Research article

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Agro-ecological distribution of the phenotypic diversity of aerial yam (*Dioscorea bulbifera* L.) in Cameroon using multivariate analysis: prospect for germplasm conservation and improvement

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Abstract: Aerial yam (*Dioscorea bulbifera L.)* is a crop of great economic importance and an excellent candidate for improving food security in developing countries. Understanding the genetic variability of any crop species is a decisive step for its improvement and requires characterization and evaluation of available germplasm. The objectives of this study were to determine the extent of genetic variability, estimate the association between agro-morphological traits and clustering among 57 genotypes of aerial yam from three distinct agro-ecological zones in Cameroon using multivariate analysis. Thirty nine characters (23 qualitative and 16 quantitative) were used for the study. Significant differences in genetic diversity indices were found. Accessions from the bimodal humid forest zone (*Na = 2.08, He = 0.27*) showed significantly lower diversity compared to both western highland (*Na = 2.30, He = 0.34*) and humid monomodal forest zones (*Na = 2.57, He = 0.32*). Means values of most quantitative traits also showed significant differences between agro-ecological zones. Batingla-3 and Bawouwoua-1 had important bulbil yield, reaching 3500 g / plant. Significant associations were found between many traits. The use of the Unweighted Pair Group Method with Arithmetic Mean allowed the distribution of the 57 genotypes into six distinct clusters with the clustering pattern not showing any parallelism with location sites or agro-ecological zones. Mahalanobis D^2 statistics revealed the highest inter-cluster distance between cluster II and VI. Accessions of these clusters are potential parents for future breeding programs. This study showed that aerial yam from Cameroon has an enormous wealth of traits variation, indicating huge potential for its genetic improvement through selection and hybridization.

Keywords: Agro-morphological traits, Genetic characterization, Genetic improvement, Phenotype, Genotype, Cluster analysis

1 Introduction

Dioscorea spp. of yam contains approximately 600 species and already sustains many livelihoods in the tropics and subtropics, especially in Africa where important commercial scale production of a few species is practiced (Ngo-Ngwe et al. 2015). *Dioscorea bulbifera* globally known as aerial yam or air potato is distinguished from the other *Dioscorea* species by having special aerial bulbils which appear at the base of the leaf petioles (Croxton et al. 2011; Silva et al. 2016). Aerial yam is of great economic, social and cultural relevance in many tropical countries (Tortoe et al. 2012). It is surprisingly underutilized and could do more to help in addressing the world's present food security issues. It is a tropical climbing plant species originating from Asia and Africa and characterized by edible aerial tubers known as bulbils (Lebot 2009; Govaerts 2007). Different plant parts are widely used in traditional and modern medicine because of their high

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therapeutic potential (Narula et al. 2003; Ghosh et al. 2012). *Dioscorea* species are reported to be good sources of essential dietary nutrients and are highly recommended by dieticians (Shanthakumari et al. 2008)

Managing crop genetic resources within a vulnerable environment driven by ecosystem destruction and climate change remains the challenge of the conservation biology (Primack 2012). The situation is worsened for locally valuable species with unclear conservation status such as *D. bulbifera* (Croxton et al. 2011). Assessing the genetic variability of a crop collection is central for crop conservation and improvement. Local landraces can contribute significantly to the genetic variation of a crop (Zeven 1998; Joshi et al. 2012) and can be the backbone of any crop improvement program. The efficiency of this program relies on the nature of the genetic material at the disposal of the breeder (Singh et al. 2012).

Agro-morphological traits have been used extensively in studying genetic variation in plants. They are more direct, convenient and less costly compared to molecular markers (Govindaraj et al. 2015). Studies on genetic diversity in *Dioscorea* species using morphological approaches have been carried out in Africa (Norman et al. 2011; Dansi et al. 2013; Tewodros and Gatechew 2013), Brazil (Bressan et al. 2011) and Asia (Islam et al. 2011; Sheikh and Kumar 2017). Few studies focus on *D. bulbifera*. In Cameroon, aerial yam is distributed across three out of the five existing agro-geographical zones where their bulbils are collected and used for food and medicinal purposes (Kuete et al. 2012). Although *D. bulbifera* is described wordwide as the most polymorphic yam species, it has yet been genetically screened in Cameroon. Its attributes remain unknown to breeders although the species is gaining more importance in cropped lands and markets. Considering the importance of the aerial yam crop in Cameroon, the present study was intended to determine its level of polymorphism using morphological and agronomic descriptors among 57 widely distributed aerial yam genotypes, with the aim of providing relevant scientific information in support of genetic improvement and domestication of the species.

2 Materials and Methods

2.1 Experimental site and plant material

The experiment was conducted during the 2016 cropping season at the Research and Teaching Farm of the Faculty of Agronomy and Agricultural Sciences of the University of Dschang, located in the Western Region of Cameroon. The experimental site is located at 5°20' N latitude and 10°05' E longitude and at a mean altitude of 1407 m above the sea level. Here, the annual rainfall ranges from 1800 to 2000 mm with an average annual air temperature and relative humidity of 20.50°C and 76.80%, respectively. Planting material consisted of the bulbils of 57 *D. bulbifera* accessions, sourced from market places and farmed fields in seven out of the ten administrative regions, covering three distinct agro-ecological zones of Cameroon. The list of the different accessions used for the study is presented in Table 1.

Table 1: List of accessions and their origin in Cameroon

Accession	Locality / Department	Region	Agroecological Zone
Mayos 2	Nyong and kelle	Centre	Bimodal humid forest
Nkoemvone	Mvila	South	Bimodal humid forest
Nkoameyos 2	Mfoundi	Centre	Bimodal humid forest
Bonis 2	Lom-and-Njerem	East	Bimodal humid forest
Elounden 2	Mfoundi	Centre	Bimodal humid forest
Meureu	Mbam and Inoubou	Centre	Bimodal humid forest
Djop	Mvila	South	Bimodal humid forest
Ngwel	Haut Nyong	East	Bimodal humid forest
Bonis1	Lom-and-Njerem	East	Bimodal humid forest
Mouloundou	Boumba and Ngoko	East	Bimodal humid forest
Nkoameyos 1	Mfoundi	Centre	Bimodal humid forest
Elounden 3	Mfoundi	Centre	Bimodal humid forest
Bertoua	Kadéi	East	Bimodal humid forest
Remis	Mbam and Inoubou	Centre	Bimodal humid forest

