Genetic variability of yam (*Dioscorea trifida*) genotypes in the Ucayali region, Peru

Variabilidad genética de genotipos de ñame (*Dioscorea trifida*) en la región Ucayali, Perú

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ABSTRACT

The aim of this research was to assess genetic variability of yam *Dioscorea trifida* genotypes using morphological descriptors for the germplasm collection conserved in the Agricultural Experiment Station in Ucayali, Peru. Thirty-eight morphological traits were evaluated for 30 *D. trifida* genotypes over ten years; from the data we estimated the Shannon-Weaver diversity index (H') and the coefficient of variation and performed principal component analysis and cluster analysis. Qualitative traits with high phenotypic diversity index were: petiole anthocyanin (0.86), internal tuber color (0.86), petiole color (0.81) and stem color (0.80). The quantitative traits with the highest coefficient of variation were: tuber weight per plant (33.01) and tuber yield (32.99). Seventy-six percent of the morphological variability is explained by four principal components, the first component is constituted by the characters tuber width, tuber weight per plant, and tuber yield (29%). Five groups of genotypes were also identified with statistically significant differences, where group B stands out for its higher yield in fewer days to harvest. This research reveals wide morphological diversity in genotypes of *D. trifida*; these results can be used to strengthen the conservation, management, and genetic improvement initiatives of this important species in the Peruvian Amazon.

Key words: ethnic groups, morphological descriptors, sachapapa, genetic diversity index, tropical tuber.

RESUMEN

El objetivo de esta investigación fue evaluar la variabilidad genética de genotipos de ñame *Dioscorea trifida* usando descriptores morfológicos a fin de conocer la variabilidad de la colección conservada en la Estación Experimental Agraria en Ucayali, Perú. Se evaluaron 38 caracteres morfológicos para treinta genotipos de *D. trifida* durante diez años, para obtener el índice de diversidad genética de Shannon-Weaver (H'), el coeficiente de variación, y análisis de componentes principales y análisis de agrupamiento. Los caracteres cualitativos con mayor índice de diversidad fueron: antocianina del peciolo (0.86), color interno del tubérculo (0.86), color del peciolo (0.81) y color del tallo (0.80). Los caracteres cuantitativos con mayor coeficiente de variación fueron peso de tubérculos por planta (33.01) y rendimiento de tubérculos (32.99). El 76% de la variabilidad morfológica se explica a través de cuatro componentes principales, el primer componente está constituido por los caracteres ancho de tubérculo, peso de tubérculos por planta y rendimiento de tubérculos (29%). También se identificaron cinco grupos de genotipos en los cuales se encontraron diferencias estadísticamente significativas, donde se destaca al grupo B por su mayor rendimiento en menor número de días a cosechar. Por lo tanto, esta investigación revela amplia diversidad morfológica en genotipos de *D. trifida,* y los resultados pueden ser usados para fortalecer la conservación, manejo e iniciativas de mejoramiento genético de esta especie de importancia en la Amazonía peruana.

Palabras clave: grupos étnicos, descriptores morfológicos, sachapapa, índice de diversidad genética, tubérculo tropical.

Introduction

The Amazon region is home to many resources for food; one of these is *Dioscorea trifida* L. f., known as sachapapa (common name in Peru) or yam. It is a tuber plant belonging to the Dioscoreaceae family. Viruel *et al.* (2016) refer to three genera that group the Dioscoreaceae family (*Stenomeris, Trichopus, Rajania,* and *Dioscorea*), and the World Checklist of Vascular Plants (2022) accepts 679 species for *Dioscorea* (15 edible and medicinal approximately), providing substantial food for more than 100 million people in the humid and sub-humid tropics, appreciated for their flavor and fine texture (Price *et al*., 2018; Padhan & Panda, 2020). The *Dioscorea* species grow in Southeast Asia, tropical America, and West Africa, in tropical and subtropical regions of the world (Kumar *et al.,* 2017). According to Montaldo (1991), in the upper and lower jungle of the Peruvian Amazon, it constitutes a main source of energy in the diet of the inhabitants. As a crop, *Dioscorea* species requires much light and humid soils

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with good drainage. Padhan and Panda (2020) reviewed the aggregate nutritional composition of old-world yam and reported that its tuber is a good source of essential nutritional compounds, such as starch, protein, lipids, vitamins, and minerals, which agrees with the description of Pérez *et al.* (2009) for the nutritional composition of three varieties of *Dioscorea trifida* in the Venezuelan Amazon. Moreover, Ramos-Escudero *et al.* (2010) determined the content of total polyphenols, flavonoids, tannins, and anthocyanins for *D. trifida*, finding values around 166.10, 27.63, 9.62, and 21.59 mg/100 g of dry matter, respectively. Furthermore, pigments of yam pulp tuber have the capacity to sequester free radicals. This indicates a good *in vitro* protective effect of the pigments extracted from sachapapa (*D. trifida*). The aforementioned studies reveal the importance of sachapapa for food and health, although there are few studies regarding its agronomic management, origin, geographical distribution, and genetic variability of its populations (Nascimento *et al.*, 2015; Arnau *et al.*, 2017). In the Ucayali region (Peru), the production of sachapapa reaches an approximate average of 612.11 t per year (Astete-Verde, 2019), although it is considered a neglected crop because it is mainly cultivated for subsistence by native communities using traditional agricultural practices. In order to develop strategies for the management and conservation of this crop, the genetic diversity must be agro-morphologically characterized (Ocampo *et al.*, 2021; Thakur *et al.*, 2021; Wada *et al.*, 2021). In this context, the objective of this research was to evaluate the genetic variability using morphological descriptors for 30 *Dioscorea trifida* genotypes. This is a broad germplasm collection maintained and conserved year after year in rotation plots under similar environmental conditions, thus ruling out environment as the cause of observed morphological differences.

