Agronomical evaluation of cape gooseberries (*Physalis peruviana* L.) from central and north-eastern Colombia

Evaluación agronómica de materiales de uchuva (*Physalis peruviana* L.), provenientes del centro y nor-oriente colombiano

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ABSTRACT

The aim of the present study was to evaluate agronomical traits in a germplasm collection of cape gooseberry from central and north-eastern Colombia in order to measure the variability of the collection in relation to the geographic origin of the accessions and their biological status (cultivated, feral and undetermined). For this purpose, a total of 54 accessions from the departments of Norte de Santander, Santander, Boyacá and Cundinamarca was evaluated using 30 descriptors (23 quantitative and seven qualitative) by means of a principal component analysis (PCA) applied to the quantitative variables and a multiple correspondence analysis (MCA) applied to the qualitative variables. The first two PCA components explained 52.42% of the total variation. The first component (39.79%) was positively related to the weight and fruit size and negatively to the pH and maturity index. A hierarchical classification analysis based on the continuous variables resulted into two classes with contrasting affinities, with 94.37% of the cultivated accessions grouped into class 2 and 64% of the undetermined accessions grouped into class 1. The first three MCA axes explained 48.48% of the total variation. The first one (20.51%) was related to strong serosity, medium fruit size and absence of damage caused by *Phoma* sp. A hierarchical classification analysis based on the categorical variables resulted in four classes (A, B, C, and D); with one of them (class B) containing five accessions characterized by having strong serosity and absence of damage caused by insects and pathogens.

Key words: germplasm collection, variability, hierarchical classification, fruit, serosity.

RESUMEN

El presente estudio propuso como objetivo la evaluación agronómica de una colección de germoplasma de uchuva proveniente de la región andina del centro y nor-oriente de Colombia, con el fin de medir la variabilidad y representatividad de los materiales de la colección en relación a su procedencia geográfica y situación de colecta (cultivada, asilvestrada o indeterminada). Se evaluaron 54 entradas provenientes de los departamentos de Norte de Santander, Santander, Boyacá y Cundinamarca, mediante el uso de 30 descriptores (23 cuantitativos y siete cualitativos) analizados mediante un análisis de componentes principales (ACP) para las variables cuantitativas y un análisis de correspondencia múltiple (ACM) para las variables cualitativas. Los dos primeros componentes del ACP explicaron el 52,42% de la variabilidad total; el primero (39,79%) reunió variables vinculadas a peso y tamaño de fruto y de manera negativa lo hicieron el pH y el índice de madurez. La clasificación jerárquica generó dos grupos con afinidades contrastantes hacia los materiales cultivados (94,37% se agruparon en la clase 2) e indeterminados (64% se agruparon en la clase 1). El ACM retuvo el 48,48% de la variabilidad total para los tres primeros ejes, el primer eje (20,51%) reunió las variables serosidad fuerte, tamaño mediano de fruto y ausencia de daño por *Phoma* sp. La clasificación jerárquica determinó la conformación de cuatro grupos (A, B, C y D), destacándose la clase B que agrupó cinco entradas sobresalientes por su serosidad fuerte y ausencia de afecciones causadas por insectos y patógenos.

Palabras clave: colección de germoplasma, variabilidad, clasificación jerárquica, fruto, serosidad.

Introduction

The area of origin and diversification of cape gooseberry (*Physalis peruviana* L.) (Solanaceae) is in the Andean zone, mainly in Colombia, Peru and Ecuador, from where it was introduced to different climates in tropical, subtropical and temperate regions (Hawkes, 1991). According to Brücher (1989), the *Physalis* genus has a few representatives in the Old World but most of the species are American in origin, with the main center of diversity in Mexico and only a dozen species present in South America. Vargas *et al.* (2001) reported approximately 85 species in the *Physalis* genus with and nearly half of them (about 46 species) endemic to Mexico.

Currently, more than 80 ecotypes of cape gooseberry have been reported worldwide on the basis of plant habit, shape of calyx, and size, color and taste of the fruit (Rodríguez

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and Bueno, 2006); among these we can find the ecotypes 'Colombia', 'Peru' and 'Kenya'. The Colombian ecotype is characterized by producing a higher number of fruits per plant and smaller fruits with a more attractive color and higher sugar content than the African ecotypes ('Kenya' and 'South Africa') (Fischer, 1995). These qualities make the Colombian cape gooseberry more competitive in international markets, placing Colombia among the main producers of this fruit (Fischer *et al*., 2007). For this reason, *P. peruviana*, though in need of improved crop management practices, has become an important genetic resource for Colombia (Lagos, 2006). Germplasm collections and their proper conservation, documentation and evaluation may contribute to the development of breeding strategies and maintenance of the species by allowing the identification of promising accessions for future selection and breeding programs (Bonilla *et al*., 2008).

