cayenensis* whereas the white flesh colour was grouped to *D. rotundata* as indicated in Figure 2(b) and Figure 2(d) respectively.

The species *D. alata* was differentiated from other groups based on its four angled stem. The average stem length of this species under study were 10 m long, it had different tuber shape apperance (Figure 2(f)). Whereas *D. abyssinica* had an average climber stem of 2 - 5 m and the number of male inflorescences observed was 3 - 6. Under this study most of the *D. abyssinica* species had male inflorescence (Figure 2(a)). Spines were observed on stem of this species. Whereas, the average stem length recorded from *D. praehensilis* was 10 m and spines were observed both on roots and stems of this species. The number of male and female inflorescences observed in *D. praehensilis* was 3 - 5 and 1 - 2 respectively (Figure 2(e)). Generaly *D. abyssinica* and *D. praehensilis* revealed three types of flesh color which were purplish colour, a central white colour surrounded by purplish colour and the mixure of white and purplish colours (Figure 2(a) and Figure 2(e)).

The species whose stem was climbing to the left or in a clock wise direction was grouped in to *D. bulbifera* (Figure 2 (c)). The average stem length of this species was 3 - 10 m with 3 - 5 male inflorescence. Its areal tuber showed both white and purple color. While, all the other species under study twining direction was anti clock wise.



(a) (b) (c) (d)

(e)

(f)

Figure 2. Morphological variations (Male and female inflorescences, fruits, twining habit and tuber flesh color) among six yam (*Dioscorea* spps.) germplasm observed in this study. (a) Collection area: Jima (South west Ethiopia) Altitude: 1753 masl, Species: *D. abyssinica*; (b) Collection area: Wonago (South Ethiopia) Altitude: 1940 masl, Species: *D. rotundata* (White yam); (c) Collection area: Wolega (Western Ethiopia) Vernacular name: Dhokunma, Species: *D. bulbifera*; (d) Collection: Kefa (South West Ethiopia), Species: *D. cayenensis*; (e) Collection area: Gamogofa (South Ethiopia) Altitude: −1140, Vernacular name: Hatiya-2, Species: *D. praehensilis*; (f) Collection area: Jima (South West Ethiopia), Species: *D. alata*.

3.2. Morphological Diversity Data of Yam Determined Based on Cluster Analysis

Among 45 qualitative morphological characters recorded on six *Dioscorea* species namely *D. abyssinica*, *D. praeihensilis*, *D. cayenensis*, *D. rotundata*, *D. alata* and *D. bulbifera* 12 traits did not reveal phenotypic variation among the 60 yam germplasm studied. These traits were not included for clustering and principal component analysis. Based on the relative magnitude of distance similarity matrix and dendrogram using Shan UPGMA cluster analysis, all sixty yam genotypes included in the study were grouped into five clusters (**Figure 3**).

At the similarity distance 1.81, the dendrogram identified three clusters 1 and 2 which contain eight to eighteen accessions per cluster (**Table 4** and **Table 5**). Cluster 1 is the second largest group and contains 18 yam accessions with green mature petiole colour. Cluster 2 contained accessions with pale purple young petiole colour, green mature petiole colour, high leaf density, presence of cracks on tuber surface, intermediate corm size, highly coloured tuber after cooking and cooked tuber sweetness.

The dendrogram at the similarity distance 1.6 identified clusters 3. This cluster group is characterized by dark brown stem color after emergency, green mature petiole color, intermediate corm size and presence of cracks on the cooked tuber.

The dendrogram with similarity distance 1.71 identifies one cluster group 4. This cluster is the largest and composed of 19 accessions. This group is characterized

Table 4. Clustering groups of six different Ethiopian *Dioscorea* species derived from distance similarity coefficient based on their morphological diversity data.

Cluster name	Sub clusters	Number of accessions	Species name and their frequencies		Phenotypic similarity within clusters
C1		18	*D. abyssinica*	6	green mature petiole colour
			D. preahensilis	5	
			D. rotundata	3	
C2		8	*D. cayenensis*	6	pale purple young petiole colour, green mature petiole colour, high leaf density, presence of cracks on tuber surface, intermediate corm size and cooked tuber sweetness
			D. alata	3	
			D. rotundata	1	
			D. bulbifera	2	
			D. abyssinica	2	
C3		7	*D. preahensilis*	2	dark brown stem color after emergency, green mature petiole color, intermediate corm size and presence of cracks on cooked tuber
			D. abyssinica	1	
			D. cayenensis	1	
			D. rotundata	1	
			D. bulbifera	2	
C4		19	*D. abyssinica*	2	yellow mature petiole color and green stem color and absence of cracks on the tuber
			D. preahensilis	4	
			D. cayenensis	4	
			D. bulbifera	1	
			D. rotundata	5	
C5	C5a	5	*D. bulbifera*	5	yellow mature petiole color, green stem color and twining direction to left , intermediate corm size and small tuber width at middle part
	C5b	3	*D. rotundata*	3	absence of barky patches on the stem, green stem color, yellow mature petiole color, small tuber width at middle part, absence of tuber cracks, late maturity group, white flesh tuber color and twining direction to right