Materials and methods

Germplasm collection

In 1997, the National Institute of Agrarian Innovation (INIA), through the Genetic Resources Subdirectorate, began the collection of *D. trifida* germplasm. By 2000, 30 accessions from the four provinces of the Ucayali department (Fig. 1, Tab. 1), were collected to maintain and

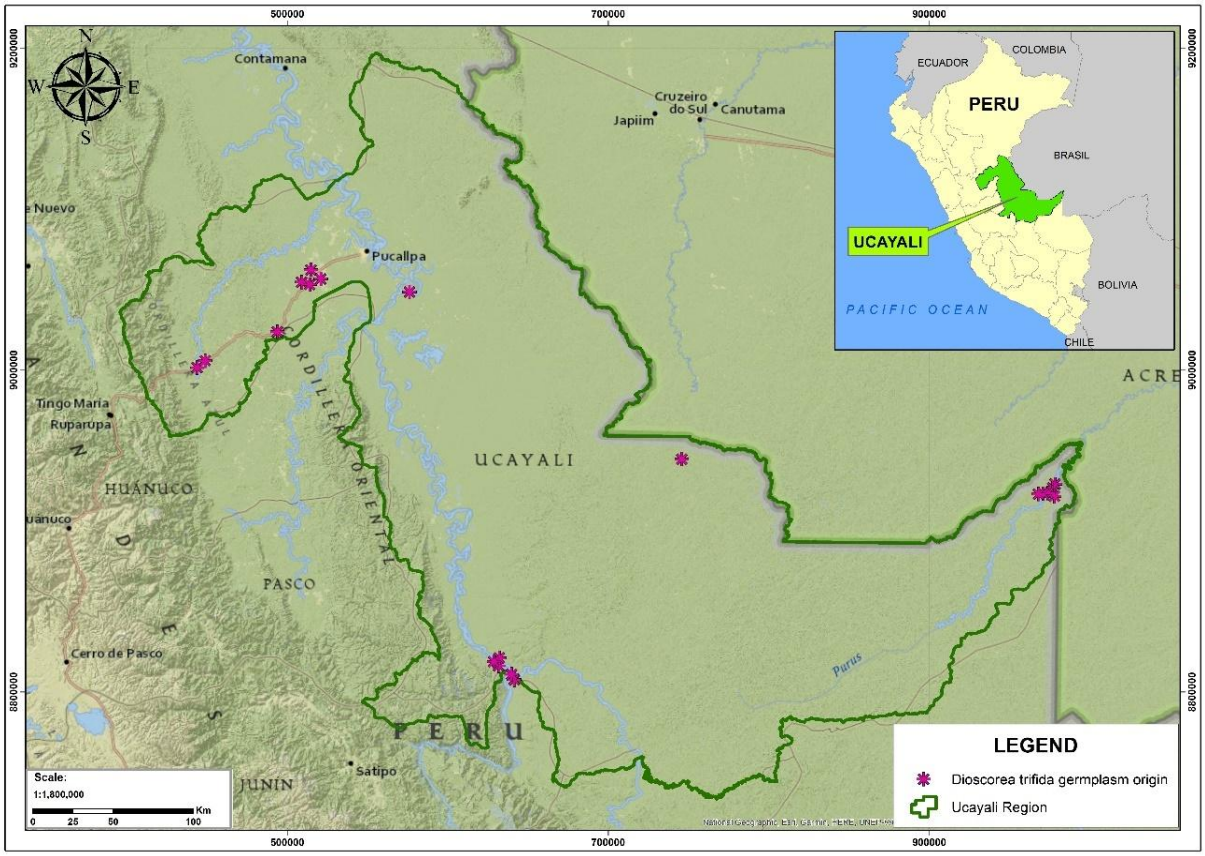

FIGURE 1. Map of *Dioscorea trifida* germplasm origin in the Ucayali region. Each circle represents the geographic origin of the sachapapa germplasm part of the National tropical root and tuber germplasm collection.

TABLE 1. List of *Dioscorea trifida* accessions conserved in a germplasm bank in the Ucayali region, Peru.