In Colombia, Arbeláez and Mora (1990) evaluated phenotypic traits in 68 materials of the *Physalis* genus preserved at the germplasm bank of the Corpoica Research Center La Selva in Rio Negro; 33 of them belonging to *P. peruviana,* mainly from the Antioquia department. Among the 36 descriptors analyzed, the size and color of the mature fruit and the size of the plant at flowering showed the highest variability. Within the same study, Ligarreto *et al.* (2005), by means of a principal component analysis (PCA), observed that the first component explained 44.44% of the total variance and the most important variables were those related to the pubescence in the leaves and shoots, leaf number during the juvenile phase (below the first flower) and flowering time. The second component explained 10.21% of the total variance and was only explained by the fruit size. Later, Trillos *et al.* (2008) evaluated morphological traits in 46 accessions of cape gooseberry from the La Selva germplasm bank using 40 qualitative and quantitative variables, which contributed to the differentiation between accessions (72.5% and 93.11%, respectively). Among the variables with the largest coefficient of variation were traits of a quantitative nature such as percentage of cracked fruits, calyx weight, fruit weight and number of fruits per plant, suggesting that the selection of parental individuals should take quantitative characteristics into account.

The Universidad de Nariño in Pasto (Colombia) holds a collection of 50 genotypes comprised of the regional accessions that were collected and morphologically evaluated by Hejeile and Ibarra (2001). These authors, by means of a PCA applied to 12 quantitative variables, identified for the first three components, 70% of the collection variability. The variables that contributed the most to these three components were fruit weight and diameter, leaf size and flower development until fruit setting (first fruit).

The Universidad Nacional de Colombia in Palmira owns a collection of 222 accessions from the departments of Nariño, Valle del Cauca, Cauca, Caldas and Cundinamarca. From this collection, Bonilla *et al.* (2008) evaluated morphologically 24 accessions based on 10 qualitative and 17 quantitative variables by means of a multiple correspondence analysis (MCA) and a PCA, respectively. This study showed that the quantitative variables that explained most of the observed variability were those related to fruit characteristics such as fruit weight, transversal and longitudinal fruit length, seed number and soluble solids content. Likewise, Madriñán (2010) evaluated, by means of a conglomerate analysis, 29 accessions of this collection based on seven qualitative and 10 quantitative characters and identified five groups differing in qualitative variables like fruit shape and color.

In Colombia, germplasm evaluations of *P. peruviana* have mainly focused on the diversity of the central and southwestern Andean zones, where attributes related to the fruit have shown the hightest variability in these collections. According to this scenario, it is necessary to continue with the evaluation and characterization of *P. peruviana* germplasm especially from Andean zones that have not been evaluated yet, with the aim of establishing levels of genetic diversity and strategies for conservation and handling of this germplasm in breeding programs. In this context, the objective of this study was to evaluate agronomical traits in materials of cape gooseberry from poorly explored geographic areas of the central and north-eastern Andes of Colombia in order to contribute to the knowledge of this valuable genetic resource and thus encourage its conservation and use in future breeding programs.

Materials and methods

Evaluated accessions

The present study evaluated 54 accessions preserved as seeds in the germplasm bank of *P. peruviana* at the Faculty of Agronomy of the Universidad Nacional de Colombia in Bogotá (Tab. 1). Among these materials, there are 21 feral accessions (of spontaneous appearance, small leaves, strong serosity, short internodes and abundance of trichomes), 19 cultivated accessions (from crop fields and markets with big leaves, weak serosity, long internodes and lower abundance of trichomes) and 14 undetermined accessions (plants of spontaneous appearance that cannot be allocated to one of the two previous categories) collected in the departments of Cundinamarca (21 accessions), Boyacá (13), Santander (5) and Norte de Santander (15).

TABLE 1. Cape gooseberry germplasm accessions used in this study and its geographic origin and classification according to a multiple correspondence analysis (MCA) and a principal component analysis (PCA).

