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REVIEW

Characterization of Sweet Pepper (*Capsicum chinense*) Collected in Venezuela

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ABSTRACT

In Venezuela the term sweet pepper is referred to the species *Capsicum chinense*, very important vegetable in Venezuelan gastronomy. The objective of this study was to characterize morphologically a collection of *Capsicum chinense*, composed by accessions collected in Venezuelan home gardens, supermarkets, wholesale markets, familiar retail markets, enterprises and agricultural research institutions. Seeds from twenty five accessions collected from seven out of twenty three states in Venezuela were planted in field under a random complete blocks design with four replications, and twenty two morphological traits (vegetative and reproductive traits, including plant, stem, leaf, flower, fruit and seed traits) proposed by IPGRI descriptor were evaluated on a total of 20 plants per accessions. The most discriminant traits were related to the fruit, especially weight, color, shape of the apex, width, and shape. Principal components and phenogram were able to group similarly the 25 accessions based on the 22 morphological traits. No relationship between the statistical grouping and the geographical collection site was found. Broad morphological diversity found, especially at fruit-associated traits allows to project a comprehensive using of *Capsicum chinense* genetic resources, and therefore to assume future successful *Capsicum chinense* breeding programs in Venezuela to get new cultivars adapted to Venezuelan agro climatic and market conditions.

Keywords: Descriptor ; Morphological Trait; Plant Breeding; Plant Genetic Resources

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1. Introduction

Genus Capsicum, which belongs to taxonomic family Solanaceae, was originated in America continent. Genus Capsicum comprises wild and domesticated species, this explains the broad variety of types of Capsicum adapted to several environments and to the cultural requirements in the societies where it is cultivated. It comprises about 33 species, 5 of them domesticated [1]: Capsicum annuum L. (1753), C. frutescens L. (1753), C. chinense Jackuin (1776), C. baccatum L. (1753) and C. pubescens Ruiz and Pavón (1799) . Archeologists and anthropologists have found in Perú and Bolivia evidence which indicates that genus Capsicum has been cultivated since about seven thousand years ago, which suggests that Capsicum genus is originated in South and Central America, where it has been cultivated before Christopher Columbus arrived to America [2,3]. Capsicum has been a source of taxonomic confusion since several centuries ago, and the basis of this confusion are related to parallel evolution of shape, size and color of the fruits in domesticated species [4,5]. This genus has been splited in two general groups according to flower color (white and purple). Domesticated species of genus Capsicum have these two flower colors, but C. baccatum has only white flowers, and C. pubescens has only purple flowers, not just the petals, also the anthers. Most of the taxonomic confusion is present in the species C. annuum, C. chinense and C. frutescens, the three species possess petals varying between white and greenish yellow, and anthers are purple. The morphological traits used to separate these three species are number of flower per node and the calix constriction [6].

Crops of the genus Capsicum cover annually about 1.5 million of hectares of the cultivated surface in the planet, generating about 24 million of tons (genus Capsicum produces fruits which together are considered among one of the seven most cultivated vegetables in the world), 32% is the surface cultivated in China, which together to Mexico, Spain and Nigeria are the main producers countries worldwide [7].

Among domesticated species of genus Capsicum, there are pungent species, or chilli pepper and non-pungent species or sweet pepper (in Spanish, unlike in English, referring to sweet pepper is not the same as referring to the species Capsicum annuum, in Spanish sweet pepper are forms of Capsicum genus, specially not pungent forms of C. chinense). Both types of Capsicum are used mainly as vegetable of fresh consumption or to elaborate stews, and demands of this vegetable is increasing. Additionally, fruits of Capsicum not only contribute to flavor and aroma in stews, they also are considered a source of vitamins A and C, essential oils and carotenoids, compounds for curative uses to pains, healing, digestion and circulation (clots prevention) in humans [8]. Pharmaceutical industry uses capsaicin to elaborate analgesic ointments [9]. Furthermore, given some restrictions in the manufacture of synthetic dyes, it exists a growing interest in species of Capsicum as source of natural dyes coming from their fruits which could be potentially used in pharmaceutical or textile industry. In some countries such as Venezuela, production of Capsicum chinense is very important because Venezuelan cuisine identity is defined by flavor and aroma conferred by a non-pungent chili [10,11].

Either to satisfy the culinary needs of countries where chili is grown, or to satisfy the growing needs of the pharmaceutical or textile industry, and due to low yields of the current cultivars, chilli genetic improvement is mandatory. Genetic improvement must be based on knowledge about plant genetic resources of the species [12]. To do that, the first step is to evaluate morphological diversity of the species. The objective of this research was to characterize morphologically chili pepper (Capsicum chinense) cultivated in Venezuela.