N°	Genotype code	Local name	Sampling code	District	Ethnic group	Latitude, S	Longitude, W	Altitude, m a.s.l.
Coronel Portillo Province								
1	IPDT001	Purple SP*	MA001	Masisea	Mestizo	8.605.300	74.306.300	166
2	IPDT002	Purple SP	SP002	Campoverde	Mestizo	8.550.800	74.916.400	208
3	IPDT003	White SP	SP003	Campoverde	Mestizo	8.550.800	74.916.400	208
4	IPDT004	SP	HB004	Campoverde	Mestizo	8.481.300	74.865.000	205
5	IPDT010	Dark purple SP	LP010	Campoverde	Mestizo	8.564.700	74.870.600	224
6	IPDT011	Purple SP	PIM011	Campoverde	Mestizo	8.532.000	74.808.700	210
7	IPDT012	White SP	PIM012	Campoverde	Mestizo	8.532.000	74.808.700	210
Padre Abad Province								
8	IPDT005	White SP	AG005	Padre Abad	Mestizo	9.031.800	75.509.400	313
9	IPDT006	Purple SP	EP006	Padre Abad	Mestizo	8.993.800	75.464.400	307
10	IPDT007	White SP	AVH007	Irazola	Mestizo	8.829.900	75.054.500	234
11	IPDT008	Dark purple SP	AVH008	Irazola	Mestizo	8.829.900	75.054.500	234
12	IPDT009	Light purple SP	AVH009	Irazola	Mestizo	8.829.900	75.054.500	234
Atalaya Province								
13	IPDT013	Purple SP	BR013	Yurua	Mestizo	9.538.900	72.759.100	200
14	IPDT014	SP	BR014	Yurua	Mestizo	9.538.900	72.759.100	200
15	IPDT015	SP	BR015	Yurua	Mestizo	9.538.900	72.759.100	200
16	IPDT017	White SP	CNA017	Raymondi	Ashaninka	10.705.833	73.793.278	241
17	IPDT018	Purple SP	CNA018	Raymondi	Ashaninka	10.705.833	73.793.278	241
18	IPDT019	White SP	CNL019	Raymondi	Ashaninka	10.681.833	73.821.778	235
19	IPDT020	White SP	PLM020	Raymondi	Mestizo	10.784.472	73.704.722	266
20	IPDT021	Purple SP	PLM021	Raymondi	Mestizo	10.783.306	73.706.611	249
21	IPDT022	White SP	JCHM022	Raymondi	Mestizo	10.753.556	73.720.750	248
22	IPDT023	Purple SP	PLCH023	Raymondi	Ashaninka	10.661.056	73.790.583	218
23	IPDT031	SP	CNL031	Raymondi	Ashaninka	10.681.833	73.821.778	235
Purus Province								
24	IPDT024	SP (maona en ashaninka)	CNRA024	Purus	Ashaninka	9.706.222	70.706.222	233
25	IPDT025	SP (maona en ashaninka)	CNRA025	Purus	Ashaninka	9.706.222	70.706.222	233
26	IPDT026	SP (maona en ashaninka)	CNNP026	Purus	Ashaninka	9.726.889	70.702.778	217
27	IPDT027	SP (pua-jushupa)	CNB027	Purus	Cashinahua	9.793.972	70.790.583	241
28	IPDT028	SP (pua-meshupa)	CNNB028	Purus	Cashinahua	9.785.722	70.761.806	235
29	IPDT029	Purple SP	CRLN029	Purus	Mestizo	9.797.222	70.715.472	228
30	IPDT030	Purple SP	PE030	Purus	Mestizo	9.770.417	70.717.694	204

*SP – sachapapa.

conserve in experimental plots a Campoverde Annex of the Pucallpa Agrarian Experimental Station (Federico Basadre Highway, Km. 44, Campo Verde district, Coronel Portillo province, Ucayali department, at coordinates 8°22'00" S and 74°34'80" W, altitude 205 m a.s.l.). The climate of the experimental area is characteristic of the lowland tropical zones; it is humid and warm without marked variations in the annual average temperature and with a defined strong dry season from May to July, with a relative humidity about 70-90%.

Field characterization plots

The 30 accessions of *D. trifida* were sowed at a distance 2 m between rows and 1 m between plants, with a localized application of 800 kg ha^{-1} of island guano and in some cases 10 t ha^{-1} of chicken manure; it was also necessary to install stakes that serve as a support because *Dioscorea trifida* is a climbing species. Field characterization plots were located in the same place as the field germplasm collection described above and plot rotation (50 m of distance between each plot) was applied every year from 2008-2017.

Descriptors

To assess genetic variability, 26 qualitative and 12 quantitative descriptors were evaluated (Tab. 2). Of the 178 descriptors listed by the International Institute of Plant Genetic Resources for *Dioscorea spp* characterization (IPGRI, 1997), 38 descriptors were adapted by the researchers according to the basic morphology of *Dioscorea trifida*.

Experimental design and data analysis

The experimental design was completely randomized with 10 repetitions (years). Rotation plots were evaluated for 10 years. Each year sowing started at the end of October, flowering took place after 5-7 months and harvesting began after approximately ten months. The climatic condition around each plot location was usually characterized by a rainy season around October 15th to April 15th, followed by a dry season from mid-April until the beginning of October. In every plot, we installed thirty accessions with ten plants per accession. For quantitative variables, five plants from the third to the seventh were selected and evaluated. For qualitative variables, we used direct observation to the ten plants and considered the most frequently occurring attribute observed.

TABLE 2. List of agro-morphological descriptors used to assess genetic variability among 30 genotypes of *Dioscorea trifida*.