Accession number	Collection situation	Department	Municipality	MCA	PCA
06Uch0001	Feral	Norte de Santander	Pamplona	A	1
06Uch0003	Cultivated	Norte de Santander	Chitagá	A	2
06Uch0005	Feral	Norte de Santander	Pamplona	A	2
06Uch0006	Feral	Norte de Santander	Pamplona	B	1
06Uch0007	Feral	Norte de Santander	Pamplona	A	2
06Uch0008	Cultivated	Norte de Santander	Pamplona	A	1
06Uch0009	Feral	Norte de Santander	Pamplona	A	2
06Uch0010	Feral	Norte de Santander	Pamplona	A	2
06Uch0011	Feral	Norte de Santander	Pamplona	C	1
06Uch0012	Feral	Norte de Santander	Pamplona	A	1
06Uch0013	Feral	Norte de Santander	Pamplona	A	2
06Uch0014	Feral	Norte de Santander	Pamplona	A	1
06Uch0015	Feral	Norte de Santander	Pamplona	A	2
06Uch0017	Market place	Norte de Santander	Pamplona	A	2
06Uch0018	Market place	Norte de Santander	Pamplona	A	2
06Uch0019	Cultivated	Cundinamarca	Granada	A	2
06Uch0020	Cultivated	Cundinamarca	Granada	A	2
06Uch0023	Cultivated	Cundinamarca	Silvania	A	2
06Uch0024	Cultivated	Cundinamarca	Silvania	A	2
06Uch0025	Feral	Cundinamarca	Bojacá	A	2
06Uch0026	Feral	Cundinamarca	Bojacá	A	2
06Uch0029	Feral	Cundinamarca	Tena	B	1
06Uch0031	Feral	Cundinamarca	Tena	B	1
06Uch0032	Cultivated	Cundinamarca	Tena	A	2
06Uch0033	Cultivated	Cundinamarca	Zipacón	A	2
06Uch0034	Undetermined	Cundinamarca	Chía	A	1
06Uch0035	Cultivated	Cundinamarca	Chía	A	2
06Uch0036	Cultivated	Cundinamarca	Cachancipá	A	2
06Uch0037	Cultivated	Cundinamarca	Cachancipá	A	2
06Uch0039	Undetermined	Cundinamarca	Guatavita	A	1
06Uch0040	Undetermined	Cundinamarca	Guasca	A	2
06Uch0041	Cultivated	Cundinamarca	Guasca	A	2
06Uch0042	Undetermined	Cundinamarca	Zipaquirá	A	2
06Uch0043	Undetermined	Cundinamarca	Zipaquirá	A	2
06Uch0045	Undetermined	Cundinamarca	Suesca	C	1
06Uch0046	Cultivated	Cundinamarca	Suesca	A	2
06Uch0047	Cultivated	Boyacá	Ventaquemada	A	2
06Uch0048	Cultivated	Boyacá	Ventaquemada	A	2
06Uch0049	Undeterminad	Boyacá	Sáchica	B	1
06Uch0050	Undetermined	Boyacá	Villa de Leyva	A	1
06Uch0051	Undetermined	Boyacá	Villa de Leyva	A	2
06Uch0052	Cultivated	Boyacá	Arcabuco	A	2
06Uch0053	Cultivated	Boyacá	Arcabuco	A	2
06Uch0055	Undetermined	Boyacá	Paipa	A	1
06Uch0056	Undetermined	Boyacá	Paipa	A	2
06Uch0057	Undetermined	Boyacá	Paipa	D	1
06Uch0059	Feral	Boyacá	Firabitoba	B	2
06Uch0061	Undetermined	Boyacá	Tota	C	1
06Uch0062	Undetermined	Boyacá	Tota	A	1
06Uch0066	Feral	Santander	Floridablanca	A	2
06Uch0067	Feral	Santander	Floridablanca	A	2
06Uch0070	Feral	Santander	Tona	A	2
06Uch0071	Feral	Santander	Zapatoca	A	1
06Uch0073	Feral	Santander	Zapatoca	A	2

Geographic location and conditions of the experiment

As described by Herrera *et al.* (2011), the evaluation process was carried out under plastic greenhouse conditions at the Universidad Nacional de Colombia in Bogotá, located at 2,556 m a.s.l. and at the geographic coordinates 4°38'08.46" N and 74°0.5'11.99" W. The temperature and relative humidity, as averaged maximums and minimums, were 37.5°C and 87.0%, and 9.7°C and 20.0%, respectively. The soil used in the experiment was loamy, with a pH of 5.7, an average organic matter content of 6.17%, cation-exchange capacity of 17.9 cmol kg^{-1} and high levels of phosphorus (>116 mg kg^{-1}) and potassium (1.04 mg kg^{-1}).

Experimental design and agronomic management

We initially measured the germination percentage (GP) of 30 seeds per accession (from the fruit samples collected in the field). Initial transplanting was performed 50 days after sowing (das) in black plastic bags (1 L) with a mixture of sieved soil, organic matter and sand (vol% 3:1:1). For the final transplant in the greenhouse at 170 das, four replicates per accession, for a total of 216 plants in the experiment, were planted at a distance of 2 x 2 m with a completely randomized distribution.

Agronomic management activities used during the trial were conducted under the commercial growing conditions typical of the Cundinamarca-Boyacá region. Formative pruning was practiced once, leaving one main stem from which reproductive shoots developed. Branches were hung up on a "V" espalier system. During the study, fertilizer was applied using a system comprised of a fertilization module via a Venturi Mazzei Injector-484 and drip irrigation (one drip line per bed with an auto offset of 1.3 L h^{-1}, spaced at 45 cm with a run time of 5-20 min d^{-1}, based on plant development). The nutritional composition of the fertilizer was as follows: N (total) 15%, P_2O_5 5%, K_2O 30%, MgO 2%, B 0.02%, Cu 0.005%, Fe 0.07%, Mn 0.03% and Zn 0.01%.