2. Materials and Methods

2.1. Plant Material

Fruits of chili pepper were collected from four major regions of Venezuela, some from farmer home gardens, some from markets (either supermarkets, or wholesale markets or familiar retail markets), some from institutions (public or private). The regions were Zulia (Zulia state), Center-Western (Lara state), East (Anzoategui, Nueva Esparta and Monagas states), and South (Bolivar state) (**Table 1**). The fruits were collected just considering evident differential traits at the fruits (within fruits collected in one location), in order to avoid to collect fruits from the same plant. Twenty five accessions were finally collected (**Table 1**), passport data were recorded for each one. From each accession, seeds were obtained, they were germinated in germination tray of 200 cells, ensuring to get 5 plantlets by accession.

Table 1. Accessions of sweetpepper (*Capsicum chinense*) collected in Venezuela.

ID of accession	Location	State	Collected from home garden or institution or market?
A1	San Pedro	Lara	Familiar retail market
A2	La Asunción	Nueva Esparta	Supermarket
A3	Maracay	Aragua	Institution (Instituto Nacional de Investigaciones Agrícolas)
A4	Maracaibo	Zulia	Supermarket
A5	Maracay	Aragua	Institution (Instituto Nacional de Investigaciones Agrícolas)
A6	Maracaibo	Zulia	Supermarket
A7	Barquisimeto	Lara	Wholesale market
A8	El Manzano	Lara	Enterprise (Semilleros Hortícolas Silverio Corpas)
A9	Maracaibo	Zulia	Supermarket
A10	Aragua de Barcelona	Anzoátegui	Retail market
A11	Porlamar	Nueva Esparta	Supermarket
A12	San Francisco de Bolívar	Bolívar	Homegarden
A13	San Francisco de Bolívar	Bolívar	Homegarden
A14	Maracaibo	Zulia	Retail familiar market
A15	Barquisimeto	Lara	Wholemarket
A16	Maracaibo	Zulia	Supermarket
A17	Barquisimeto	Lara	Wholemarket
A18	El Manzano	Lara	Enterprise (Semilleros Hortícolas Silverio Corpas)
A19	Caicara de Maturín	Monagas	Minor familiar market
A20	El Manzano	Lara	Enterprise (Semilleros Hortícolas Silverio Corpas)
A21	El Manzano	Lara	Enterprise (Semilleros Hortícolas Silverio Corpas)
A22	El Manzano	Lara	Enterprise (Semilleros Hortícolas Silverio Corpas)
A23	El Manzano	Lara	Enterprise (Semilleros Hortícolas Silverio Corpas)
A24	El Manzano	Lara	Enterprise (Semilleros Hortícolas Silverio Corpas)
A25	Barquisimeto	Lara	Wholemarket

2.2. Morphological Characterization

To achieve morphological characterization, plantlets were transplanted into a field of Sabana de Parra (Yaracuy state, center western of Venezuela) under an experimental design of complete random blocks with four replications. Treatments were represented by 5 plants of each accession, sown on a single row, separated by 0.35 m. Distance between rows was 0.85 m.

Twenty two morphological traits defined by descriptor of Capsicum of International Plant Genetic Resources Institute (IPGRI) [13] were evaluated on each of the 5 plants representing each replication of each accession (**Table 2**). Ten traits were related to vegetative step of the plant, and 12 traits were related to reproductive step, 10 of them related to the fruit. The quantitative value for each trait within each accession, was the average on the twenty plants. To get standardization of the measurement, some details were considered, such as for plant width was measured immediately after the first harvest, measuring the widest extent of the canopy. For mature leaf width, leaf shape and leaf pubescence data were recorded when ripening fruit began at the 50% of the plants within each accession, measuring 10 mature leaves from the main branches, for leaf width was considered the widest section of the leaves. Leaf shape was determined at intermediate leaves, leaf pubescence was determined in the youngest mature leaves. For ripe fruit, data were recorded on 10 fruits of the first harvest, fruit weight was determined as the average of 10 ripe fruits of the second harvest.

Table 2. Twenty two morphological traits evaluated on 25 accessions of Venezuelan *Capsicum chinense*, according to IPGRI (1995) descriptors.