N	Stage/character	Evaluation/evaluation code
1	**Vegetative phase**	
1.1	Percentage of emergence	%
1.2	Plant type	1. Dwarf, 2. Shrub-like, 3. Climbing
1.3	Twining habit	0. No, 2. Yes
1.4	Stem color	1. Green, 2. Slightly pigmented, 3. Moderately pigmented, 4. Fully pigmented – red, 5. Fully pigmented – purple
1.5	Stem wings	0. Absent, 1. Present
1.6	Stem hairs	0. Absent, 1. Present
1.7	Leaf color	1. Light green, 2. Dark green, 3. Purple green, 4. Purple
1.8	Vein color	1. Light green, 2. Dark green, 3. Purple green, 4. Purple
1.9	Hairiness of upper/ lower surface of leaf	0. Absent, 1. Present
1.10	Leaf type	1. Entire, 2. Very shallowly lobed, 3. Shallowly lobed, 4. Moderately lobed, 5. Deeply lobed, 6. Very deeply lobed
1.11	Position of leaves	1. Verticillate, 2. Alternate, 3. Opposite
1.12	Number of lobes	1. 01 lobe, 3. 03 lobes, 5. 05 lobes, 7. 07 lobes, 9. 09 lobes
1.13	Central lobe shape	0. Absent, 1. Dentate, 2. Semicircular, 3. Semi-elliptical, 4. Elliptical, 5. Lanceolate, 6. Oblanceolate, 7. Linear, 8 Oval, 9. Cordate
1.14	Leaf size	Record the length and width of 5 leaves in cm, with one decimal place, from the base to the apex of the leaf taken from the middle part of the plant
1.15	Petiole color	1. Light green, 2. Dark green, 3. Purple green, 4. Purple
1.16	Petiole pubescence	0. Absent, 1. Present
1.17	Anthocyanin in petiole	0. Absent, 1. Apical part, 2. Basal part, 3. Slightly pigmented, 4. Medium pigmented, 5. Completely pigmented
1.18	Petiole wing	0. Absent, 1 Present

N	Stage/character	Evaluation/evaluation code
2	**Flowering**	
2.1	Flowering	1. Female, 2. Male, 3. Female and male (predominantly female), 4. Male and female (predominantly male)
2.2	Inflorescence type	1. Spike, 2. Raceme, 3. Panicle, 9. Other
2.3	Flower color	1. White, 2. Yellow, 3. Light Green, 4. Purple Green/Pigmented Green
2.4	Number of flowers per inflorescence	For male and female plants
2.5	Flower length	Average of 5 flowers (male or female) per plant in mm (total length from the base of receptacle to the top)
2.6	Fruit formation	0. Absent, 1 Present
2.7	Fruit size	Record length of 5 fruits per plant in mm
2.8	Tuber formation (appearance)	1. Closed/kidney-shaped bunch, 2. Open bunch
2.9	Tuber shape	1. Round, 2. Irregular round (kidney-shaped), 3. Cylindrical, 4. Ovate, 5. Oblong, 6. Oblong oval, 7. Elliptical length, 8. Elongated round, 9. Irregular or curved length, 10. Compact
2.10	Tuber external color	1. White, 2. Cream, 3. Yellow, 4. Light brown, 5. Dark brown, 6. Purple, 7. Gray
2.11	Tuber internal color	1. White or cream, 2. Yellow, 3. Pink, 4. Light purple, 5. Dark purple
2.12	Rootlets	0. Absent, 1. Slight, 2. Intermediate, 3. Abundant
2.13	Pulp color	1. White, 2. Cream, 3. Yellow, 4. Light purple/pink, 5. Light purple, 6. Dark purple, 7. Concentric light purple. 8. Mottled
2.14	Peduncle length (average)	0. Absent or sessile, 1. Very short: < 2 cm, 3. Short: 2-5 cm, 5. Intermediate: 5-8 cm, 7. Long: 9-12 cm, 9 Very long: > 12 cm
2.16	Tuber size	Record 5 tuber length and width
2.17	Number of tubers per plant	
2.18	Weight of tubers/plant in kg	
2.19	Tuber yield in t ha^{-1}	
2.20	Days to harvest	

Simple descriptive statistics were obtained for all variables. The Chi-square test was performed for each qualitative character. The phenotypic diversity for the qualitative variables was determined using the Shannon-Weaver genetic diversity Index (H'). The range of H' is from 0 to 1, where 1 indicates maximum diversity. H' is defined as $H' = \Sigma P_i Log2P_i$, where P_i is the proportion of the total number of genotypes belonging to each category. According to Jamago (2000), H' is classified as low (H'<0.50), intermediate (H'=0.50-0.75), and high (H'>0.75). To determine the similarity between the *D. trifida* germplasm, a hierarchical cluster analysis (CA) was done with Ward's clustering method using Euclidean distance. To determine the occurrence of statistical differences between the groups of the dendrogram, a one-way analysis of variance was performed, and the Tukey test was used ($P \leq 0.05$). A Pearson correlation analysis was added between quantitative descriptors. Likewise, a principal component analysis (PCA) of the twelve quantitative variables under study was carried out. StatGraphics V. 19 software (StatGraphics, 2009) was used for all analyses.