by yellow mature petiole color, green stem color and absence of cracks on the tuber. Cluster 5 contained two cluster groups cluster 5a and cluster 5b. Cluster 5a is a group of *D. bulbifera* species with yellow mature petiole color and green stem color. Cluster 5b is a group of *D. rotundata* composed from three yam accessions. This group is characterized by absence of barky patches on the stem, green stem color, and yellow mature petiole color, small tuber width at middle part, absence of tuber cracks, late maturity group and white tuber color after cooking. In this analysis the cophenetic correlation coefficient result was r = 80 which revealed the efficiency of the dendrogram.

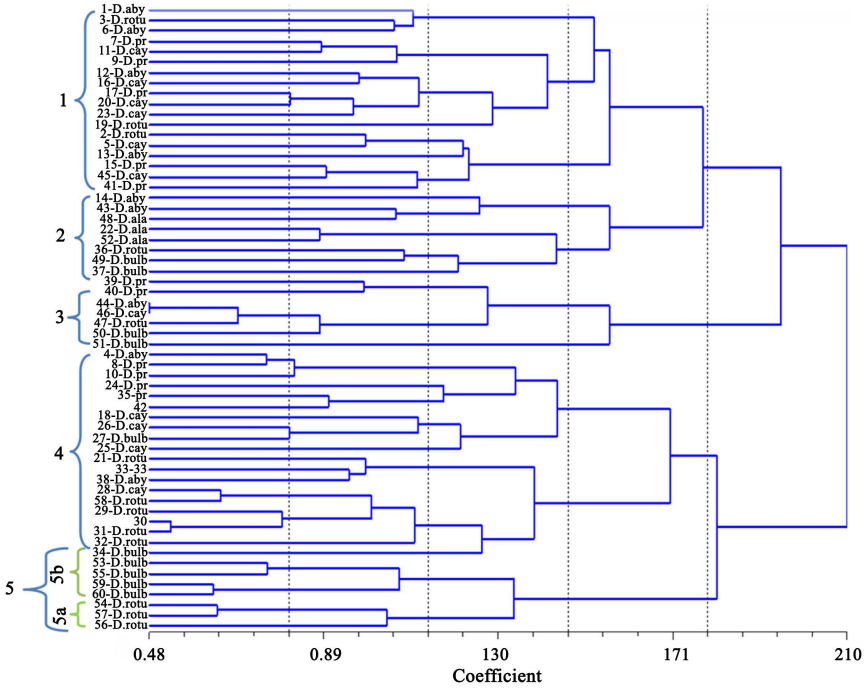


Figure 3. Relationship of six yams (*Dioscorea* spp.) species collected from ten major growing areas of Ethiopia based on distance UPGMA hierarchical cluster analysis.

Table 5. Clustering pattern of yam (*Dioscorea* spp.) accessions derived from the similarity matrix of 60 accessions based on their morphological traits.

Cluster name (Sub clusters)	Number of accessions	Accessions included (SN)	Species name	Origin
C1	18	(1, 3, 6, 7, 11, 9, 12, 16, 17, 20, 2319, 2, 5, 3, 15, 4541)	*D. abyssinica* *D. preahensilis* *D. rotundata* *D. cayenensis*	(Ji, Wo, Kf, Ga, Ga, Ar, Wo, Wo, Ga, Si, Ar, Ga, Ge, Kf, Ge, Ge, Wo, Ge, Wo, Wo)
C2	8	(14, 43, 48, 22, 52, 36, 49, 37)	*D. alata* *D. rotundata* *D. bulbifera* *D. abyssinica*	(Ji, Ar, Ji, Wo, Ji, Da)
C3	7	(39, 40, 44, 46, 47, 50, 51)	*D. abyssinica* *D. preahensilis* *D. rotundata* *D. cayenensis* *D. bulbifera*	(Wo, Km, Wg, Wg, Wg, Wg, Wg)
C4	19	(4, 8, 10, 24, 35, 42, 18, 26, 27, 25, 21, 33, 38, 28, 58, 29, 30, 31, 32)	*D. cayenensis* *D. rotundata* *D. bulbifera* *D. preahensilis* *D. abyssinica*	(Ga, Ga, Ar, Ar, Si, GaGa, Ga, Ar, Ar, Si, Da, Si, Un, Si, Si, Si, Ji)
C5 (C5a)	5	(34, 53, 55, 59, 60)	*D. bulbifera*	(Wo, Wo, Wo, Ge, Ge)
(C5b)	3	(54, 56, 57)	*D. rotundata*	(Wo, Wo, Wo)