Trait	ID of the trait	Measurement scale
Stem shape	SS	Cylindrical=1; Angular=2; Oblate=3
Stem Pubescence	SP	Sparce=3; Intermediate=5; Dense=7
Leaf color	LC	Yellow=1; Light green=2; Green=3; Dark green=4; light purple=5; purple=6; Variegated=7; Other=8
Plant width	PW	Centimeters
Leaf length	LL	Centimeters
Mature leaf width	MLW	Centimeters
Plant height	PH	<25 cm=1; 25–45 cm=2; 46–65cm=3; 66–85cm=4; >85cm=5
Leaf shape	LS	Deltoid=1; Oval=2; Lanceolate=3
Plant growth habit	PGH	Prostrate=3; Intermediate (compact)=5; Erect=7
Leaf pubescence	LP	Sparce=3; Intermediate=5; Dense=7
Number of flowers per leaf axil	NFLA	One=1; Two=2; Three=3; Many flowers in cluster=4; Other=5
Fruit shape	FS	Elongate=1; Almost round=2; Triangular=3; Bell-shaped=4; Bell-shaped and blocky=5; Other=6
Ripe fruit color	RFC	White=1; Lemon yellow=2; Pale orange yellow=3; Orange yellow=4; Pale orange=5; Orange=6; Light red=7; Red=8; Dark red=9; Purple=10; Brown=11; Black=12; Other=13
Shape of the fruit apex	SFA	Pointed=1; Blunt=2; Sunked=3; Sunked and pointed=4; Other=5
Shape of the fruit at the junction with the pedicel	SFP	Acute=1; Obtused=2; Truncated=3; Chordated=4; Lobed=5
Fruit length	FL	Centimeters
Fruit width	FWi	Centimeters
Fruit weight	FWe	Grams
Number of locules	NL	Number of locules more frequent on 10 fruits
Seed color	SC	Dark yellow (Straw)=1; Brown=2; Black=3; Other=4
Number of seeds per fruit	NSF	<20=1; 20–50=2; >50=3 (average on 10 fruits)
Seed size	SSi	Small=3; Intermediate=5; Big=7 (average on 10 seeds)

2.3. Statistical Analysis

Four statistical analyses were performed. The first one was just descriptive statistics, to describe each trait, mean, standard deviation, minimum and maximum value, and variation coefficient were calculated for each quantitative trait (PW, LW, MLW, FL, FWe, FWi, NL). Nominal qualitative traits (SS, LC, LS, PGH, FS, RFC, SFA, SFP, SC) were described as frequency distribution. Ordinal qualitative traits (SP, PH, LP, NFLA, NSF, SSi) were described by means of frequency distribution and calculation of median and mode. The second statistical analysis was performed to get the relationship among traits, to get that, Pearson correlation was achieved. The third statistical analysis tested hypothesis that traits for each accession had the same mean value, to do that variance analysis was performed and also Tukey mean test to know which averages were the same. For the traits in which no normality in the data distribution was identified, non-parametric test of Kruskal y Wallis was achieved. All the statistical analysis until here described were achieved with the software Statistix for Windows v. 8.0.

A fourth statistical analysis was achieved, to get the relationship among accessions based on the values of all traits for each accession at the same time. To achieve this, a principal component analysis was carried out, beginning by the obtaining of a matrix with the average values for each trait in each accession. This matrix was standardized within each variable by subtracting its average value and dividing it by the standard deviation. The correlations between variables were calculated on this matrix, obtaining a new variable. On the latter, the eigenvalues and eigenvectors were calculated, achieving an orthogonal projection of the eigenvectors in a two-dimensional and three-dimensional space. This analysis was achieved with the software NTSYS (numerical taxonomy system) v. 1.72.

3. Results

Table 3 displays how the eight quantitative traits are characterized across 25 *Capsicum chinense* accessions collected in Venezuela. Nominal qualitative traits are shown at the **Table 4**. Within vegetative traits, stem shape had the lowest variability, 96% of the plants evaluated had cylindrical shape, while in the other vegetative traits three of the categories defined were represented in the collection Within reproductive traits, seed color had the lowest variability, 100% of the plants resulted with seeds dark yellow (straw), while ripe fruit color resulted with broad variability, showing plants in six out of nine categories. For the other traits related to the fruit, also high variability was found: for fruit shape five out six categories were represented in the collection, for shape of the fruit apex all categories (5 out 5) were represented in the collection, and for shape of the fruit at the junction with the pedicel the collection had plants in four out five categories. Frequency, median and mode of the ordinal qualitative traits are showed in **Table 5**. Only plant width did not have variability across the accessions, for the other seven quantitative traits significant differences ($p < 0.05$) were detected. **Table 6** shows means for each of the quantitative traits evaluated on each of the 25 accessions, displaying results of the Tukey mean test ($p < 0.05$), this table displays creation of many categories for the four fruit traits evaluated, it means, more than for any other of the traits evaluated. This situation makes these fruit traits could be considered as the most discriminant within *Capsicum chinense* in Venezuela. **Table 7** shows correlation between pairs of traits, considering twenty traits. One hundred seven correlations resulted statistically significant ($p < 0.05$), highest values of correlation were found for fruit traits, correlated to fruit traits.