Accession	Locality / Department	Region	Agroecological Zone
Bandoumou	Mfoundi	Centre	Bimodal humid forest
Fotomena 1	Menoua	West	Western highland
Batsingla 4	Menoua	West	Western highland
Bana 1	Haut-Nkam	West	Western highland
Batsingla 2	Menoua	West	Western highland
Bapou 1	Haut-Nkam	West	Western highland
Bapou 2	Haut-Nkam	West	Western highland
Babone 1	Haut-Nkam	West	Western highland
Bana 2	Haut-Nkam	West	Western highland
Niebe 2	Mezam	North-West	Western highland
Babone 2	Haut-Nkam	West	Western highland
Batsingla 3	Menoua	West	Western highland
Bafut 2	Mezam	North-West	Western highland
Bapou 1	Haut-Nkam	West	Western highland
Fotomena 3	Menoua	West	Western highland
Nforia	Mezam	North West	Western highland
Mbesse	Mezam	North West	Western highland
Batsingla 1	Menoua	West	Western highland
Mbatu	Mezam	North-West	Western highland
Bawouwoua 1	Menoua	West	Western highland
Fotomena 2	Menoua	West	Western highland
Chomba 2	Mezam	North-West	Western highland
Bapou 3	Haut-Nkam	West	Western highland
Nforia 2	Mezam	North-West	Western highland
Nkimbou	Mezam	North-West	Western highland
Fotomena 4	Menoua	West	Western highland
Babone 1	Haut-Nkam	West	Western highland
Bafut 1	Mezam	North-West	Western highland
Babone 3	Haut-Nkam	West	Western highland
Niebe 1	Mezam	North-West	Western highland
Chomba 1	Mezam	North-West	Western highland
Alou 2	Lebielem	South-West	Humid monomodal Forest
Muyengue	Wouri	Littoral	Humid monomodal Forest
Fontem 2	Lebialem	South-West	Humid monomodal Forest
Nkong 2	Lebialem	South-West	Humid monomodal Forest
Ekite	Sanaga Maritime	Littoral	Humid monomodal Forest
Nkapa	Moungo	Littoral	Humid monomodal Forest
Elogbatsindi	Sanaga Maritime	Littoral	Humid monomodal Forest
Nkong 1	Moungo	Littoral	Humid monomodal Forest
Nkong 3	Moungo	Littoral	Humid monomodal Forest
Sikoum	Sanaga Maritime	Littoral	Humid monomodal Forest
Fontem 1	Lebialem	South-West	Humid monomodal Forest
Bomono	Moungo	Littoral	Humid monomodal Forest

2.2 Experimental design and data collection

The experimental planting was arranged in ridges with planting at the beginning of the rainy season (April 2016). A single row plot was used for each accession, each row measuring 7m long with 1.5m spacing between rows and 1m spaces between plants within a row. This spacing regimen was done to avoid competition among neighbouring plants and to ensure sound establishment of each accession. Individual plants were supported by bamboo stakes. Standard weeding and agronomic practices were regularly applied to provide plants with adequate growing conditions. The middle five plants from each row were used for data collection. Morphological and agronomic evaluations were carried out on individual plants of each accession in the experimental field. The morphological descriptors used in this study were recommended for yam (*Dioscorea spp.*) by the International Plant Genetic Resources Institute / International Institute of Tropical Agriculture (IPGRI/IITA 1997). We evaluated a total of 39 traits of which eighteen were related to leaf characteristics, eight to stem and thirteen to bulbils. Observations for quantitative traits were based on phenotypic average of measurements for leaves, stems and bulbils in each individual plant. We assessed a total of sixteen descriptors quantitatively and the further 23 traits qualitatively, which were transformed into different classes, attributing codes to each class (Table 2)

Table 2: List of qualitative and quantitative traits, their codes and their descriptions for *Dioscorea bulbifera* plants

No	Traits	Code	Description
	Qualitative traits		
1	Young leaf colour	YLCOL	1-Yellowish; 2-Pale green; 3-Purplish green; 4-Purple; 99-Other
2	Leaf position	LPOS	1-Alternate; 2-Opposite; 3-Alternate at base /opposite above; 99-Other
3	Mature leaf colour	MLCOL	1-Yellowish; 2-Pale green;3-Purplish green; 4-Purple; 99-Other
4	Leaf vein colour (upper surface)	LVCOL-U	1-Yellowish; 2-Green;3-Pale purple;4-Purple; 99-Other
5	Leaf vein colour (lower surface)	LVCOL-L	1-Yellowish; 2-Green;3-Pale purple;4-Purple; 99-Other
6	Petiole length	PLENGTH	1- 0-5 cm; 2- 6-9 cm; 3- 10-20 cm
7	Young stem colour	YSCOL	1-Green; 2-Purplish green; 3-Brownish green; 4-Dark brown; 5-Purple; 99-Other
8	Young stem hairiness	YSH	1-present; 0-abscent
9	Twining direction	TWINDIR	1-Clockwise; 2-Anticlockwise
10	Mature stem colour	MSCOL	1-Green; 2-Purplish green; 3-Brownish green; 4-Dark brown; 5-Purple; 99-Other
11	Leaf margin colour	LMCOL	1-Green; 2-Purple; 3-Other
12	Young petiole colour	YPCOL	1-Green with purple base; 2-Green; 3-Purple; 4-Brown; 5-Brownish green, 99-Other
13	Leaf hairiness	LH	1-Upper surface; 2-Lower surface; 3-Both
14	Leaf density	LD	1-Low;2-High; 3-intermediate
15	Leaf type	LTYPE	1-Simple; 2-Compound
16	Leaf shape	LS	1-Ovate;2-Cordate long;3-Cordate broad;4-Sagittate long;5-Sagittate broad; 6-Hastate; 99-Other
17	Leaf apex shape	LAS	1-Optuse; 2-Acute; 3-Emarginate; 99-Other
18	Mature petiole colour	MPCOL	1-Green with purple base; 2-Green; 3-Purple; 4-Brown; 5-Brownish green, 99-Other
19	Bulbils shape	BS	1-Round; 2-Oval; 3-Irregular; 4-Elongate
20	Skin colour	SKCOL	1-Greyish;2-Light brown;3-Dark brown; 99-Other
21	Surface texture	STEXT	1-Smooth; 2-Rough; 3-Wrinkled
22	Flesh colour	FCOL	1-White; 2-Yellow; 3-Orange; 4-Purple; 5-Purple with white; 7-Yellowish;9-Yellow surrounding with purple
23	Flesh bitterness	FBITT	1-Yes; 2-No

No	Traits	Code	Description
	Quantitative traits		
1	Time to germination (days)	TGERM	Number of days from sowing to the germination of bulbil
2	Plant height (m)	PH	Mean height of the selected plant at four weeks from sowing
3	Number of stem per plant (No)	SPP	Mean number of stem per plant of the selected plants
4	Number of branches on main stem (No)	NBMS	Mean number of branches on the main stem per plant of the selected plants
5	Stem diameter (mm)	STEMDIA	Mean diameter of the stem of the selected plants
6	Time to first leaf appearance (days)	TFL	Number of days from sowing to appearance of first leaf on the selected plants
7	Number of leaves (No)	NL	Mean number of leaves per plant of the selected plants
8	Leaf length (cm)	LLENGTH	Mean length of the selected leaf in f the selected plants
9	Leaf width (cm)	LWIDTH	Mean width of the selected leaf in the selected plants
10	Time to the first bulbil appearance (days)	TFB	Number of days from sowing to appearance of fist bulbil on the selected plants
11	Bulbil diameter (mm)	BDIA	Average diameter of one bulbil from the selected plants
12	Skin thickness (mm)	SKTHICK	Average thickness of the skin of one bulbil from the selected plants
13	Bulbil width (mm)	BWIDTH	Average width of one bulbil from the selected plants
14	Bulbil weight (g)	BWEIGHT	Average weight of one bulbil from the selected plants
15	Number of bubils per plant (No)	BPP	Total number of bulbils per plant counted at the time of harvest
16	Bulbils yield (g/plant)	BYIELD	Total weight of all the bulbils per plant of the selected plants at harvest