Results and discussion

Qualitative descriptors

Of the 26 qualitative characters evaluated in 30 genotypes of *D. trifida*, eleven (11) were not discriminating (Tab. 3) and allows the species to be described as having a climbing habit with a twisted appearance, with wings, but without pubescence on the stem. The leaves are alternately arranged, without pubescence and with light green veins. Pubescent wings are recorded on the petiole. In all genotypes, spike-type inflorescences with light green flowers were observed. Nascimento *et al*. (2015) also reported genotypes of *D. trifida* with climbing plant behavior, with winged polygonal stems and green petioles with brown pigments and alternate leaves.

TABLE 3. List of descriptors without variability for 30 genotypes of *Dioscorea trifida.*

N	Descriptors	Attribute
1	Plant type	Climbing
2	Twining habit	Yes
3	Stem wings	Present
4	Stem pubescence	Absent
5	Vein color	Light green
6	Leaf pubescence	Absent
7	Leave position	Alternate
8	Petiole pubescence	Absent
9	Petiole wings	Present
10	Type of inflorescence	Spike
11	Flower color	Light green

About fifty eight percent of the qualitative characters evaluated for 30 genotypes of *D. trifida* resulted discriminant. According to the Chi-square analysis and the Shannon-Weaver Genetic Diversity Index (H') (Tab. 4), the most variable qualitative characters of *D. trifida* are: petiole anthocyanin (0.86), internal tuber color (0.86), petiole color (0.81), and stem color (0.80). While the number of lobes and the color of the mature leaf were the characters with the least variability (0.35), which would be consider as low variability (Jamago, 2000). The morphological variability of *Dioscorea spp.* was also determined using the Shannon-Weaver Genetic Diversity Index (H') of Islam *et al*. (2011). These authors also found high diversity indexes for petiole color and tuber shape in *Dioscorea alata* and *Dioscorea bulbifera*. Moreira *et al*. (2017) evaluated the external color and tuber shape of *Dioscorea cayennensis*, finding a low diversity index, which is expected for descriptors with fewer categories.

The slightly pigmented color predominated for the stems, which are green with purple or brown pigments. The predominant color of the petiole was purple green, characteristics that coincide with the description for *D. trifida* genotypes reported by Nascimento *et al*. (2015) in three states of Brazil. Similarly, the number of lobes per leaf can vary from three to five, although five-lobed leaves were predominant.

This result is in sharp contrast with *Dioscorea alata*, a species characterized by single lobe leaves (Norman *et al*., 2011). The color of the pulp for *Dioscorea* species ranges from white, yellow to dark purple (González, 2012). In this study, white pulp color (50%) was predominant, followed by light purple (36.7%), consistent with the results of other studies (Pérez *et al*., 2009; Nascimento *et al*., 2015). Pérez *et al*. (2009) analyzed the nutritional content of *D. trifida* with three colors of pulp, finding a higher content of crude protein in white pulp (6.8 ± 0.02%) in contrast to the values for purple pulp (4.3 ± 0.54%).

Quantitative descriptors

Values regarding the descriptive statistics analysis for 12 quantitative descriptors evaluated in 30 genotypes of *D. trifida* are shown in Table 5. The descriptors with the highest coefficient of variation are tuber weight per plant (33.01) followed by tuber yield (32.99) and the number of female flowers per inflorescence (27.42%).

TABLE 4. Absolute frequency, proportion, and variability within 16 qualitative descriptors of *Dioscorea trifida*.

N	Descriptors	Attribute	Absolute frequency	Proportion	X^2	***H'
1	Stem color	Green	1	0.033	14.53**	0.80
		Slightly pigmented	14	0.467		
		Moderately pigmented	11	0.367		
		Fully pigmented – purple	4	0.133		
2	Leaf type	Shallowly lobed	1	0.033	30.2**	0.53
		Moderately lobed	5	0.167		
		Deeply lobed	24	0.800		
3	Number of lobes	3 lobes	2	0.067	22.53**	0.35
		5 lobes	28	0.933		
4	Central lobe shape	Semi-elliptical	2	0.048	16.8**	0.73
		Elliptical	20	0.476		
		Oval	8	0.190		
5	Petiole color	Light green	7	0.233	12.6**	0.81
		Purple green	19	0.633		
		Purple	4	0.133		
6	Presence of anthocyanin in petiole	Absent	4	0.133	13.2**	0.86
		Slightly pigmented	16	0.533		
		Medium pigmented	6	0.200		
		Completely pigmented	4	0.133		
7	Flowering	Female	11	0.367	--	--
		Male	19	0.633		
8	Fruit	Absent	15	0.500	0.00	1.00
		Present	15	0.500		
9	Tuber formation (appearance)	Closed/kidney-shaped bunch	4	0.133	16.13**	0.57
		Open bunch	26	0.867		
10	Tuber shape	Irregular round (kidney-shaped)	1	0.033	18.2**	0.68
		Ovate	9	0.300		
		Oblong oval	20	0.667		
11	Tuber external color	Light brown	11	0.367	2.13	0.95
		Dark brown	19	0.633		
12	Tuber internal color	White or cream	9	0.300	8.67*	0.86
		Pink	1	0.033		
		Light purple	12	0.400		
		Dark purple	8	0.267		
13	Rootlets	Absent	2	0.067	19.4**	0.70
		Slight	21	0.700		
		Intermediate	7	0.233		
14	Pulp color	White	15	0.500	28.67**	0.70
		Cream	1	0.033		
		Light purple	11	0.367		
		Dark purple	1	0.033		
		Mottled	2	0.067		
15	Leaf color	Light green	2	0.067	22.53	0.35
		Dark green	28	0.933		

* Significant Chi-square, ** Highly significant Chi-square (X^2), *** Shannon-Weaver Genetic Diversity Index (H').