Table 3. Mean, variance and variation coefficient of the eight quantitative traits evaluated on 25 accessions of *Capsicum chinense* collected in Venezuela.

Trait	Mean	Variance	Variation coefficient	Minimum	Maximum
Plant width	81.605	348.61	22.88	18	125
Leaf length	9	4.919	24.642	2	15
Leaf width	5.1328	2.805	32.627	1	10
Plant height	2.4897	0.449	26.922	1	5
Fruit length	5.0833	1.322	22.622	2	8
Fruit width	9.8937	5.740	24.215	2	14.50
Fruit weight	8.1324	17.026	50.733	0.6	26.04
Number of locules	3.1374	0.400	18.749	2	5

Table 4. Frequency distribution of nominal qualitative traits evaluated on 25 *Capsicum chinense* accessions collected in Venezuela. For each trait the following is shown: median value, categories in bold (explained in **Table 2**), and number of plants presenting each category.

Trait	Median	Category frequency							
Stem shape	1	**1**	**2**	**3**					
		383	18	0					
Leaf shape	2	**1**	**2**	**3**					
		24	202	17					
Plant growth habit	5	**3**	**5**	**7**					
		59	149	45					
Leaf color	3	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
		0	26	226	19	0	0	0	0
Fruit shape	5	**1**	**2**	**3**	**4**	**5**	**6**		
		9	11	43	53	130	0		

Table 4. *Cont.*

Trait	Median	Category frequency								
Ripe fruit color	8	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
		0	29	0	16	0	32	22	144	3
Shape of the fruit apex	3	**1**	**2**	**3**	**4**	**5**				
		13	58	111	61	3				
Shape of the fruit at the junction with the pedicel	4	**1**	**2**	**3**	**4**	**5**				
		0	9	69	153	15				
Seed color	1	**1**	**2**	**3**	**4**	**5**				
		168	0	0	0	0				

Table 5. Frequency, median and mode of the five qualitative traits evaluated on 25 *Capsicum chinense* accessions collected in Venezuela.

Trait	Median	Mode	Frequency of each category (categories in bold)			
Number of flowers per leaf axil	1	1	**1**	**2**	**3**	**4**
			120	114	9	0
Leaf pubescence	1	3	**3**	**5**	**7**	
			243	0	0	
Stem pubescence	1	3	**3**	**5**	**7**	
			401	0	0	
Number of seeds per fruit	3	3	**1**	**2**	**3**	
			0	22	146	
Seed size	5	5	**3**	**5**	**7**	
			10	130	28	

Table 6. Mean test for quantitative traits measured on 25 accessions of *Capsicum chinense* collected in Venezuela.

Accession	Quantitative Traits							
	PW	LL	MLW	PH	FL	FWi	FWe	NL
A1	84,99 a	8,53ab	5,14abc	2,82 b	6,53c	9,39bcd	9,81cd	3,01bcd
A2	72,21 a	9,21ab	5,63bc	2,40 ab	4,46abc	10,13cd	6,65abcd	3,38cde
A3	90,31 a	10,63b	5,60bc	2,08 ab	4,33abc	9,99cd	6,05abcd	3,50cde
A4	66,87 a	9,28ab	5,50bc	2,75 b	4,91abc	8,55bcd	6,28abcd	2,94abcd
A5	91,93 a	9,76ab	5,88bc	2,78 b	3,89abc	8,87bcd	4,49abc	1,96ab
A6	84,00 a	8,63ab	4,44abc	2,27 ab	5,19abc	10,83cd	9,30bcd	3,31cde
A7	73,69 a	7,88ab	4,25abc	2,29 ab	5,28abc	11,38cd	9,23bcd	3,26cde
A8	85,92 a	10,25b	6,23bc	2,50 b	4,88abc	11,43cd	9,85cd	3,50cde
A9	88,42 a	9,79ab	6,17bc	3,00 ab	4,67abc	10,83cd	8,27abcd	3,79cde
A10	79,19 a	9,06ab	5,69bc	2,00 ab	4,50abc	8,27bc	5,74abcd	3,25cde
A11	75,31 a	8,19ab	5,00abc	2,30 ab	4,06abc	9,41bcd	5,43abcd	3,00bcd
A12	67,27 a	5,64 a	2,49 a	2,44 ab	5,06abc	3,11 a	1,21 a	1,93 a
A13	81,66 a	7,18ab	3,69ab	2,78 b	3,05 a	5,58ab	1,89ab	3,92cde
A14	85,92 a	7,68ab	4,07abc	2,00 ab	5,38abc	10,57cd	8,55abcd	3,75cde
A15	87,92 a	9,25ab	5,29abc	2,75 b	4,63abc	9,66bcd	7,64abcd	4,00de
A16	71,98 a	8,29ab	4,02abc	2,45 ab	5,50abc	10,41cd	8,87abcd	3,38cde
A17	75,68 a	8,06ab	4,58abc	2,44 ab	5,05abc	9,12bcd	7,33abcd	3,01bcd
A18	92,21 a	10,51b	6,64c	2,93 b	4,98abc	8,42bc	6,01abcd	3,00bcd
A19	79,54 a	8,84ab	4,93abc	2,50 b	6,19bc	11,98cd	13,04d	3,63cde
A20	78,69 a	9,24ab	5,22abc	2,50 ab	5,58abc	12,13cd	11,01cd	3,57cde
A21	63,92 a	7,58ab	4,10abc	2,50 ab	6,06bc	10,45cd	9,96cd	3,38cde