Note: Ji-Jima, Ga-Gamogofa, , Da-Dauro, Wo-Wolayita, Si-Sidama, Ar-Areka, Km-Kembata, Ge-Gedio, Wg-Wolega, Kf-Kefa.

3.3. Principal Component Analysis

The PCA results revealed that the first axis largely accounted for the variation among yam accessions (24.87%) followed by the second axis (14.96%) and third axis (11.63%). The first five axes with eighteen values greater than unity accounted for the total variations among 33 characters describing 69.31% and the first three axes accounted for 51.48% (Table 6 and Table 7). Traits with comparatively greater weight in PC1 and PC3 were young petiole color. Correspondingly greater weight in PC2 was color of tuber after cooking. Similarly, flesh color at the lower part of tuber and flavor of cooked tuber resulted in larger weight in the first three principal components while tendency of tuber to branch gave greater weight to the first two principal components.

Table 6. Eigen values, variability percentage and accumulated variation with respect to five character in 60 yam accessions.

SN	Plant Characters	Eigen values	Variation of each component (%)	Accumulated variation (%)
1	leaf color	3.42	24.88	24.88
2	leaf margin color	2.05	14.97	39.84
3	vein color	1.59	11.64	51.48
4	young petiole color	1.27	9.23	60.71
5	young petiole wing color	1.18	8.60	69.31

Note: SN = Serial number.

Table 7. First 3 principal components (PCs) scores of 33 morphological traits across yam genotypes collected from 11 major growing areas of Ethiopia.

SN	Traits	PC1	PC2	PC3
1	Leaf color	0.0813	0.0763	0.1160
2	Leaf margin color	0.0664	0.2335	0.0434
3	Vein color	0.1859	0.0522	0.1136
4	Young petiole color	**−0.9765**	−0.1410	**−0.6175**
5	Young petiole wing color	0.0836	0.0784	−0.0530
6	Stem color after emergency	0.0148	0.1391	0.1029
7	Stem spines	−0.0201	−0.0488	0.0241
8	Mature petiole color	0.1051	0.0811	0.0075
9	Leaf density	0.1531	0.1683	0.1752
10	Leathernes	−0.0991	−0.0644	0.0008
11	Waxiness upper surface	−0.0555	−0.1583	0.1090
12	Distance between lobes	0.1234	−0.0665	0.0231
13	Upward folding of leaf along main vein	0.2860	−0.2163	−0.1774
14	Dawn ward folding of leaf along main vein	−0.0211	−0.1028	−0.0398

Continued

15	Twining direction	0.0155	−0.0532	−0.0265
16	Stem color	0.1884	0.1268	0.0464
17	Corm size	−0.0454	0.1533	0.0638
18	Root spines	0.2627	−0.0496	−0.2855
19	Over all acceptability	0.1587	0.0000	0.0854
20	Tendency of tuber to branch	**−0.5125**	**0.3635**	−0.2231
21	Absence and presence cracks on tuber surface	−0.0467	0.0503	0.0445
22	Roots on tuber surface	0.1763	0.0309	−0.2152
23	Place of roots on the tuber	0.2880	0.1962	−0.2392
24	Stickiness of cooked tuber	0.1267	0.1009	−0.0341
25	Flavor of cooked tuber	**−0.4546**	**−0.5504**	**0.6893**
26	Absence or presence of moisture on cooked tuber	−0.0348	0.0077	−0.0067
27	Bitterness of cooked tuber	−0.0591	0.0177	−0.0221
28	After cooking appearance	−0.0625	−0.3185	0.2617
29	Color of tuber after cooking	0.1375	**0.8728**	0.2634
30	Over all acceptability	−0.0259	**−0.3934**	0.1703
31	Flesh color lower part tuber	**0.9137**	**0.5159**	**−0.4399**
32	Uniformity of flesh color	−0.1156	0.0159	0.0792
33	Maturity after emergency	−0.0833	0.0328	0.0605

Note: SN = Serial number; *Bolded values revealed highly correlated morphological traits to respective principal components.