TABLE 5. Descriptive statistics of 12 quantitative descriptors from the evaluation of 30 genotypes of *Dioscorea trifida*.

Descriptors	Mean n=30	SD	CV	Minimum	Maximum
PE	81.00	8.49	10.48	55.00	93.60
LL	17.59	1.19	6.79	15.30	20.40
LW	17.86	1.47	8.25	14.90	22.00
NFFI	18	4.93	27.42	7	25
NMFI	23	3.58	15.73	18	35
FFS	10.50	1.59	15.19	6.00	11.60
MFS	4.45	0.60	13.42	3.90	6.50
LPed	7.02	1.72	24.51	2.60	10.80
TL	11.16	1.37	12.27	7.60	14.20
TW	4.70	0.73	15.60	3.40	6.80
NTP	7	1.65	23.15	5	11
WTP	0.87	0.29	33.01	0.52	1.71
Yield	4.35	1.43	32.99	2.58	8.56
DH	303	11.73	3.87	292	339

SD: Standard deviation; CV: Coefficient of variation PE: Percentage of emergency; LL: Leaf length; LW: Leaf width; NFFI: Number of female flowers per inflorescence; NMFI: Number of male flowers per inflorescence; FFS: Female flower size; MFS: Male flower size; LPed: Length of peduncle; TL: Tuber length, TW: Tuber width; NTP: Number of tubers per plant; WTP: Weight of the tubers per plant; DH: Days to harvest.

Taking into account the coefficients of variation and the ranges of the quantitative variables, wide genetic variability is suggested. However, it is important to evaluate and consider which characteristics are truly inherited and the edaphoclimatic factors that can influence the agro-morphological variation and the management of the genotypes of *D. trifida* for genetic improvement purposes. For example, the genotypes with the highest yield were BR013 and CNNB028. This yield, in addition to other physicochemical characteristics (Carlos *et al.,* 2020), must be evaluated under different environmental conditions prior to technology transfer to farmers. Figure 2 shows the yield in tons per hectares by each *D. trifida* genotype, an important trait to select genotypes for genetic improvement and food security.

Correlation analysis

Leaf width and length, tuber weight per plant and tuber width, tuber yield per plant and tuber width, correlated in a positive and highly significant way (Tab. 6). Peduncle length and tuber length as well as leaf length and number of tubers per plant showed significant and positive correlations.

Principal component analysis

Four components were selected that may explain 86% of the variability among *D. trifida* genotypes (Tab. 7). The first component is constituted mainly by tuber traits: tuber width, tuber weight per plant, and tuber yield (38%). The second component is made up of the descriptors: leaf length and tuber length (20%). The third component is represented

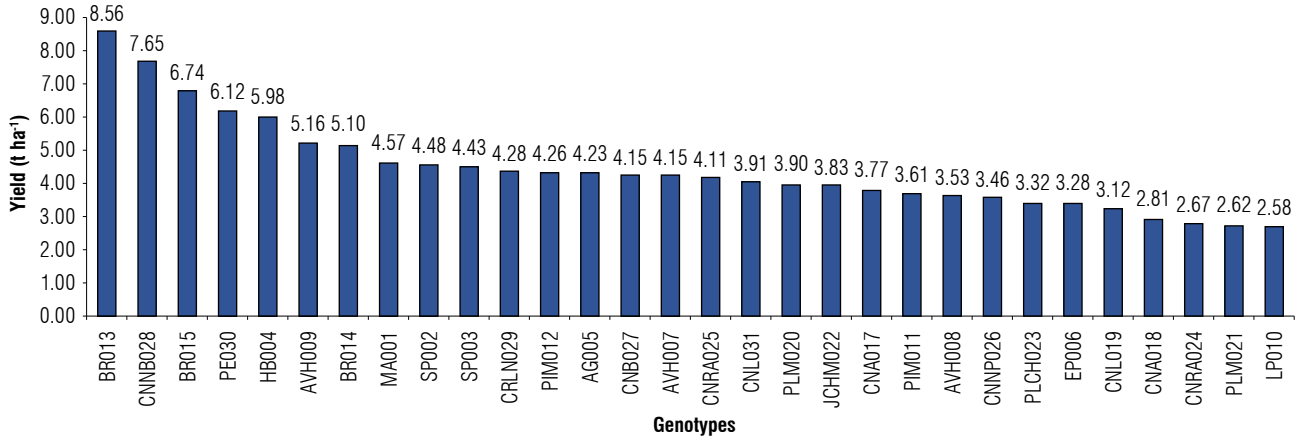

FIGURE 2. Tuber yield for 30 genotypes of *Dioscorea trifida* production.