Table 6. *Cont.*

Accession	Quantitative Traits							
	PW	**LL**	**MLW**	**PH**	**FL**	**FWi**	**FWe**	**NL**
A22	72,59 a	7,90ab	4,29abc	2,50 ab	5,26abc	11,16cd	10,64cd	4,10e
A23	83,00 a	9,58ab	5,42bc	2,29 ab	3,61ab	9,66bcd	5,38abcd	2,93abc
A24	87,66 a	8,73ab	5,27abc	2,00 ab	5,86bc	12,62d	12,54d	2,98abcd
A25	79,13 a	8,58ab	5,08abc	1,80 a	6,19bc	10,95cd	11,15cd	2,96abcd
Mean	80,47	8,85	5,04	2,41	5,06	9,86	8,04	3,27
Coefficient of variation	16,32	17,69	20,14	26,12	17,48	13,54	32,20	10,31

PW=plant width, LL=leaf lenght, MLW=mature leaf widht, PH=plant height, FL=fruit length, FWi=fruit widht, Few=fruit weight, NL=number of locules. Means followed by the same letter within each column do not differ statistically ($p < 0.05$) according Tukey's mean test.

Table 7. Pearson correlation between traits evaluated on 25 *Capcisum chinense* accessions collected in Venezuela.

Traits	SS	LC	PW	LL	MLW	FS	RFC	SFA	SFP	PH	LS	NFLA	PGH	LP	FL	FWi	FWe	NL	NSF	SSi
SS	**1.00**																			
LC	**0.12**	**1.00**																		
PW	0.03	-0.03	**1.00**																	
LL	**0.11**	0.00	**0.33**	**1.00**																
MLW	**0.11**	-0.02	**0.33**	**0.91**	**1.00**															
FS	-0.01	-0.06	0.06	**0.28**	**0.19**	**1.00**														
RFC	**-0.26**	**-0.25**	-0.02	**-0.21**	**-0.29**	**-0.07**	**1.00**													
SFA	**0.12**	**0.14**	**0.11**	**0.36**	**0.38**	**0.58**	**-0.42**	**1.00**												
SFP	-0.06	0.00	0.07	**0.28**	**0.25**	**0.74**	**-0.21**	**0.56**	**1.00**											
PH	-0.05	0.00	**0.13**	**0.23**	**0.19**	**-0.13**	**0.18**	-0.07	**-0.15**	**1.00**										
LS	-0.06	0.04	0.01	**-0.37**	**-0.40**	**-0.25**	**0.22**	**-0.21**	**-0.22**	0.04	**1.00**									
NFLA	0.03	0.02	**0.20**	**0.12**	**0.14**	0.00	0.04	0.00	0.00	**0.16**	-0.01	**1.00**								
PGH	**0.12**	0.00	**-0.20**	-0.08	0.00	**-0.39**	**-0.10**	**-0.10**	**-0.32**	**0.29**	-0.04	0.08	**1.00**							
LP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**1.00**						
FL	-0.02	-0.05	0.04	**0.25**	**0.18**	**0.37**	**0.24**	**0.13**	**0.25**	**0.14**	0.03	**-0.13**	**-0.23**	0.00	**1.00**					
FWi	0.06	0.08	**0.13**	**0.51**	**0.45**	**0.74**	-0.06	**0.62**	**0.66**	0.00	**-0.35**	-0.05	**-0.37**	0.00	**0.56**	**1.00**				
FWe	0.00	0.05	0.07	**0.37**	**0.30**	**0.59**	**0.15**	**0.38**	**0.54**	**0.12**	**-0.17**	-0.06	**-0.32**	0.00	**0.79**	**0.86**	**1.00**			
NL	0.06	-0.04	0.00	**0.12**	**0.10**	**0.38**	**0.14**	**0.26**	**0.33**	0.01	**-0.24**	**0.23**	**-0.10**	0.00	-0.04	**0.33**	**0.32**	**1.00**		
NSF	0.04	**-0.11**	0.05	**0.17**	**0.47**	**0.47**	0.05	**0.25**	**0.40**	-0.01	**-0.26**	-0.03	**-0.33**	0.00	**0.12**	**0.51**	**0.41**	**0.32**	**1.00**	
SSi	-0.02	-0.03	**-0.17**	0.01	**0.15**	**0.15**	0.07	0.03	0.03	-0.09	**0.11**	**-0.16**	0.07	0.00	**0.18**	0.08	**0.13**	-0.03	**-0.22**	**1.00**