2.3 Statistical analysis

To assess the overall phenotypic diversity of each qualitative character for all accessions, the observed (*Na*) and the effective (*Ne*) numbers of phenotypic classes were calculated. Phenotypic class frequencies were used to compute gene diversity (*He*) after Nei (1987) and the Shannon-Weaver diversity index (*H'*). The Nei's gene diversity was calculated as follow: $He = 1 - \sum x_i^2$. The Shannon-Weaver diversity index was estimated as suggested by Jain et al. (1975) using this formula: $H' = - \sum x_i log_e(x_i)$, with x_i representing the relative frequency of the i^{th} phenotypic class of a trait. Mean values of each quantitative trait were computed and used for statistical analysis. For each quantitative trait, the data collected was submitted to the analysis of variance (ANOVA) to test the variations among agro-ecological zones and accession clusters. Genetic diversity estimates for qualitative traits were also tested for difference among agro-ecological zones using ANOVA. Quantitative data were further analyzed using Euclidian distance coefficients. Hierarchical cluster analyses were then carried out from these coefficients and to produce a dendogram via the Unweighted Pair Group Method with Arithmetic Mean (UPGMA). Pearson correlation coefficients were computed to assess the association among the different phenotypic traits. The same data were exposed to Principal Component Analysis (PCA) in order to determinate the patterns of quantitative variation with the eigenvectors and eigenvalues determined. Mean data for each character were subjected to Mahalanobis D^2 statistics to determine the genetic distance between clusters as suggested by Mahalanobis (1936). The different pairwise genetic distances were tested for significance using Fisher's t- test. All these analyses were performed using XLSTAT version 2014 (Addinsoft 2014) and Prism 6.0 (GraphPad Software, Inc, USA) computer software programs.

Ethical approval: The conducted research is not related to either human or animals use.

3 Results:

3.1 Phenotypic diversity

Twenty of the 23 qualitative traits (89.96%) showed variation among the 57 indigenous aerial yam genotypes. No variation was observed for traits such as twining direction (TWINDIR), leaf type (LTYPE) and leaf apex shape (LAS) (Table 4). The number of observed phenotypic classes ranges from 1 (monomorphic trait) to 6 (young leaf

Table 3: Quantitative traits estimates for fifty-seven genotypes of *Dioscorea bulbifera* collected in Cameroon

Accession	TGERM	PH	SPP	NBMS	STEMDIA	TFLA	NL	LLENGTH	LWIDTH	TFBA	BDIA	SKTHICK	BWIDTH	BWEIGHT	BPP	BYIELD
	(days)	(m)	(No)	(No)	(mm)	(days)	(No)	(cm)	(cm)	(days)	(mm)	(mm)	(mm)	(g)	(No)	(g)
Mayos 2	24	1.17	1	2	2.93	5	17	12.5	8	119	65.76	0.39	32.78	65	8	520
Nkoemvone	33	1.6	1	4	3.01	5	13	15	9.5	123	55.91	0.24	33.63	42	8	336
Nkouameyos 2	27	1.32	1	0	1.33	6	12	15	11.3	122	55.18	0.39	25.94	29	4	116
Bonis 2	21	1.65	1	4	3.12	5	10	14	10.5	119	87.87	0.14	46.14	111	13	1443
Eloumdem 2	24	1.1	1	1	2.47	6	10	16	12.5	125	56.67	0.51	38.28	59	20	1180
Meureu	19	1.6	1	0	4.05	5	9	16	11.5	124	90.66	0.56	48.4	82	8	656
Njop	22	1.25	1	1	3.1	2	7	13	9.5	112	40.21	0.48	30.92	29	5	145
Ngwel	23	1.5	1	1	2	6	8	12	8	125	73.61	0.18	40.71	48	4	192
Bonis1	30	0.95	1	3	4.13	5	6	17	11	125	40.36	0.26	74.49	70	4	280
Mouloundou	23	1.15	1	1	1.5	4	8	11	8.5	130	67.22	0.12	29.72	50	11	550
Nkouameyos 1	25	1.3	1	0	5	6	10	16	11	115	57.79	0.16	40.89	66	19	1254
Eloundem 3	20	1.11	1	0	1.89	6	8	11	7.5	127	63.56	0.3	43.24	57	13	741
Bertoua	22	1.3	1	3	4.12	5	7	18	15	123	79.08	0.2	47.75	157	7	1099
Remis	20	1.67	1	0	5.8	5	10	18	15	103	59.35	0.29	58.44	70	5	350
Bandoumou	19	1.35	1	0	2.6	4	8	15	9	128	63.35	0.46	38.77	67	5	335
Fotomena 1	17	1.8	1	1	5.41	5	14	19.5	13.17	104	96.84	0.16	54.42	178	7	1246
Batsingla 4	30	1.8	2	1	5.34	5	13	19	14	119	76.62	0.27	43.23	127	8	1016
Bana 1	17	1.63	1	0	4.4	6	14	20	15.5	115	79.26	0.2	42.94	149	17	2533
Batsingla 2	18	1.65	1	0	1.26	5	15	13	9.5	115	65.69	0.26	41.65	72	10	720
Bapou 1	23	1.6	1	3	3.14	5	15	20	15	123	75.92	0.2	35.58	117	14	1638
Bapou 2	21	0.56	1	0	1.66	3	6	14	10	125	85.37	0.2	67.93	210	6	1260
Babone 1	24	1.35	2	0	6.68	4	15	22	16	122	92.16	1.27	40.41	137	3	411
Bana 2	5	1.65	1	0	4.3	5	10	19	17	115	73.85	0.7	49.93	137	4	548
Niebe 2	19	1.3	1	1	4.81	5	8	19	12.5	117	77.81	0.48	45.52	111	5	555
Babone 2	21	1.6	1	3	1.9	6	11	13	10.5	109	129.48	0.18	45.86	197	9	1773
Batsingla 3	22	0.9	1	1	3.2	6	15	17	12	120	91.67	0.22	63.41	276	13	3588
Bafut 2	24	1.15	2	1	4.4	4	13	19	15.5	118	61.13	0.16	44.45	97	16	1552
Bapou 1	27	1.3	2	1	3.43	6	12	19	12.5	124	75.92	0.2	36.77	117	14	1638
Fotomena 3	19	1.5	1	1	3.2	5	8	16.5	11.6	103	62.5	0.1	34.17	62	9	558
Nforia	27	0.7	1	0	2.09	4	9	11	9	117	61.73	0.41	38.66	64	17	1088
Mbesse	22	1.63	1	1	1.56	4	10	16.5	12	123	55.88	0.12	36.95	40	6	240
Batsingla 1	15	1.97	1	1	2.3	6	11	16	10	121	70.66	0.5	31.74	66	16	1056
Mbatu	25	1.2	2	1	2	7	6	14	10	125	39.17	0.2	39.9	26	8	208
Bawouwoua 1	20	0.3	1	0	2.03	4	5	14	12	105	109.19	0.3	61.01	260	14	3640