Evaluated variables and methodology

The agronomical variables were selected according to the reports of Arbeláez and Mora (1990), Lagos (2006) and Bonilla *et al.* (2008), and were related to yield and fruit quality. A total of 23 quantitative (Tab. 2) and seven qualitative variables (Tab. 3) were studied.

At 290 das, fruit harvest began at the optimal harvest time, i.e. at the time when the ripe fruit becomes visible through

TABLE 2. Basic descriptive analysis for the quantitative characteristics evaluated in the collection.

	Variable	Unit	Avg	SD	CV	1**	2**	3**	4**
1	Germination (GP)	%	81.73	23.94	29.29	1.40	0	1.30	2.30
2	Fresh fruit weight (FW)	g	5.62	0.92	16.39	8.30	0.10	0.10	0.40
3	Fresh fruit weight with calyx (FWC)	g	5.89	0.95	16.20	8.30	0.10	0.10	0.60
4	Equatorial diameter of fruit (EDF)	mm	20.82	1.45	6.95	8.00	0.0	0.40	1.00
5	Polar diameter of fruit (PDF)	mm	20.68	1.18	5.69	5.20	0.20	3.20	3.10
6	Fruit volume (V)	mL	5.34	0.95	17.81	8.30	0.10	0.10	0.50
	Fruit shape (EDF/PDF) (Sh)*	mm	1.01	0.05	4.82	2.30	0.30	7.10	10.50
	Fruit size (EDF+PDF/2) (Si)*	mm	20.75	1.22	5.87	7.90	0	0.20	0
7	Fruit firmness (F)	lb	2.67	0.19	6.97	1.90	4.30	6.10	2.40
8	Equatorial diameter of calyx (EDC)	mm	28.61	3.36	11.73	7.10	0.10	0	0.10
9	Polar diameter of calyx (PDC)	mm	35.72	5.28	14.77	6.10	0.10	0	2.40
	Calyx shape (EDC/PDC) (SC)	mm	0.82	0.08	9.84	0.40	1.00	0.40	18.0
	Calyx size (EDC+PDC/2) (TC)	mm	32.17	4.15	12.91	4.90	0.10	0	1.40
10	Dry fruit weight (DW)	g	0.89	0.18	20.48	7.00	0	0.30	2.40
11	Dry fruit weight with calyx (DWC)	g	1.06	0.21	19.94	7.20	0	0.10	2.50
12	Cracked fruits (CF)	%	20.16	21.62	107.22	0	10.00	0.20	6.20
13	Number of fruits per plant (NFP)	Fruits/plant	1,070.45	416.47	38.91	0	0.80	15.00	16.70
14	Total soluble solids of fruit (TSS)	°Brix	14.26	1.43	10.06	0.40	11.50	0	5.20
15	Fruit pH (pH)		4.01	0.25	6.29	1.30	9.80	0.60	0.10
16	Fruit total titratable acidity (TTA)	% citric acid	1.41	0.27	19.35	2.50	8.90	0.20	0
17	Maturity index of fruit (MI)	TSS/TTA	10.80	4.14	38.38	1.40	16.0	0.90	0
18	Yield (Y)	kg/plant	6.28	2.46	39.19	1.40	1.0	15.90	12.40
19	Internode length in first order branches (IL1)*	cm	10.07	2.29	22.75	0.90	6.70	9.30	2.90
20	Internode length in second order branches (IL2)	cm	9.97	2.24	22.50	0.30	9.10	3.10	3.80
21	Internode length in third order branches (IL3)	cm	11.78	2.64	22.42	0.60	6.60	0.40	5.60
22	Stem length below first flower (SLF)*	cm	35.40	8.39	23.70	1.60	1.30	15.10	0.70
23	Node number below first flower (NNF)	No.	12.38	2.83	22.87	1.60	1.10	12.10	0.10

(*) Variables transformed into categories – ordinals (Tab. 3). Avg: average. SD: standard deviation. CV: coefficient of variation (%). (**) Contribution of variables to the first four principal components (%).

the husk. With a two-week sampling method over a period of 4 months (at the end of which production peaks) and with a sample size of 20 fruits per accession, we evaluated physical fruit variables such as size (using a digital DC-515 calibrator), volume (water displacement method), fresh and dry weight (measured with a Precise BJ 4100 electronic scale, accuracy ±0.0005 g), firmness (Wagner Fruit Test FT Series penetrometer), percentage of cracked fruits and yield. The chemical variables evaluated were total soluble solids (measured with a Carl Zeiss Jena table refractometer), percentage of total titratable acidity (assessed by the potentiometric titration method), maturity index and pH value with samples taken at 105 d after harvest was initiated. Variables such as stem length and node number below the first flower, internode length in the first, second and third order branches (second internode in each branch), and serosity (on shoots and leaves) were evaluated at the end of the study. At the same time, a qualitative record on the presence of pests (such as *Epitrix* sp. and *Copitarsia* sp.) and diseases (*Phoma* sp.) was also taken.