Figures 1 and 2 display the relationship among the 25 accessions of *C. chinense* collected in Venezuela, based on the 22 morphological traits. For the phenogram, comparison of the matrix of genetic similarities to the similarities represented in the phenogram, resulted in a cophenetic correlation coefficient of 0.91. When biplot from principal component analysis was built, 50% of the variation was explained with the two first axis (according to eigenvalues), and values of eigenvectors was obtained, which is showed in **Table 8**.

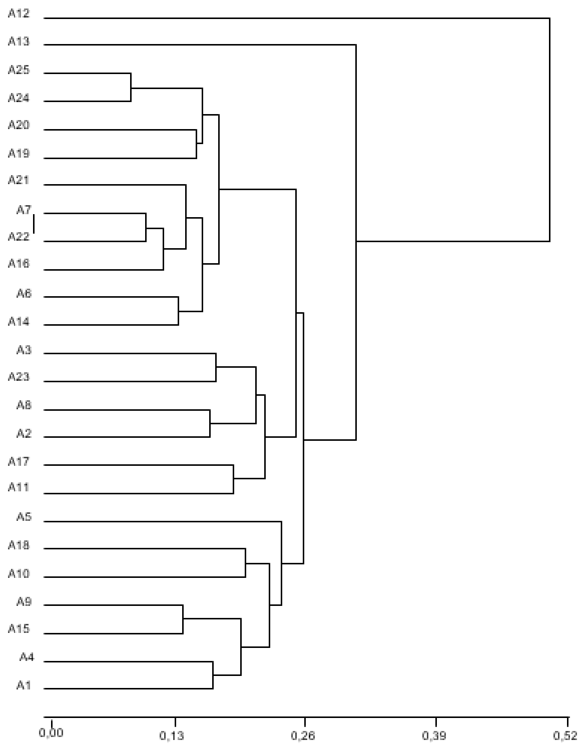

Figure 1. Phenogram representing relationship among 25 *C. chinense* accessions collected in Venezuela, based on 22 morphological traits, using UPGMA algorithm and Gower distance.

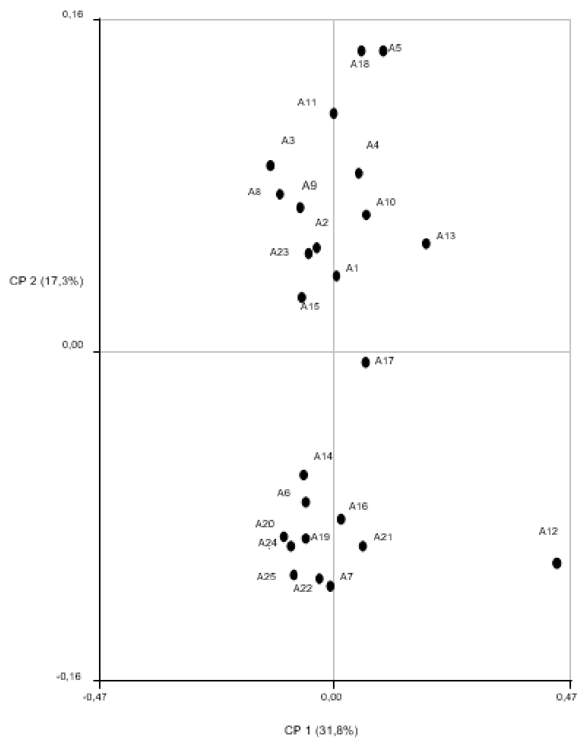

Figure 2. Biplot representing relationship among 25 *C. chinense* accessions collected in Venezuela, based on 22 morphological traits, using UPGMA algorithm and Gower distance.