Accession	TGERM	PH	SPP	NBMS	STEMDIA	TFLA	NL	LLENGTH	LWIDTH	TFBA	BDIA	SKTHICK	BWIDTH	BWEIGHT	BPP	BYIELD
	(days)	(m)	(No)	(No)	(mm)	(days)	(No)	(cm)	(cm)	(days)	(mm)	(mm)	(mm)	(g)	(No)	(g)
Fotomena 2	28	1.6	1	1	2.88	3	12	11.5	9	118	51.29	0.56	32.56	38	5	190
Chomba 2	15	1.23	1	1	3.91	4	6	12	8	95	68.23	0.08	30.11	60	33	1980
Bapou 3	15	1.3	1	0	4	5	5	17	14.5	93	109.56	0.64	38.1	120	4	480
Nforia 2	40	0.7	1	1	3	5	7	9	7	123	47.61	0.18	27.62	23	5	115
Nkimbou	24	1.3	1	1	2.95	5	10	16.5	12	114	68.1	0.17	42.37	69	6	414
Fotomena 4	23	1.6	1	1	4.5	4	13	21	14.5	103	88.74	0.48	48.56	142	5	710
Babone 1	21	1.6	1	1	6.1	6	13	24	18	110	92.16	1.27	40.41	137	4	548
Bafut 1	30	1	2	1	2.5	4	5	15	12	116	55.17	0.12	41.16	59	5	295
Babone 3	19	1.6	1	0	4.2	5	6	18	15	125	62.71	0.32	48.14	81	6	486
Niebe 1	18	1.1	1	0	2.21	5	6	10	7	117	51.35	0.27	33.21	47	2	94
Chomba 1	18	1.5	1	0	3	5	9	17	12	105	61.31	0.16	40.89	60	5	300
Alou 2	27	1	2	0	3.58	4	9	17.5	11.5	123	139.15	0.53	60.96	119	3	357
Muyengue	24	1.2	1	4	3.26	7	13	17.5	12	117	80.65	0.08	40.46	89	21	1869
Fontem 2	5	1.4	1	2	2.82	8	13	13	10.5	117	55.95	0.54	31.94	42	8	336
Nkong 2	20	1.3	1	1	2.88	4	8	13	9	127	60.67	0.12	37.32	54	23	1242
Ekite	41	1	1	0	2.1	4	5	14.5	9.5	117	45.28	1.03	40.41	36	3	108
Nkapa	20	1.12	1	1	2	5	8	17	13	125	111.28	0.08	38.83	83	11	913
Elogbatsindi	26	1.4	1	0	1.77	6	5	15	9	125	84.57	0.1	46.76	121	12	1452
Nkong 1	21	1.14	1	3	3.2	3	6	15.5	10	125	60	0.2	50	79	19	1501
Nkong 3	20	1.22	1	0	2.6	4	6	14	10	127	63.1	0.08	31.64	58	7	406
Fontem 1	20	1	1	1	1.88	4	6	17	12	125	54.69	0.15	37.03	49	9	441
Bomono	21	1.1	1	1	3	5	13	17	13	106	55.6	0.3	33.16	110	16	1760
Sikoum	24	1.59	1	4	5.5	5	7	19	13	107	70.14	0.06	45.47	111	16	1776
Minimum	5	0.3	1	0	1.26	2	5	9	7	93	39.17	0.06	25.94	23	2	94
Maximum	41	1.97	2	4	6.68	8	17	24	18	130	139.15	1.27	74.49	276	33	3640
Mean	**22.25**	**1.31**	**1.12**	**1.05**	**3.23**	**4.91**	**9.55**	**15.82**	**11.53**	**117.55**	**71.49**	**0.32**	**42.14**	**91.79**	**9.79**	**916.46**
Standard error	0.81	0.04	0.04	0.16	0.17	0.14	0.44	0.41	0.34	1.15	2.76	0.03	1.32	7.3	0.82	104.35
Coefficient of variation (%)	27.28	24.89	29.23	111.73	39.59	21.86	34.14	19.5	22.3	7.28	28.91	81.11	23.47	59.49	63.05	85.21

Trait abbreviations: see Table 2

Table 4: Distribution of diversity parameters for twenty three qualitative traits in *Dioscorea bulbifera* collected in Cameroon

No	Qualitative trait	Diversity parameters				
		Na	Ne	He	H'	Polymorphism
1	Young leaf colour	6.00	3.19	0.68	1.35	Yes
2	Leaf position	3.00	1.15	0.13	0.25	Yes
3	Mature leaf colour	4.00	1.98	0.49	0.92	Yes
4	Leaf vein colour (upper surface)	2.00	1.05	0.05	0.12	Yes
5	Leaf vein colour (lower surface)	2.00	1.05	0.05	0.12	Yes
6	Petiole length	3.00	1.94	0.48	0.70	Yes
7	Young stem colour	5.00	2.07	0.52	0.99	Yes
8	Young stem hairiness	2.00	1.15	0.13	0.25	Yes
9	Twining direction	1.00	1.00	0.00	0.00	No
10	Mature stem colour	4.00	1.90	0.47	0.79	Yes
11	Leaf margin colour	2.00	1.05	0.05	0.12	Yes
12	Young petiole colour	4.00	2.18	0.54	0.97	Yes
13	Leaf hairiness	2.00	1.15	0.13	0.25	Yes
14	Leaf density	3.00	2.49	0.60	0.99	Yes
15	Leaf type	1.00	1.00	0.00	0.00	No
16	Leaf shape	2.00	1.90	0.47	0.67	Yes
17	Leaf apex shape	1.00	1.00	0.00	0.00	No
18	Mature petiole colour	3.00	1.77	0.43	0.76	Yes
19	Bulbils shape	4.00	1.54	0.35	0.72	Yes
20	Skin colour	3.00	2.26	0.56	0.89	Yes
21	Surface texture	3.00	2.15	0.53	0.85	Yes
22	Flesh colour	4.00	2.62	0.62	1.15	Yes
23	Flesh bitterness	2.00	1.97	0.42	0.69	Yes
	Mean	**2.87±0.20**	**1.72±0.09**	**0.34±0.04**	**0.59±0.06**	**86.96%**

