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Evaluation of production and quality traits in interspecific hybrids of ornamental pepper

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ABSTRACT

The cultivation of potted peppers as ornamental plants has increased considerably throughout the planet. In Brazil, this crop is more recent and still lacks cultivars. In order to increase the available variability and obtain new cultivars, the interspecific hybridization is very useful in add a desirable attribute that occurs in one species to another species, resulting in a new cultivar of agronomic interest. The objective of this study was to characterize parents and interspecific hybrids based on 27 quantitative traits and evaluate their genetic diversity by multivariate procedures. Parents of seven pepper genotypes were crossed, and, seven hybrids were generated. The experiment was conducted in a completely randomized design. Data were subjected to analysis of variance, and means were subsequently grouped by Scott-Knott's method. Tocher's method was utilized based on Mahalanobis distance, and the relative importance was evaluated by Singh's method. The effects of treatment were significant by F test at 1 and 5% probability for all studied traits, except for anther length and titratable acidity. According to Scott-Knott's test, the genotypes were grouped into two to eight classes. By Tocher's method, the genotypes were separated into four groups. The first three canonical variables explained 92.02% of the total variance. By Singh method, fruit yield per plant was the trait that most contributed to the divergence explaining 21% of the total variance. The studied parents and hybrids diverged for the evaluated traits; however, there was difficulty in obtaining good interspecific hybrids with traits of importance, wherein combinations HS1×L7, L2×L6, and HS1×L2 met these requirements.

Keywords: *Capsicum* spp., hybridization, relative importance, breeding, characterization.

RESUMO

Avaliação da produção e caracteres de qualidade em híbridos interespecíficos de pimenteiras ornamentais

O cultivo de pimentas em vaso como planta ornamental tem aumentado consideravelmente em todo o planeta. No Brasil, esse cultivo é mais recente e ainda carece de cultivares. Para ampliar a variabilidade disponível e obter novas cultivares, a hibridação interespecífica é muito útil como forma de inserir um atributo desejável que ocorre em uma espécie para outra espécie resultando em uma nova cultivar de interesse agronômico. O objetivo deste foi caracterizar parentais e híbridos interespecíficos baseados em 27 caracteres quantitativos e avaliar a diversidade genética dos mesmos por meio de procedimentos multivariados. Sete genótipos de pimenta foram utilizados como genitores, gerando sete híbridos. O experimento foi conduzido em delineamento inteiramente casualizado. Os dados foram submetidos à análise de variância, com posterior agrupamento das médias pelo método de Scott-Knott. O método de Tocher foi utilizado com base na distânciade Mahalanobis e a importância relativa foi avaliada por meio do método de Singh. Os efeitos de tratamento foram significativos, pelo teste F a 1 e 5% de probabilidade para todas as características estudadas, exceto para comprimento da antera e acidez titulável. De acordo com teste de Scott & Knott, os genótipos foram agrupados entre duas a oito classes. Pelo método de Tocher, os genótipos foram separados em quatro grupos. As três primeiras variáveis canônicas explicaram 92,02% da variância total. Pelo método de Singh (1981), o número de frutos por planta foi a característica que mais contribuiu para a divergência explicando 21% da variância total. Os parentais e híbridos estudados foram divergentes, para os caracteres avaliados, entretanto houve dificuldade na obtenção de bons híbridos interespecíficos quanto a caracteres de importância, tendo as combinações HS1xL7, L2xL6 e HS1xL2 atendido tais requisitos.

Palavras-chave: *Capsicum* spp., hibridação, importância relativa, melhoramento, caracterização.

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The cultivation of peppers as an ornamental potted plant has increased considerably throughout the planet. In Brazil the internal and external commercialization of ornamental peppers can be considered an important alternative source of income for the agricultural populations (Rêgo & Rêgo, 2016). Small farmers have been the main responsible for the expansion of cultivated area with peppers in several Brazilian states (Ferrão *et al.*, 2011; Rêgo & Rêgo, 2016).

The challenge is to select cultivars with high aesthetic value, good production, protect against abiotic and biotic stresses, earliness, uniformity, and improve the quality of the fruit (Rêgo *et al.*, 2011; Rêgo & Rêgo, 2016).