Table 8. Autovectors values of the first two principal components when 25 accessions of *Capsicum chinense* collected in Venezuela were characterized with 22 morphological traits. Table shows just the 16 traits which had major contribution to the first two axis.

Traits	Principal Components	
	1	2
Stem shape	0.1150	0.2299
Leaf color	0.0854	–0.0409
Mature leaf width	0.5839	0.6828
Fruit shape	0.8938	–0.1938
Shape of the fruit apex	0.7963	0.0818
Shape of the fruit at pedicel junction	0.8911	–0.1996
Plant height	–0.1693	0.5295
Leaf shape	–0.5190	–0.5328
Number of flowers per leaf axil	0.0733	0.6176
Plant growth habit	–0.4771	0.4460
Fruit length	0.3307	–0.5683
Fruit width	0.9485	–0.1909
Fruit weight	0.7930	–0.4349
Number of locules	0.5783	–0.1365
Number of seeds per fruit	0.8388	0.0195
Seed size	–0.0661	–0.1464

4. Discussion

Data indicate that all traits had a variation coefficient lower than 51%, it indicates low diversity for these traits, in some way it indicates that changing these traits, improve them, would be a hard task. Traits number of locules, fruit length and plant width had the lowest variation coefficients, indicating they are not suitable to act as discriminant traits in the species *Capsicum chinense* in Venezuela.

Despite the low genetic variability displayed by most of the quantitative traits evaluated (all of them with variation coefficient under 51%), genetic variability level of a trait, does not indicate necessarily how useful the trait is, it depends on the species uses [14].

Other studies of genetic diversity in the species of genus *Capsicum* have reported results which differ of the present study. For instance, present study found 23% of the plants with a plant growth habit prostrate, but Martin and Gonzalez (1991) [15] found this plant growth habit in only 3.4% of the cases, when they characterized 59 accessions. Crop domestication has favored plant with growth habit erect because it get easy plant management and also application of product to control pest and diseases, furthermore for this growth habit plants are less exposed to soil-borne fungi. Additionally, erect plants will have more branches than prostrate plants, and it is positively correlated to yield [16]. Present study found that traits related to fruits, among the quantitative traits studied, presented the highest variability, it was found also by other studies characterizing species of genus *Capsicum* [17,18], especially in fruit color. Present study identified lemon yellow, orange yellow, orange, light red, red and dark red as color of ripe fruits, being red the most predominant color (68% of the accessions), having agreement to the study that reported fruit color as the most discriminant trait in Capsicum [17]. Predominance of red as fruit color in genus Capsicum characterization has already been reported [19]. Independent domestication could be the cause of the broad morphological diversity in fruits, but also is necessary to consider as one of the causes, the eventual cross pollination in spite C. chinense in predominantly a self-pollinated crop [20]. Median and mode of three of the five ordinal qualitative traits evaluated, were the same, it happened because most of the accessions were identified in just one category. Within these traits, only seed size had plants in all the proposed categories, it was the most variable. On the contrary leaf and stem pubescence were the less variable, plants evaluated were defined in just one category of each of these traits. Previous characterizations of Capsicum have identified more categories [15], however, authors remark most of the accessions had sparse pubescence at leaf and at stem, like present study. Plants evaluated were defined by just two categories in the trait number of flowers per axil , it means, it was just a little variable, it was found also by other characterization in *Capsicum chinense* [15], due to the little variation for this trait, these authors consider it could be a distinctive trait to discriminate species within genus Capsicum. The trait number of seeds per fruit define that accessions from Venezuela have a large number of seeds, it resulted different as compared to other studies in this species, which report a low number of seeds in fruits and they explain it as consequence of breeding, because large number of seed in a fruit decreases the quality of the products that are marketed from it [15], if it is so, without doubt this statement does not apply to the expected quality of Venezuelan *Capsicum chinense*.

Fruit traits showed high variability in the present study, and this is one of the most studied traits in other Capsicum characterizations, for instance one of these studies reported high variability in fruit length, but with predominance of intermediate length, almost 77% of de plant studied had this fruit length and just 19% showed long fruits [15]. Similarly fruit diameter had high variability, authors found that most of the plant studied had narrow fruits, just 7 plants had broad fruits [16,17,18]. Predominance of fruit traits in this kind of characterization for *C. chinense*, is related to the finding of Achal et al. (1986) [19] who state that fruit length was very related to the yield. Some authors have correlated number of locules to the number of seeds in the fruit [21], however, in the present study these trait were not correlated, in agreement to other study [22].