Na = Number of observed phenotypic classes; *Ne* = Number of effective phenotypic classes. *He* = Nei's genetic diversity ; *H'* = Shannon-Weaver diversity index

colour) with a total of 66 phenotypic classes observed for the 23 qualitative traits studied. A mean of 2.870 ± 0.200 phenotypic classes per individual qualitative trait was observed (Table 4). The mean effective number of phenotypic classes was Ne = 1.720 ± 0.09, with values ranging from 1 (monomorphic trait) to 3.190 (young leaf colour). The overall mean of Nei's gene diversity and Shannon Weaver diversity index were 0.340 ± 0.04 and 0.590 ± 0.06 respectively (Table 4). Nei's gene diversity ranged from zero (monomorphic trait) to 0.680 (young leaf colour) and Shannon Weaver diversity index ranged from zero (monomorphic trait) to 1.350 (young leaf colour) (Table 4). Analysis of variance revealed that in the bimodal humid forest zone, the number of observed phenotypic classes (*Na* = 2.087±0.088), the effective number of phenotypic classes (*Ne* = 1.543±0.050), the expected Nei's gene diversity (*He* = 0.272±0.019) and the Shannon-Weaver diversity index (*H'* = 0.450±0.034) were significantly lower compared to the western highland zone (*Na* = 2.303±0.087, *Ne* = 1.719±0.051, *He* = 0.342±0.020 and *H'* = 0.566±0.035) and the humid monomodal forest zone (*Na* = 2.565±0.124, *Ne* = 1.697±0.072, *He* = 0.322±0.028 and *H'* = 0.548±0.048) (Table 5). Statistically, the western highland zone and the humid monomodal forest zone presented similar values for genetic diversity parameters assessed (Table 5). For the different quantitative traits measured, the coefficients of variation are presented in Table 3. The highest coefficient of variation values, exceeding 50%, were observed for the number of branches on the main stem (111.73%), skin thickness (81.11%), bulbil weight (59.49%), number of bulbil per plant (63.05%) and fruit yield (85.21%). The lowest coefficient of variation found was the number of

days from planting until first bulbil appearance (7.28%). Genotypes *Bawouwoua 1* and *Batsingla 3* were the most productive with bulbil yields of 3640 and 3588 g/plant respectively. The least productive genotypes were *Niebe 1, Nforia 2* and *Nkouameyos 2* with bulbil yields of 94, 115 and 116 g/plant respectively (Table 3). Based on ANOVA, twelve out of the sixteen quantitative traits showed significant differences when comparing genotypes derived from different agro-ecological zones. Bulbil weight, number of bulbils per plant and bulbil yield were significantly lower in genotypes from the bimodal humid forest zone compared to genotypes from the western highland zone and humid monomodal forest zone (Table 5)

3.2 Genetic divergence and cluster analysis

The UPGMA dendrogram from the hierarchical cluster analysis (HCA) divided the 57 genotypes into different clusters with Euclidean distance dissimilarities (Figure 1). The dendrogram identified six major clusters: I, II, III, IV, V and VI. Cluster I was the largest with 30 genotypes, followed by Cluster III (16 genotypes). Cluster IV and II included five and four genotypes respectively. Cluster V and VI had only one genotype each. Mean values of all quantitative traits for each cluster are presented in Table 7. Cluster I is characterized by genotypes with important bulbil yield, higher number of bulbils and leaves per plant than those of the remaining clusters. Cluster II has the characteristic of taking the maximum number of days from planting until germination. Cluster III is characterized by higher leaf length and width. Cluster IV possessed the highest plant height and Cluster V the biggest bulbil width. Cluster VI is characterized by the greater skin thickness. Clustering pattern and average inter-cluster mahalanobis D^2 distances are presented in Table 8. The Minimum and maximum Mahalanobis D^2 inter-cluster distances were 7.352 and 132.167 respectively, observed respectively between clusters III and IV and between cluster II and VI. Almost all clusters showed highly significant ($P<0.01$) difference among each other, apart from the distances between cluster II and IV ($p= 0.190$) and between III and IV ($p = 0.261$) which did not diverge from each other.

3.3 Character association and principal component analysis

The 16 quantitative traits produced one hundred and twenty associations with their correlation coefficients and their significances presented in Table 6. Among these associations, seventy-seven (64.17%) were found to be not correlated; thirty-five (29.17%) were positively associated while eight (6.67%) were negatively interrelated. Tuber yield was positively correlated to the number of branches on the main stem, bulbil diameter, bulbil width, bulbil weight and number of bulbils per plant. However tuber yield was negatively correlated with skin thickness of bulbils. The principal component analysis (PCA) based on 16 quantitative traits showed that the first, second, third, fourth, fifth and sixth principal components accounted respectively for 25.28, 15.50, 12.45, 9.08, 6.90 and 6.13% of the total variability (Table 9). The first six principal components explained a cumulative 75.34% of the total variance (Table 9). The first principal component (PC1), were correlated with stem diameter, leaf length and width, bulbil diameter and weight. The second component (PC2) was associated with skin thickness, number of bulbils per plant and tuber yield. The third principal component (PC3) was correlated with plant height, number of leaves, and bulbil width. PC4 was connected to time to germination, number of stem per plant, and time to the first bulbil appearance. PC5 was linked to time to first leaf appearance and PC6 correlated with the number of branches on main stem.

4 Discussion

The the amount of genetic variability in a crop species is vital in initiating a breeding program and is a central dogma for the development of superior cultivars. Likewise, the use of appropriate descriptors is essential for diversity expression. The descriptor list for *Dioscorea spp*. developed by IPGRI/IITA (1997) was found to be a useful tool in assessing the available genetic variation among *D. bulbifera* genotypes from Cameroon. The data which have been collected and analysed in the present study have shown significant variability in the genotypes tested, providing large scope for management of the breeding agenda in this species. The general appearance of the plant, tuber and/or bulbils traits in *Dioscorea spp* are of great importance in identifying cultivars (Dansi et al. 1999; Adaramola et al. 2016). The massive rate of polymorphism obtained with qualitative traits (86.96%) coupled with the important observed phenotypic classes per qualitative trait (2.87), large differences between minimum and maximum values and the high coefficients of variations of most quantitative traits are strong indicators of the suitability of the selected descriptors for addressing *D. bulbifera* diversity. The coefficient of variation compares the relative amount of variability