TABLE 3. Categories created for the evaluation of qualitative descriptors and their frequencies.

Variable	Category	Frequency (%)
Damage by *Phoma* sp. (Dph)	Absent: 0	23
	Shoots of 3rd order: 1	32
	Shoots of 2nd and 3rd order: 2	36
	Shoots of 1st order: 3	6
	Fruits and some shoot type: 4	3
	Complete plant: 5	0
Type of damage (Dt)	Absent: 0	42
	Epitrix sp.: 1	23
	Copitarsia sp.: 2	28
	Copitarsia sp. + *Epitrix* sp.: 3	7
Serosity of leaves (Sle)	Absent to low: 1	85
	Moderate: 2	8
	Strong: 3	7
Stem length below first flower (Lf)	Short (<20 cm): 3	1
	Medium (20–40 cm): 5	74
	Long (>40 cm): 7	25
Internode length in first order branches (Li)	Short: <5 cm	0
	Medium: 5-7 cm	6
	Long: >7 cm	94
Fruit shape (Shf): Equatorial diameter (Def)/Polar diameter (Dpf)	Elongated (<0.95): 1	15
	Round (1.05-0.95): 2	64
	Flattened (>1.05): 3	21
Fruit size (Sf): (Def+Dpf)/2	Small (<15.0 mm): 1	0
	Medium (15.0-20.0 mm): 2	20
	Large (>20.0 mm): 3	80

Statistic analysis of data

The analysis started with the calculation of measures of central tendency. The quantitative descriptors were studied by means of a principal component analysis (PCA). Four of the quantitative variables (size and shape of fruit, stem length below first flower and internode length in first order branches) were transformed into categorical variables according to former studies (Bonilla *et al.,* 2008; Arbeláez and Mora, 1990), and these, together with the other qualitative variables, were subjected to a multiple correspondence analysis (MCA), applying the criterion of Benzecri for the selection of the number of representative axes. Each description simultaneously involved an analysis of hierarchical classification using the Euclidean distance for PCA and the chi squared distance for MCA; the Ward method was applied as a procedure of agglomeration. The statistical analyses were carried out using the program R (2.9.0) of free distribution (R Development Core Team, 2010).

Results and discussion

Descriptive analysis of the evaluated variables

In order to describe the general behavior of the accessions in relation to each variable, a basic descriptive analysis for the quantitative (Tab. 2) and qualitative variables (Tab. 3) was carried out.

The variables related to fruit traits (TSS, TTA, FWC and Y) showed average values contained within the standard values of the Icontec 4580 normative (Icontec, 1999). On the other hand, fruit cracking was the most variable trait between accessions, possibly due to sensibility of this trait to changes in ecophysiological factors (Trillos *et al*., 2008) such as soil humidity, relative air humidity and air temperature (Fischer, 2005). Cracking was more frequent during the first harvests as well as in advanced fruit ripening stages (later than stage 4 of the Icontec norm) (Gordillo *et al*., 2004). The high variability observed in yield, similar to the findings of Lagos (2006), could be explained by the dependency between yield and other variables such as length and number of internodes in productive shoots (with fruit at each node), variables that themselves also showed large variation coefficients.

With regard to fruit size, 80% of the collection presented fruit larger than 20 mm, an outstanding size taking into account that the typical size for the Colombian ecotype is around 18.5 mm (Fischer *et al*., 2007). Around 64% of the collection had fruits that can be classified as round and 21% as flattened, according to the classification used by Bonilla *et al*. (2008).

Fig. 1 shows the accession 06Uch0049, which was characterized by having strong serosity, potentially associated with the absence of damage, as it was also observed in four additional accessions.

FIGURE 1. Accession 06Uch0049 characterized by strong serosity (presence of gland trichomes).

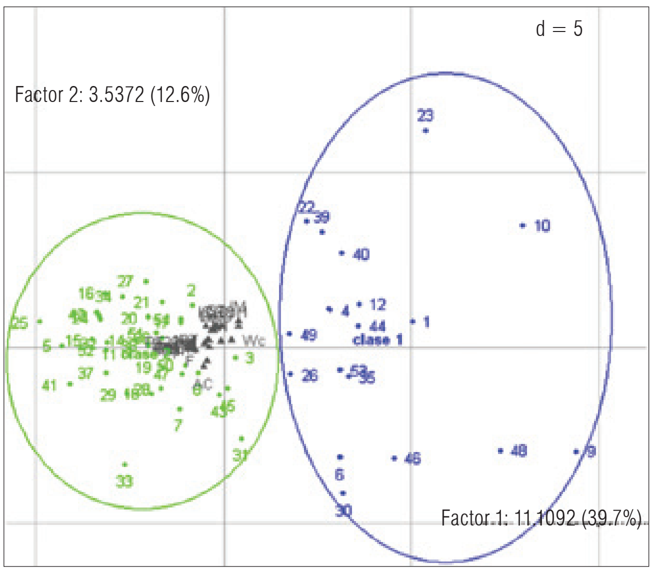

FIGURE 2. Biplot of the first two principal components obtained from 23 quantitative variables measured in 54 accessions of cape gooseberry.