TABLE 6. Pearson's correlation analysis between nine quantitative characters for *Dioscorea trifida.*

	PE	LL	LW	LPed	TL	TW	NTP	WTP	Yield
PE	1								
LL	0.28	1							
LW	0.34	0.84**	1						
LPed	0.09	0.0005	0.15	1					
TL	0.26	-0.07	0.21	0.51*	1				
TW	0.07	0.34	0.08	0.02	0.03	1			
NTP	0.21	0.41*	0.26	0.06	0.18	0.3	1		
WTP	0.05	0.34	0.27	0.31	0.34	0.69**	0.4*	1	
Yield	0.05	0.34	0.27	0.31	0.34	0.69**	0.4*	1**	1

PE: Percentage of emergency; LL: Leaf length; LW: Leaf width; LPed: Length of peduncle; TL: Tuber length, TW: Tuber width; NTP: Number of tubers per plant; WTP: Weight of the tubers per plant.* Significant at 5% level; ** Significant at 1% level.

by peduncle length and leaf width (17%). Tuber yield and tuber length are included in the set of priority descriptors for characterization of *Dioscorea* genetic resources (Biodiversity International and International Institute of Tropical Agriculture (IITA), 2009), therefore, it is consistent with the principal component analysis.

TABLE 7. Eigenvectors of the principal component analysis for *D. trifida* descriptors.

Descriptors	e1	e2	e3	e4
PE	-0.04	-0.43	-0.32	**0.63**
LL	0.35	**0.48**	0.13	0.21
LW	0.31	0.39	**0.41**	0.26
LPed	0.19	-0.31	**0.48**	-0.03
TL	0.17	**-0.47**	0.46	0.15
TW	**0.38**	-0.01	-0.37	-0.40
NTP	0.30	0.13	-0.33	**0.52**
WTP	**0.49**	-0.21	-0.12	-0.15
Yield	**0.49**	-0.21	-0.12	-0.15

PE: Percentage of emergency; LL: Leaf length; LW: Leaf width; LPed: Length of peduncle; TL: Tuber length, TW: Tuber width; NTP: Number of tubers per plant; WTP: Weight of the tubers per plant.

Clustering analysis

Clustering analysis distributed the 30 sachapapa genotypes in different clusters based on the Euclidean distance in a range from 0 to 20.63. The dendrogram identified five groups using a cut distance of 5.15 (Fig. 3, Tab. 8). Groups B and D comprise five genotypes each, group C has three genotypes, and groups A and E have eight and nine genotypes, respectively. Among the groups, the descriptors with statistically significant differences are emergence percentage, leaf length, leaf width, number of flowers per cluster, number of tubers per plant, and days to harvest (Tab. 8). Group C registered the lowest percentage of emergence, while group B registered the highest percentage of emergence. Likewise, the group with the longest leaf length and width was group C (19.38 cm and 20.34 cm, respectively), while group E was made up of genotypes with the smallest leaf size (16.47 cm and 16.34 cm). Group C registered genotypes with the highest number of flowers per cluster and the longest peduncle length (28.16 cm and 8.58 cm, respectively). Regarding tuber traits, group D registered the highest number of tubers per plant (9), while groups A and E registered the lowest number of tubers per plant. Group

TABLE 8. Comparison of means between the groups formed in the cluster analysis.

Groups	PE (%)	LL (cm)	LW (cm)	LPed (cm)	TL (cm)	TW (cm)	NTP	WTP (kg)	Yield (t ha^{-1})
A	77.74^{ab}	17.16^{cd}	17.16^{bc}	5.73^{a}	10.17^{a}	4.39^{a}	6^{b}	0.60^{a}	3.02^{a}
B	86.84^{a}	17.87^{bc}	17.77^{abc}	7.03^{a}	11.85^{a}	5.72^{a}	8^{ab}	1.30^{a}	6.50^{a}
C	65.62^{b}	19.38^{a}	20.34^{a}	8.58^{a}	11.30^{a}	5.13^{a}	8^{ab}	1.03^{a}	5.13^{a}
D	84.14^{a}	18.74^{ab}	19.16^{ab}	6.95^{a}	10.96^{a}	4.67^{a}	9^{a}	0.91^{a}	4.56^{a}
E	85.62^{a}	16.47^{d}	16.34^{c}	6.89^{a}	11.70^{a}	4.94^{a}	6^{ab}	1.09^{a}	3.95^{a}

PE: Percentage of emergency; LL: Leaf length; LW: Leaf width; LPed: Length of peduncle; TL: Tuber length, TW: Tuber width; NTP: Number of tubers per plant; WTP: Weight of the tubers per plant. Averages with different letters are significantly different at 0.05 *P-value*.