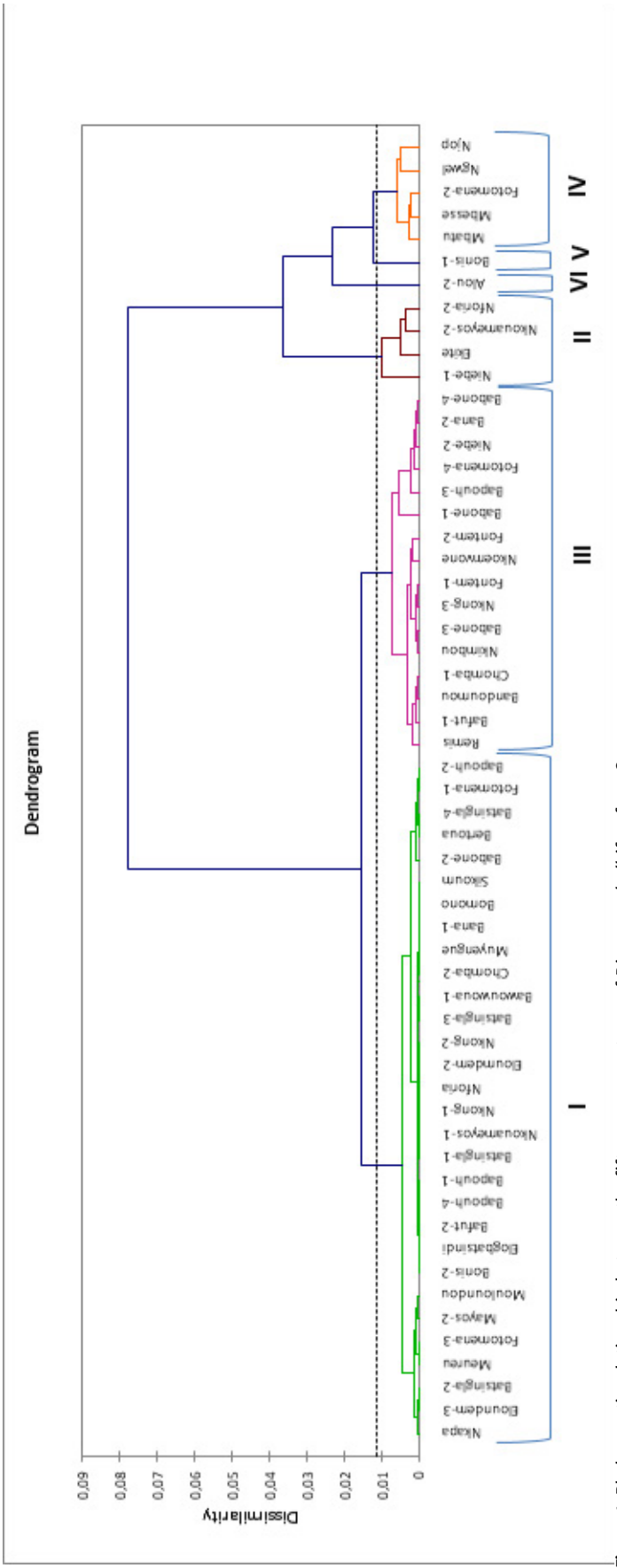

Figure 1: Phylogenetic relationship between the fifty-seven genotypes of *Dioscorea bulbifera* from Cameroon

Table 5: Analysis of variances of means of 16 quantitative traits and diversity parameters for *Dioscorea bulbifera* in three distinct agro-ecological zones of Cameroon

	Agro-ecological zones			ANOVA test		
	Bimodal humid forest	**Western highland**	**Humid monomodal Forest**	**F-values**	**P-values**	**Significance**
Quantitative trait						
Time to germination (days)	23.467±0.782^{a}	21.567±0.553^{a}	22.417±0.874^{a}	1.994	0.139	^{NS}
Plant height (m)	1.336±0.043^{a}	1.339±0.030^{a}	1.206±0.047^{b}	3.121	0.046	*
Number of stem per plant (No)	1.001±0.041^{b}	1.200±0.029^{a}	1.083±0.046^{ab}	8.338	0.000	***
Number of branches on main stem (No)	1.333±0.148^{b}	0.767±0.104^{b}	1.417±0.165^{a}	7.985	0.000	***
Stem diameter (mm)	3.137±0.164^{ab}	3.412±0.116^{a}	2.883±0.183^{b}	3.197	0.043	*
Time to first leaf appearance (days)	5.000±0.139^{a}	4.862±0.100^{a}	4.917±0.156^{a}	0.324	0.727	^{NS}
Number of leaves (No)	9.533±0.413^{ab}	10.103±0.297^{a}	8.250±0.462^{b}	5.687	0.004	**
Leaf length (cm)	14.633±0.389^{b}	16.417±0.275^{a}	15.834±0.435^{ab}	7.003	0.001	**
Leaf width (cm)	10.520±0.319^{b}	12.226±0.225^{a}	11.042±0.357^{b}	10.684	0.000	***
Time to the first bulbil appearance (days)	121.333±1.035^{a}	114.633±0.732^{b}	120.364±1.208^{a}	17.343	0.000	***
Bulbil diameter (mm)	63.772±2.618^{b}	74.569±1.851^{a}	73.423±2.927^{a}	5.949	0.003	**
Skin thickness (mm)	0.312±0.034^{a}	0.346±0.024^{a}	0.273±0.038^{a}	1.415	0.245	^{NS}
Bulbil width (mm)	42.007±1.283^{a}	42.589±0.907^{a}	41.165±0.145^{a}	0.358	0.699	^{NS}
Bulbil weight (g)	66.800±6.655^{b}	109.300±4.706^{a}	79.250±7.441^{b}	15.392	0.000	***
Number of bulbils per plant (No)	8.933±0.784^{b}	9.201±0.514^{b}	12.333±0.876^{a}	5.378	0.005	**
Bulbils yield (g/plant)	613.133±98.709^{b}	1029.334±69.798^{a}	1013.417±110.360^{a}	6.415	0.002	**
Diversity parameters						
Na	2.087±0.088^{b}	2.304±0.087^{ab}	2.565±0.124^{a}	5.086	0.007	**
Ne	1.543±0.050^{b}	1.719±0.051^{a}	1.697±0.072^{a}	3.347	0.036	*
He	0.272±0.019^{b}	0.342±0.020^{a}	0.322±0.028^{a}	3.192	0.042	*
H'	0.450±0.034^{b}	0.566±0.035^{a}	0.548±0.048^{a}	3.178	0.043	*

Na = Number of observed phenotypic classes; *Ne* = Number of effective phenotypic classes. *He* = Nei's genetic diversity; *H'* = Shannon-Weaver diversity index. ***: Significant at 0.001 probability level, **: Significant at 0.01 probability level; *: Significant at 0.05 probability level; ^{NS}: Not significant. Means followed by the same letter in the same row are not significantly different at p = 0.050 probability level

between morphological traits (Sharma 1988). A high coefficient of variation indicates a wide range while a low coefficient of variation designates only a small range of the measured trait. With the exception of the time from planting until first bulbil appearance, large coefficients of variation (exceeding 20%) were recorded for yield components and other studied quantitative traits (Table 3). These results indicate that there is a large and readily exploitable genetic variability among the aerial yam accessions studied here. This significant variability among *D. bulbifera* genotypes was expected, since the study was carried out on genotypes sourced from different backgrounds. Likewise, Tewodros and Gatechew (2013) using morphological descriptors also reported the existence of important genetic variation among *D. bulbifera* accessions from different locations and agro-ecological sites in Ethiopia. Similar observations have been reported for other *Dioscorea* species such as *D. alata* (Bressan et al. 2011) and *D. dumetorum* (Adeigbe et al. 2015) as well as other root and tuberous species such as *Manihot esculenta* Crantz (Kosh-Komba et al. 2017). *D. bulbifera* is a dioecious plant species like most of *Dioscorea* spp. Therefore, the variability observed may be associated with cross pollination and sexual recombination (Tostain et al. 2007). Variability in this species may also have arisen as a result of natural mutation and long term selection occurring in the course of its ongoing domestication process in some agro-ecological zones (western highland and monomodal