Principal component analysis

The first four axes retained 70.19% of the total variance. The first component explained 39.79% of the total variance and the variables related to physical aspects of the fruit as weight, volume and diameter (FWC, FW, DWC, DW, V, EDC, and PDC) were the ones that positively contributed the most to this component, whereas the variables pH and maturity (MI) contributed negatively. The second component explained 12.63% of the total variance, with positive contributions from variables such as maturity, pH, total soluble solids content (TSS), fruit cracking (CF) and internode length in first order branches (IL1), and with negative contributions from variables such as acidity (TTA) and firmness (F). The third component accounted for 9.39% of the total variance and allowed us to distinguish materials

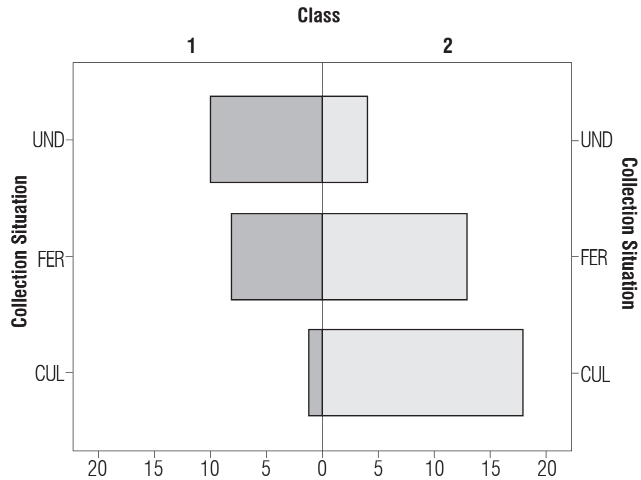

FIGURE 3. Segmented population histogram for classes according to the principal component analysis showing the collection status of the accessions. CUL: cultivated, FER: feral, UND: undetermined.

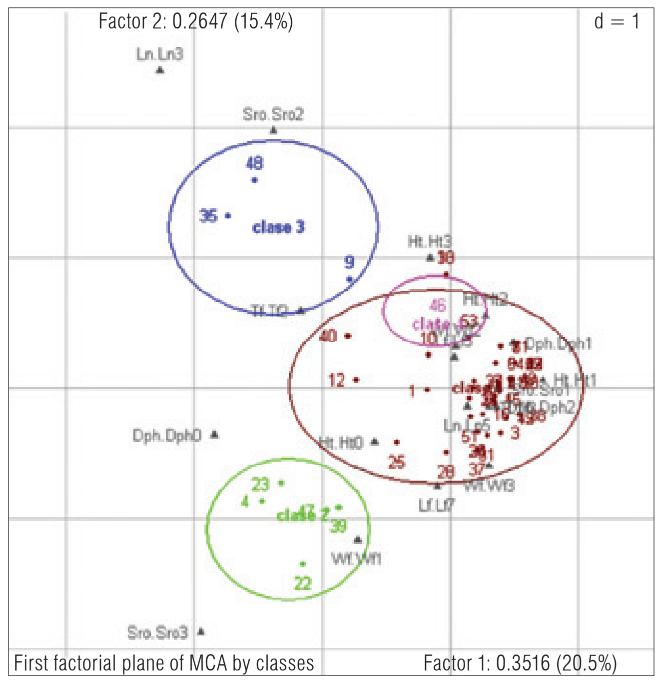

FIGURE 4. Biplot of the first two factorial axes and classification of the collection according to multiple correspondence analysis.

of poor performance that showed a small number of fruits per plant, fruits of light weight and elongated shape, and tall plants with long internodes in the branches. The fourth component retained 8.41% of the total variance and was associated with materials of high performance that showed a large number of fruits per plant and globosely shaped fruits. Tab. 2 shows in detail the contribution of each of the quantitative variables to the first four components.