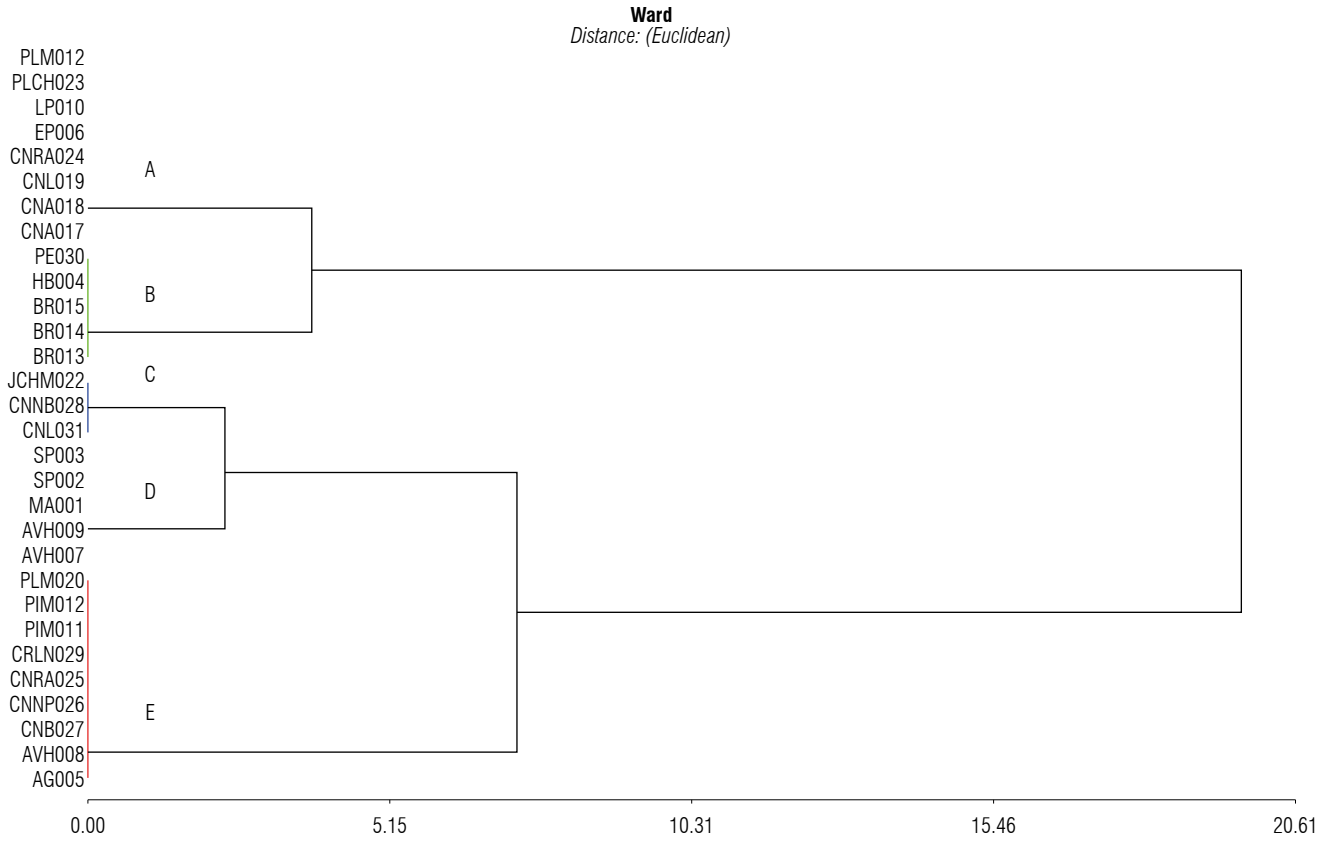

FIGURE 3. Dendrogram generated by the Euclidean distance for thirty genotypes of *Dioscorea trifida*.

B registered greater length and width of tubers (11.70 cm and 5.72 cm, respectively). This group also stands out with higher yield (6.50 t ha^{-1}) in a shorter period (295 d on average) and with light purple pulp. Moreover, groups B and D comprise genotypes of the Mestizo ethnicity, therefore, the cluster analysis may reflect the grouping in relation to the ethnic group to which it belongs. In this context, a conservation strategy within ethnic groups would be to promote the repopulation of the diversity of sachapapa genotypes along with teaching agronomic management techniques applied in the germplasm collection of this study.

Conclusions

The morphological characterization of thirty genotypes of *Dioscorea trifida* using 38 descriptors revealed high variability for the qualitative characters of petiole anthocyanin, internal tuber color, pulp color, and stem color. The quantitative descriptors with the highest coefficient of variation were tuber weight per plant and tuber yield. Four main components can explain 86% of the variability of the 30 genotypes of *D. trifida*. Descriptors with the greatest contribution to variance are tuber width, tuber weight per plant, and tuber yield (38%). It was also possible to distinguish five groups based on the Euclidean distance and Ward hierarchical clustering method, where group B highlights with genotypes HB004, BR013, BR014, BR015, PE030 registering higher tuber yield in fewer days. This is a preliminary study aiming at assessing genetic variability of the germplasm collection rather than high yielding genotypes. For more reliable yield data, replicated trails in different locations would be required. Moreover, complementary studies of nutritional value and biochemical composition of these genotypes are suggested, so that they can be shared with the population and additional molecular analysis must be performed to support the basis for the genetic improvement of this species. In addition, the agro-industrial potential of yam pulp tuber color varieties for food and health should be analyzed.

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Conflict of interest statement

The authors declare that there is no conflict of interest regarding the publication of this article.

Author´s contributions

WFGH designed the experiments, collected and organized the data and conducted the research. LLTC formulated the research aims and performed the data analysis. LLTC and WFGH wrote and reviewed the manuscript. All authors have reviewed the manuscript.

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