Table 6: Pearson's correlation coefficients between 16 quantitative traits in *Dioscorea bulbifera* accessions collected in Cameroon

Variables	TGERM	PH	SPP	NBMS	STEMDIA	TFLA	NL	LLENGTH	LWIDTH	TFBA	BDIA	SKTHICK	BWIDTH	BWEIGHT	BPP	BYIELD
TGERM	1															
PH	-0.307*	1														
SPP	0.276*	-0.061	1													
NBMS	0.138	0.17	-0.108	1												
STEMDIA	-0.087	0.356**	0.223	0.084	1											
TFLA	-0.186	0.255*	-0.019	0.159	0.017	1										
NL	-0.089	0.422**	0.101	0.174	0.276*	0.300*	1									
LLENGTH	-0.137	0.380**	0.255*	0.07	0.696***	0.115	0.357**	1								
LWIDTH	-0.253*	0.314*	0.225	-0.005	0.654***	0.102	0.311*	0.905***	1							
TFBA	0.274*	-0.159	0.152	0.045	-0.370**	0.026	-0.071	-0.205	-0.284*	1						
BDIA	-0.219	0.047	0.101	-0.010	0.182	0.077	0.149	0.329*	0.327*	-0.208	1					
SKTHICK	0.001	0.080	0.102	-0.287*	0.349**	-0.049	0.189	0.310*	0.319*	-0.077	0.118	1				
BWIDTH	-0.032	-0.202	0.064	0.007	0.262*	-0.078	-0.117	0.316*	0.285*	-0.025	0.388**	-0.021	1			
BWEIGHT	-0.205	-0.121	0.039	0.024	0.272*	0.032	0.207	0.423**	0.449**	-0.264*	0.706***	0.049	0.634***	1		
BPP	-0.139	-0.088	-0.1	0.271*	-0.041	0.111	0.064	-0.096	-0.127	-0.083	-0.024	-0.392**	-0.136	0.053	1	
BYIELD	-0.152	-0.203	-0.064	0.284*	0.065	0.13	0.185	0.166	0.176	-0.200	0.401**	-0.290*	0.331*	0.725***	0.654***	1

Trait abbreviations: see Table 2. ***: Significant at 0.001 probability level, **: Significant at 0.01 probability level; *: Significant at 0.05 probability level; ^{NS}: Not significant

Table 7: Clusters characteristics and analysis of variance for 16 quantitative traits for *Discorea bulbifera* accessions collected in Cameroon

Quantitative traits	Cluster Means						ANOVA Test		
	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V	Cluster VI	F-values	P-values	Significance
Time to germination (days)	21.667	31.500	19.688	24.000	30.000	27.000	15.982	0.000	***
Plant height (m)	1.297	0.933	1.409	1.436	0.950	1.000	7.635	0.000	***
Number of stem per plant (No)	1.100	1.000	1.125	1.200	1.000	2.000	7.530	0.000	***
Number of branches on main stem (No)	1.300	0.250	0.750	1.000	3.000	0.000	7.041	0.000	***
Stem diameter (mm)	3.145	2.160	3.854	2.308	4.130	3.580	9.433	0.000	***
Time to first leaf appearance (days)	5.033	5.000	4.867	4.400	5.000	4.000	1.869	0.101	^{NS}
Number of leaves (No)	10.200	7.500	9.400	8.600	6.000	9.000	3.754	0.003	**
Leaf length (cm)	15.717	12.125	17.531	13.400	17.000	17.500	14.741	0.000	***
Leaf width (cm)	11.392	8.700	13.094	9.700	11.000	11.500	13.681	0.000	***
Time to the first bulbil appearance (days)	117.567	120.667	115.188	120.600	125.000	123.000	2.829	0.017	*
Bulbil diameter (mm)	76.724	49.855	70.870	52.032	40.360	139.150	31.689	0.000	***
Skin thickness (mm)	0.225	0.468	0.461	0.308	0.260	0.530	10.458	0.000	***
Bulbil width (mm)	43.038	31.795	41.684	36.208	74.490	60.960	25.458	0.000	***
Bulbil weight (g)	111.533	33.750	86.313	36.200	70.000	119.000	14.722	0.000	***
Number of bubils per plant (No)	14.000	3.500	5.563	5.600	4.000	3.000	49.375	0.000	***
Bulbils yield (g/plant)	1441.400	108.250	434.437	195.000	280.000	357.000	47.237	0.000	***

***: Significant at 0.001 probability level, **: Significant at 0.01 probability level; *: Significant at 0.05 probability level; ^{NS}: Not significant

Table 8: Clustering pattern, average inter-cluster mahalanobis D^2 distances and Fisher test p-values matrices for *Dioscorea bulbifera* genotypes collected in Cameroon

			Mahalanobis inter-cluster distance values (Above the diagonal) and p values of the Fisher test (Below the diagonal)					
Cluster	**Number of accessions**	**Accession included**	**Cluster I**	**Cluster II**	**Cluster III**	**Cluster IV**	**Cluster V**	**Cluster VI**
Cluster I	30	Mayos-2, Elogbatsindi, Bapouh-4, Bapouh-2, Bomono, Eloumdem-2, Nkouameyos-1, Sikoum, Babone-2, Batsingla-3, Bapouh-1, Bafut-2, Meureu, Bonis-2, Chomba-2, Fotomena-3, Batsingla-1, Fotomena-1, Mouloundou, Bertoua, Batsingla-4, Bawouwoua-1, Nkong-2, Bana-1, Muyengue, Nkapa,		36.290	10.972	16.506	73.574	83.799
Cluster II	4	Nkouameyos-2, Ekite, Nforia-2, Niebe-1	<0.001		19.541	13.883	75.424	132.167
Cluster III	16	Remis, Badoumou, Niebe-2, Chomba-1, Nkimbou, Bafut-1, Babone-3, Nkoemvone, Fontem-2, Nkong-3, Fontem-1, Babone-4, Bana-2, Bapouh-3, Fotomena-4, Babone-1	<0.001	0.004		7.352	57.158	86.537
Cluster IV	5	Ngwel, Mbesse, Mbatu, Fotomena-2, Njop	0.002	0.190	0.261		68.128	100.755
Cluster V	1	Bonis-1	<0.001	<0.001	<0.001	<0.001		110.818
Cluster VI	1	Alou-2	<0.001	<0.001	<0.001	<0.001	<0.001	