The current trend in genetic breeding emphasizes the need to identify, transfer, and preserve new sources of genetic variation (Neitzke *et al*., 2016). Thus, the genetic research on morpho-agronomic traits should be better acknowledged, aiming to evaluate the genetic potential of parents to produce better offspring and increase the efficiency of breeding methods (Pessoa *et al.*, 2018).

Studies of variability in ornamentals are based on characteristics of size, flower and fruit, through multivariate analysis (Barroso *et al.*, 2012; Silva Neto *et al.*, 2014; Neitzke *et al.*, 2016; Costa *et al.*, 2016; Pessoa *et al*., 2018; Lima *et al.*, 2019). To estimate genetic divergence, some methodologies are used, such as multivariate analysis (Cruz *et al*., 2011). These techniques enable the breeder to evaluate genetic material with a set of characteristics that combine the multiple information contained in the experimental unit (Alvares *et al*., 2012).

The existing genetic diversity in a population helps to select genetically dissimilar parents, i.e., parents with differences in allelic frequencies, which, when crossed, will be the most convenient to produce progeny and obtain greater genetic variability in segregating generations (Nascimento *et al.*, 2012a). Interspecific hybridization is very useful in the cultivation of plants as a way to add a desirable attribute that occurs in a wild or cultivated plant to another cultivated species, resulting a new cultivar of agronomic interest (Nascimento *et al*., 2012a). Yet, few records exist on the use of interspecific hybridization in breeding programs for *Capsicum*, probably because of the low viability of the obtained hybrid seeds (Rêgo *et al*., 2012).

It is then necessary to standardize ideotypes of plants with desirable traits in order to target the needs of a growing market. In Brazil this market is going through big changes, with an increasing use of new types of pepper, including those for ornamental interest (Rêgo & Rêgo, 2016; França *et al.*, 2018).

The objective of this study was to characterize morphologically parents and interspecific hybrids belonging to the *Capsicum* germplasm bank of Universidade Federal da Paraíba based on 27 quantitative traits of plantlet, plant, inflorescence, and fruit quality, and to evaluate their genetic diversity through multivariate procedures.

MATERIAL AND METHODS

This study was conducted in a greenhouse at the Plant Biotechnology Laboratory of the Center for Agricultural Sciences at Universidade Federal da Paraíba, in Areia-PB, Brazil, in the Brejo Paraibano, Microregion (6°58'S, 35°42'W, 574 m altitude). According to the bioclimatic classification of Gaussem, the predominant bioclimate in the area is the 3rd sub-dry Northeast, with annual average rainfall around 1,400 mm. By Köppen's classification, the climate is As type, characterized as hot and humid, with autumn-winter rains. The average annual temperature ranges from 23 to 24ºC.

Crossings and evaluation of parents and hybrids of ornamental peppers were performed in that facility. The Universidade Federal da Paraíba has been developing, together with Universidade Federal de Viçosa, a breeding program for ornamental peppers aiming to select pepper lines and promote intra- and interspecific hybridization among the selected lines for a subsequent release to family farmers in Paraíba State (Brazil).

Seven pepper accessions belonging to the germplasm bank of CCA-UFPB were utilized as parents: *Capsicum annuum* (a simple hybrid (HS1) and three lineages L1, L4 and L5), *C. chinense* lineage (L2), *C. baccatum* lineage (L6), and *C. frutescens* lineage (L7). The parents were crossed with each other aiming to obtain all possible combinations (Tables 1 and 2); however, because of the incompatibility for some crosses (Nascimento *et al*., 2012a), only seven hybrids were generated (HS1×L2, HS1×L7, L1×L7, L2×L5, L2×L6, L6×L4, and L6×L7). There was no compatibility for the reciprocal crosses L2xHS1, L7xHS1, L7xL1, L5×L2, L6×L2, L4×L6, and L7×L6.

Crossings were performed manually in emasculated flower buds before the anthesis. Immediately after emasculation, flowers were pollinated by transferring pollen from a plant to the stigma of the recipient flower. After pollination, the flower was covered with aluminum foil to prevent contamination, and labeled (Nascimento *et al*., 2012a; Rêgo *et al*., 2012). Mature fruits were collected, one to two months after pollination, according to the species crossed.

Two seeds of each parent and each progeny were seeded in 200-cell styrofoam trays containing commercial substrate. When the plants reached the stage of three pairs of mature leaves, they were transplanted to 900 mL pots, one plant per pot. Whenever necessary, the cultivation practices recommended for the culture were applied.