According to the hierarchical classification analysis, the collection could be grouped into two classes. Class 1 grouped 33% of the accessions on the basis of the variables pH and MI, while class 2 grouped the rest of accessions based on the remaining quantitative variables (Fig. 2). Tab. 1 shows the class to which each accession belongs according to the PCA. With respect to the collection situation of each accession (feral, cultivated or undetermined), 64% of the undetermined materials were grouped into class 1, while 94.37% of the cultivated materials were grouped into class 2 (Fig. 3). Almost all the commercial materials, characterized by increased fruit weight with calyx (FWC) and increased fruit size (Si), were clustered into class 2. Interestingly, there is a difference of more than 1 g in the FWC between the two classes (Tab. 4). These results are in agreement with those reported by Ligarreto *et al.* (2005), where the fruit size was the second most discriminating variable, and with the studies of Bonilla *et al.* (2008) and Hejeile and Ibarra (2001), who found that quantitative variables related to the fruit (weight, size and TSS) had the highest contribution to the variability observed in *P. peruviana*.

Importantly, class 1 showed small values for the variables TSS, TTA, Si and FWC and was characterized by a higher degree of ripening and pH in the fruits. During ripening of fleshy fruits, changes in chemical composition, texture, and respiration rate are common (Kader, 1992). Among the most common changes observed during ripening in the cape gooseberry, Novoa *et al.* (2006) reported an increase in TSS and pH and a decrease in TTA. However in our case, the higher degree of ripening shown by class 1 had no apparent relation to the degree of fruit firmness (Herrera *et al.*, 2011), an indicator of the degree of maturity commonly used for the cape gooseberry (Ciro and Osorio, 2007). This suggests a differential behavior of the metabolic processes associated with maturation between feral/undetermined plant materials (predominant in class 1) and cultivated materials (predominant in class 2), given the low variation observed in the firmness variable for the whole collection (Herrera *et al.*, 2011) (Tab. 2).

Additionally, in tomato, a longer ripening time has been observed in fruits from wild materials compared to fruits from commercial crops, which could be explained by an apparent adaptive strategy consisting of a lower and prolonged respiration rate, allowing maintenance of the organoleptic properties (Pratta *et al.*, 2000). This could explain in part the behavior observed in class 1. In contrast, using the maturity index as an indicator of the flavor of the fruit (Rodriguez *et al.*, 2006), we can see that fruits from class 1 were less acidic due to a relatively lower concentration of TTA (and higher MI), but also slightly less sweet (low values of TSS), compared to fruits from class 2. This hightlights the presence of wild traits among class 1 plants (mostly feral and undetermined), particularly among those classified as undetermined (Fig. 3). Cape gooseberry fruits are originally characterized by a slightly acidic taste (bitter) (National Research Council, 1989).

TABLE 4. Cluster description of the quantitative variables.

Variable*	Class 1			Class 2			Overall mean
	V. test	Frequency	Mean in category	V. test	Frequency	Mean in category	
SLF	-2.73	18	32.35	2.73	36	36.92	35.4
TTA	-3.98	18	1.25	3.98	36	1.49	1.41
EDC	-5.95	18	25.33	5.95	36	30.26	28.62
PDC	-5.54	18	31.03	5.54	36	38.07	35.72
EDF	-5.93	18	19.43	5.93	36	21.5	20.81
PDF	-4.53	18	19.86	4.53	36	21.08	20.68
IL1	-2.17	18	9.37	2.17	36	10.42	10.07
F	-3.04	18	2.6	3.04	36	2.7	2.67
GP	-2.53	18	70.01	2.53	36	87.6	81.73
MI	3.18	18	12.65	-3.18	36	9.87	10.8
NNF	-2.11	18	11.63	2.11	36	12.75	12.38
FW	-6.13	18	4.74	6.13	36	6.05	5.62
FWC	-6.17	18	4.97	6.17	36	6.34	5.89
DWC	-5.89	18	0.88	5.89	36	1.16	1.06
DW	-5.7	18	0.74	5.7	36	0.96	0.89
pH	2.9	18	4.13	-2.9	36	3.96	4.01
Sh	-3.42	18	0.98	3.42	36	1.02	1.01
Si	-5.78	18	19.64	5.78	36	21.29	20.74
V	-6.16	18	4.43	6.16	36	5.79	5.34

*For abbreviations of variables see Tab. 2.

TABLE 5. Cluster description of the categorical variables.

Class	Category	V. test	p value	Class. mod. (%)	Class. mod. (%)	Global (%)
A	Weak or absent serosity	4.09	0.00002	95.45	93.33	81.48
	Large fruit size	3.05	0.00113	93.02	88.89	79.63
	Long internode length	2.71	0.00339	88.24	100.00	94.44
	Damage caused by *Phoma* sp. in third order branches	2.33	0.00986	100.00	44.44	37.04
	Situation of collection: cultivated	2.22	0.01328	100.00	42.22	35.19
B	Strong serosity	4.98	0.00000	100.00	100.00	9.26
	Absence of damage caused by *Phoma* sp.	3.78	0.00008	50.00	100.00	18.52
	Absent herbivory	2.21	0.01344	20.83	100.00	44.44
C	Medium internode length	3.94	0.00004	100.00	100.00	5.56
	Medium fruit size	2.48	0.00665	27.27	100.00	20.37
	Moderate serosity	2.05	0.02016	40.00	66.67	9.26
D	Presence of herbivory: *Copitarsia* sp. + *Epitrix* sp.	2.09	0.01852	100.00	100.00	1.85