Figure 1 displays the relationship among the 25 accessions based on the 22 morphological traits evaluated, in form of phenogram, in a hierarchical structure, while **Figure 2** displays also this relationship but not in a hierarchical structure, but in a two-dimensional space. In general, both representations show similar relationships. If a line is drawn perpendicular to the X axis in **Figure 1**, approximately at the level of 0.25, the formation of five groups can be observed. From top to bottom, the first one is composed just by A12, the second one is composed just by A13, the third one is composed by two subgroups: the first one composed by A25, A24, A20 and A19, the second one by A21, A7, A22, A16, A6 and A14. The fourth one is composed by A3, A23, A8, A2, A17, A11, and the fifth one is composed by A5, A18, A10, A9, A15, A4 and A1. The third group comprises accessions with the highest values for fruit weight and fruit width, furthermore they presented a shape of the fruit apex sunked, their plants presented three categories for fruit shape: bell-shaped, bell-shaped and blocky, and triangular; shape of the fruit at the junction with the pedicel chordated, ripe fruit color red, light red and dark red. Within this group, the first subgroup was characterized by the highest weight (between 11 and 13 grams) and width (between 10 and 12 cm) while the second subgroup ranged between 8 and 10 grams for fruit weight and between 10 and 11 cm for fruit width. The fourth subgroup comprises accessions with ripe fruit colors different to red (orange, yellow orange, pale orange, lemon yellow), fruits with an intermediate weight, ranged from 5 to 9 grams, fruit shapes such as bell-shaped and bell-shaped and blocky; shapes of the fruit apex blunt, sunked and sunked and pointed, shape of the fruit at the junction with the pedicel truncated, chordated. The fifth group comprises accessions whose plants are characterized by the highest length and width of the leaves, one flower per leaf axil, fruits bell-shaped, also triangular, and shape of the fruit apex blunt and also sunked. A12 and A13 do not belong to any group which involve any other accession, they do not have similar categories enough to form some additional group, but they represent the only relationship between the **Figure 1** and the geographical origin: both come from Bolivar state, state which could be considered the state with less commercial exchange with other states in Venezuela. **Figure 2** shows two "clouds of points", one in the top part of the biplot, and one in the bottom part of the biplot, and two point which do not belong to any of these "clouds". It is in agreement to the **Figure 1**, the two points which do not belong to any cloud are the same point that **Figure 1** did not put in any cluster (A12 and A13). The upper cloud comprises the same accession than the fourth and fifth group of the phenogram, while the lower cloud comprises the same accessions than the third group in the phenogram.

Grouping of accessions have been achieved in other studies, one of them was achieved where the most important traits to get it were leaf length, leaf width, stem diameter, fruit weight and plant height [23], in other one the most discriminant traits were width of the fruit wall, capsaicin content and vitamin C content in the fruit [24].

Association between genetic similarity and geographic distance among accessions is not always clear [25], in the case of *Capsicum chinense* collected in Venezuela this could be explained because of farmers cultivate several accessions in the same field, and, in spite *Capsicum sp.* is predominantly self-pollinated, large percentage of cross pollination is reported [26]. Additionally, in present study most of the accessions were collected from markets (familiar retail markets, wholesalemarket, supermarket), therefore there is not sure that collection site is the geographical site where the accession was collected. Furthermore, chilli cultivation in Venezuela, traditionally, uses seeds harvested by farmers, and they exchange them, so, it is possible that seeds from one accession are cultivated in different parts of the country.

Most discriminant traits to get the grouping of accessions according their values for the 22 traits evaluated, are seen at **Table 8**. At axis 1 in biplot shown in **Figure 2** the eigenvectors with highest values were three traits associated to the fruit: fruit width, fruit shape and shape of the fruit at junction with the pedicel, and at axis 2 are mature leaf width and number of flower per leaf axil. At **Figure 1**, there are no evident difference between both point clouds at axis 1, but there is for axis 2, it means, most discriminant traits between both points clouds are mature leaf width and number of flower per leaf axil.

5. Conclusions

Broad morphological diversity within a *Capsicum chinense* collection from Venezuela was found, especially at fruit-associated traits. These findings and extensive gastronomic tradition around this crop in the country, allows assuming successful genetic improvement programs for *Capsicum chinense* in the future in Venezuela.

Author Contributions

Conceptualization, H.L. and R.J.; methodology, H.L.; software, H.L.; validation, R.J., and H.L.; formal analysis, R.J and H.L..; investigation, R.J.; writing—original draft preparation, H.L.; writing—review and editing, H.L. and R.J.; supervision, H.L.; project administration, R.J.; funding acquisition, R.J. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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