4. Discussion

Morphological Characterization

Morphological characterization is advisable to be taken as the first step before biochemical or molecular studies [11]. In the present study, tuber flesh colour and tuber shape revealed differences among different species (**Figure 2** and **Figure 4**). Similarly, it is stated that tubers vary greatly in size, colour and shape depending on species, cultivar and environment [12] [13] [14]. In this study, yam tubers of *D. praehensilis* and *D. alata* had finger like appearance while tubers of *D. rotundata*, *D. cayenensis* and *D. abyssinica* were long with oval shape (**Figure 4**). It is also reported that the tuber shape of *D. alata* is often irregular which increases harvest time and thus is labour intensive [15].

In the present study pink and red purplish colors were observed in *D. abyssinica* and *D. praehensilis*, whereas *D. cayenensis* and *D. alata* revealed yellow and white tuber flesh colors respectively. It is indicated that anthocyanins and carotenoids are pigments found in yams (*Dioscorea* spp.) which give their distinctive tuber flesh colors [14]. B-carotene and Xanthophyll esters are responsible for the yellow flesh color of *D. cayenensis*.

Figure 4. Tuber shape similarities and differences among six different species of yam (*Dioscorea* spp.) germplasm with their respective collection area (vernacular name and altitude). (a-1) Wolayita (Chocha, 1850 masl), (a-2) Gedio (Gedio), (a-3) Sidama (Gellawcho, 1940 masl), (a-4) Sidama (Adame Ado) and (a-5) Jima Species: *D. rotunda*; (b-1) Jima (Kembata, 1753 masl); (b-2) (1630 masl), Species: *D. abyssinica*. (c) Gedio (Feres kotae); Areal tuber of species: *D. bulbifera*; (3d-1) Wolayita and; (d-2) Jima, Species: *D. alata*; (e-1) Gamogofa (Bunne 2, 1655); (e-2) Awasa (Bunne 1); (e-3) Gamogofa (Bunne 1), Species: *D. perhensilies*.

Morphological characterization indicated only one cluster which grouped yam accessions based on their geographic origin where most accessions of Wolega origin were in cluster 3 (Table 5). It is supported and recommended that geographic diversity may serve as an indicator of genetic diversity in parental selection [16]. Yam genotypes of Wolayita origin showed more morphological diversity and were distributed in all clustering groups (Table 5). Earlier studies showed a presence of more morphological diversity in Wolayita yam cultivars [5]. Species of *D. abyssinica*, *D. rotundata*, *D. cayenensis* and *D. praehensilis* revealed relatedness. This relationship could be due to the likelihood of *D. praehensilis* and *D. abyssinica* being one of the wild parents of several cultivars of *D. cayenensis* and *D. rotundata* [7].

The efficiency of different cluster algorithms can be compared through estimation of the cophenetic correlation coefficient. It is a product moment correlation coefficient measuring agreement between the dissimilarity and similarity indicated by the dendrogram which is output of the dissimilarity and similarity matrix [9]. In this analysis the cophenetic correlation coefficient r = 80 revealed the efficiency of the dendrogram.

In this study, morphological traits that best discriminate between the landraces were young petiole color, flesh color at lower part of tuber, tendency of tuber to branch, color of tuber after cooking and flavor of cooked tuber. In the same way, it was reported that *D. alata* that scores morphological variability on the first principal component (PC-1) was highly correlated with the characters related to the tuber flesh colours and petiole colour [17]. Similarly, it was indicated in morphological variability study of Kenyan yam that Pc3 was mainly correlated to characters related to the tuber flesh colour [18]. It is also showed that the most effectively used characters in classification of *D. alata* are tuber, leaf and growth characteristics [17].

Generally the present study indicated that, the presence of important heritable phenotypic trait of yam to achieve genetic improvement of the crop. Clustering the accessions helped in identifying parents with diverse characters. Most of the morphological variations among the yam genotypes were contributed by young petiole color, tendency of tuber to branch, tuber flesh color at lower part, color of tuber after cooking and flavor of cooked tuber. Hence, these morphological and organoleptic traits can be taken as useful characters for identification of yam cultivars. Morphological characterization of Ethiopian yam accessions showed that Wolayita regions had wide genetic diversity and most yam landraces from Wolega revealed different genetic base. Therefore, it is important to consider yam germplasms from Wolega and Wolayita regions during breeding and improvement activities of the crop.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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