Table 9: Eigenvectors and eigenvalues of the first six principle components for 16 quantitative traits of 57 *Dioscorea bulbifera* accessions from Cameroon

Quantitative trait	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**	**PC6**
Time to germination	-0.161	-0.071	-0.234	**0.551**	-0.164	0.018
Plant height	0.167	-0.277	**0.440**	-0.070	0.043	0.218
Number of stem per plant	0.090	-0.159	-0.214	**0.483**	0.030	-0.427
Number of branches on main stem	0.035	0.153	0.312	0.398	-0.180	**0.535**
Stem diameter	**0.357**	-0.211	0.023	0.081	-0.378	0.018
Time to first leaf appearance	0.090	0.026	0.368	0.102	**0.524**	-0.018
Number of leaves	0.225	-0.099	**0.333**	0.210	0.259	-0.215
Leaf length	**0.422**	-0.181	0.005	0.146	-0.112	0.052
Leaf width	**0.421**	-0.170	-0.015	0.035	-0.111	-0.003
Time to the first bulbil appearance	-0.204	-0.034	-0.097	**0.409**	0.439	0.124
Bulbil diameter	**0.306**	0.186	-0.166	-0.100	0.328	0.020
Skin thickness	0.144	**-0.380**	-0.179	-0.137	0.125	-0.224
Bulbil width	0.236	0.197	**-0.383**	0.043	0.054	0.410
Bulbil weight	**0.366**	0.311	-0.218	-0.035	0.167	0.039
Number of bulbils per plant	0.003	**0.410**	0.310	0.106	-0.283	-0.388
Bulbils yield	0.223	**0.519**	0.050	0.081	-0.038	-0.221
Eigenvalue	4.044	2.480	1.992	1.453	1.104	0.981
Variability (%)	25.276	15.498	12.449	9.084	6.901	6.130
Cumulative variance (%)	25.276	40.775	53.223	62.308	69.209	75.340

PC: Principle component

forest) of Cameroon with distinct environmental conditions (Mignouna and Dansi 2003; Hasan et al. 2008). This suggestion is supported by the higher value of diversity parameters obtained in the highlands and monomodal forest zone where the species is already being cultivated as compared to other more recent collections from the bimodal forest zone. The domestication process consists of bringing a new species into cultivation after selection and vegetative multiplication of preferred locally acknowledged morphotypes (Padonou et al. 2017). In time, this process leads to positive change in the morphological and biochemical traits at tuber level and sometimes new cultivars as observed in some yam species (Mignouna and Dansi 2003). The average Nei's genetic diversity value and Shannon-Weaver diversity index recorded in this study were close to values recently published for cultivated cowpea in western Cameroon (*He* = 0.37, *H'* = 0.61; Ngompe-Deffo et al. 2017) and are comparatively lower than the values reported for *D. bulbifera* accessions from Ethiopia (*H'* = 0.18; Tewodros and Gatechew 2013). The fifty-seven analyzed genotypes were grouped into six distinct clusters using dissimilarity coefficients. The federation of genotypes into different constellations did not follow any specific pattern or parallelisms. The grouping was found to be independent of the geographical region and the agro-ecological zones distributions. This grouping of diverse genotypes from different localities of origin into a cluster might be due to unidirectional selection practiced by farmers and breeders in their search for promising genotypes. Such results were already reported in aerial yam (Tewodros and Gatechew 2013), pomegranate (Raina et al. 2015), gladiolus (Sharma et al. 2017) and mango (Manchekar et al. 2011). Phenotypic plasticity is highly common in plants which usually express plasticity for a number of morphological traits, such as organ size (Sultan 2003). This clustering of accessions independently of the place of origin suggests the presence of important plasticity in the studied *Dioscorea bulbifera* accessions. As cluster I comprising 30 genotypes shows the highest performance for fruit yield, number of bulbils and number of leaves per plant, each of the other clusters has higher means for others quantitative traits (Table 7). This shows that each cluster is associated with a particular breeding value and these characteristics help breeders in parental selection and improvement of different traits based on the merit of each cluster. As highlighted by Gemechu et al. (1997), cluster performance and inter-cluster distance should both be considered when selecting genotypes from a particular cluster for breeding. As the Mahalanobis D^2 inter-cluster distance varied from 7.352 to 132.167, the pair-wise distance between clusters, presented in Table 8, shows that the distance between most of the clusters was highly significant ($P < 0.01$). This suggests significant diversity among genotypes in these different clusters. Minimum cluster distance points to a low genetic difference among the genotypes of these clusters. However, maximum inter-cluster distance is indicative of wide genetic divergence among genotypes of those clusters. Crossing of genotypes with high inter-cluster distance can be expected to produce more genetic variability and desirable recombinants than would crosses with smaller inter cluster distance. As suggested by Raina et al. (2015), breeders should focus on clusters with maximum distance for their hybridization program because maximum distinct parents can be obtained through segregation. Therefore for example, crossing of genotypes from cluster I and VI, II and VI are likely to produce desirable recombinants for bulbil yield. For a crop species, it is known that the correlations between morphological traits are important and useful in designing a proper and effective crop improvement program. As fruit yield is known to be a complex trait, direct selection may be difficult and the identification of highly correlated characters therefore appears more appropriate. This study has revealed positive correlations between the number of branches on the main stem and bulbil yield, bulbil diameter and bulbil yield, number of bulbils per plant and bulbil yield. Some of these traits such as number of branches on the main stem and bulbil diameter can be considered in early selection for yield improvement in *D. bulbifera*. The important number of clusters obtained indicates a high level of diversity in the studied genotypes. This was confirmed by principal component analysis. The first six principal components composed explained 75.34 % of the total variation. Likewise, Tewodros and Gatechew (2013) classified forty-seven genotypes of aerial yam into six distinct clusters using 32 morphological traits with the first six principal components explaining 85.30% of the total variation, confirming the diverse genetic base and great breeding potential of this species.

5 Conclusion

Dioscorea bulbifera accessions from the western highland and humid monomodal forest zones were found to have significantly more phenotypic classes per trait and more important gene diversity, compared to accessions from the bimodal humid forest zone. Each of the studied genotypes had specific phenotypic features and this detail reinforces the value of collection of promising plant material using judgement of phenotypic features. Genotypes with

desirable agronomic traits such as bulbil yield; higher number of bulbils per plant; greater bulbil weight; rapid bulbil and leaf appearance; higher number of branches on the main stem were also identified in this study. These discriminatory traits are discussed and proposed for aerial yam conservation and for use in genetic improvement. The significant correlation found among some important traits could be exploited in breeding effort and genetic improvement of *D. bulbifera*.

Author contribution: VDL and HMA collected the plant material. VDL performed the experimental trial. EBK and MLAT conceived of the study and wrote the paper. EBK analyzed data and interpreted results. DPK and RSP reviewed the manuscript and contributed to the interpretation and presentation of results. All authors read and approved the final manuscript.

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