Multiple Correspondence Analysis

The first three axes of the MCA retained 48.48% of total variation. The variables with the highest contribution to the first axis, which held 20.51% of the variability, were absence of damage caused by *Phoma* sp. (25.68%), strong serosity (14.26%) and medium fruit size (15-20 mm) (11.34%). For the second axis, which retained 15.44% of the variability, the variables with the highest contribution were medium length of internodes (5-7cm) (17.79%) and strong and moderate serosity (17.52% and 19.42%, respectively). The third axis retained 12.53% of the variability and was characterized by presence of damage caused by *Copitarsia* sp. and *Epitrix* sp. (15.51%), damage caused by *Phoma* sp. in the secondary and tertiary shoots (13.85%) and stem length below the first flower (>40 cm) (12.14%).

The hierarchical classification analysis grouped the accessions into four classes (Fig. 4), with around 83.33% of the accessions clustered in the first class (A), characterized by long internodes (>7 cm), absence of serosity, large fruit size (>20 mm) and presence of damage caused by *Phoma* sp. in the tertiary shoots (in 44% of the plant materials). The second class (B) was comprised of the accessions 06Uch0006, 06Uch0029, 06Uch0031, 06Uch0049 and 06Uch0059 (9.26%), which showed strong serosity and absence of damage caused by *Phoma* sp. Class C contained the accessions 06Uch0011, 06Uch0045 and 06Uch0061, defined by medium internode length, medium-sized fruits and moderate serosity. The accession 06Uch0057 was grouped independently in class D and showed severe damage caused by *Copitarsia* sp. and *Epitrix* sp. Tab. 1 shows the classification of each accession in classes according to the MCA, and the cluster description of the categorical variables can be seen in Tab. 5.

The results confirm the discriminating power of the weight and size of the fruit in the variability of the species as observed in class A, which grouped all the commercial materials (Fig. 5). Thus, it can be concluded that the variables related to the size and shape of the fruit were important in the hierarchical classification of the categorical and continuous variables, thus validating previous observations from germplasm evaluations carried out on *P. peruviana* (Hejeile and Ibarra, 2001; Ligarreto *et al*., 2005; Bonilla *et al*., 2008; Madriñan, 2010).

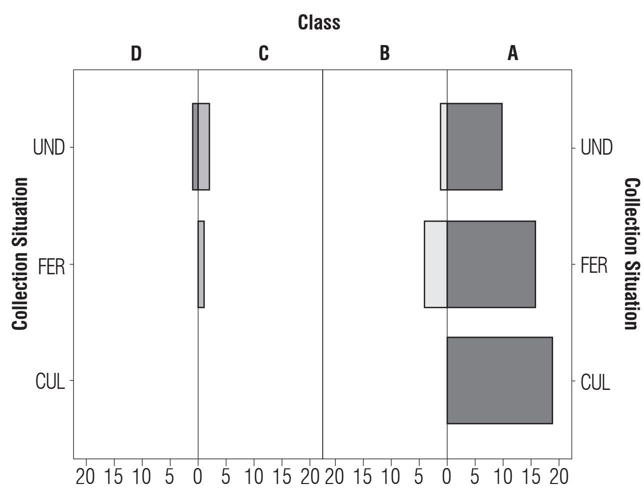

FIGURE 5. Segmented population histogram for classes according to the multiple correspondence analysis showing the collection status of the accessions. CUL: Cultivated, FER: feral, and UND: undetermined.

Bonilla *et al*. (2008) obtained similar results to those observed here, especially the contribution of serosity as a discriminating factor in the second component; a fact that is important because this variable is related to the sanitary state of the plant, as clearly observed in class B (absence of damage and strong serosity).

With regards to geographic origin, it seems there is not a clear clustering pattern, a result similar to what was found by Trillos *et al*. (2008) and Lagos (2006) for the central

Andean genetic group from the department of Nariño. The absence of geographic structuring might be a consequence of the high economical and commercial activity of the cape gooseberry in the Andean region and its wide dispersion in this part of the country.

Conclusions

In the principal component analysis, descriptors such as the total titratable acidity and the weight and size of the fruits were informative in the first two components, explaining 52.42% of the total variability of the collection and grouping the accessions into two classes. In the multiple correspondence analysis, the descriptor related to serosity was decisive in the classification of one category of materials, which also grouped together due to their lack of pest damage in the field; so further studies related to such prominent features in these accessions are recommended. In summary, the assessment of the collection by applying multivariate statistical tools facilitated the documentation and identification of variability between accessions, the grouping of accessions based on the set of evaluated descriptors and the establishment of a rich base of genetic resources characterized for this species, which will be useful in future breeding programs.

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