Morpho-agronomic characterization of the hybrids, regarding seedling, plant, inflorescence, and fruit traits of *Capsicum* spp. was based on the list of quantitative descriptors suggested by IPGRI (1995).

For this purpose, 27 descriptors were utilized. The evaluated traits (in cm) were: cotyledonary leaf length, cotyledonary leaf width, plant height, canopy width, height at the first bifurcation, stem width, leaf length, leaf width, corolla length, anther length, filament length, fruit length, fruit diameter, peduncle length, pericarp thickness, placenta length; (in g): fruit fresh matter, dry matter content, seed yield per fruit, fruit yield per plant, fruit weight, yield (g/plant), days to flowering, days to fructification, total soluble solids (%), titratable acidity (%), and vitamin C content (%). To obtain the dimension data, measurements were made using a pachymeter. Weight traits were taken in a scale. Quantitative values as number of locules and seeds per fruit were obtained by counting.

The experiment was analyzed in a completely randomized design, in which analyses of the parents and hybrids resulted from three replicates. There were 14 treatments, 3 replicates, and 3 plants per replicate. Data were subjected to analysis of variance with subsequent clustering of means by Scott-Knott's method at 5% probability.

Tocher's method and canonical variable analyses were used for

Table 1. Phenotypic description of the hybrids and lineages used in this study. Areia, UFPB, 2015.

Genotype	Species	Characterístics				
		LC	CC	PF	CIF	CRF
HS1	*C. annuum*	Dark green	White with purple margin	Erect	Black	Red
L1	*C. annuum*	Light green	White	Erect	Orange	Red
L2	*C. chinense*	variegated	White	Pendant	Black	Dark red
L4	*C. annuum*	Dark green	White	Erect	Yellow	Orange
L5	*C. annuum*	Green	White	Erect	Light brown	Orange
L6	*C. baccatum*	Light green	White	Erect	Black	Red
L7	*C. frutescens*	Green	White	Erect	Light brown	Red

LC= leaf color; CC= corolla color; PF= position of the fruit; CIF= color of the intermediate fruit; CRF= color of ripe fruit.

the analysis of genetic diversity. In the clustering analysis, generalized Mahalanobis distance was used as a measure of genetic dissimilarity and in the formation of groups. In addition, the relative importance of the evaluated traits was calculated by Singh's method (1981).

All analyses were performed using the Genes computer software (Cruz, 2013).

RESULTS AND DISCUSSION

There was significant difference between mean values of the accessions at 1 and 5% probability by F test for all studied traits, except for anther length and titratable acidity. The significant differences observed among the analyzed parents and hybrids confirm the existence of genetic variability among them. An important result is the selection of genotypes that can maximize genetic gain (Pessoa *et al.*, 2018).

The coefficients of variation of the experiment ranged from 1.82 (days to flowering) to 25.37% (peduncle length), which were satisfactory values, as significant differences were detected between evaluated parents and interspecific hybrids. Silva *et al.* (2011) stated that the classification of the coefficients of variation into morpho-agronomic traits of peppers of the genus *Capsicum* depends on the genotype and trait under study.

From the mean-clustering analysis by Scott-Knott's test at 5% probability, variability was detected between parents and interspecific hybrids for all analyzed traits, except anther length (0.28 cm) and titratable acidity (0.82 cm) (Table 3).

Higher variability was observed for height of the first bifurcation, which formed eight classes (Table 3), according to Scott Knott's criteria at 5% probability, with means varying between 2.5 and 52.66 cm. The lineage L1 showed the highest mean, and hybrid L6×L4 obtained the lowest; the latter was most suitable for ornamental purposes, because higher bifurcations increase the plant size, which is undesirable for plants grown in a pot (Rêgo *et al.*, 2009).

Four classes were formed for cotyledonary leaf length, plant height, canopy width, and stem width, all plant-size related. These traits are important for the cultivation of ornamental plants in a pot (Figure 1), because plant height and canopy width must be 1.5 to 2 times greater than the pot diameter, and this ratio is important in forming a harmonic set (Barroso *et al.*, 2012). Therefore, only parent L4 and hybrid HS1×L7 met this criterion, with average heights of 15.33 cm and 25.33 cm, respectively, and 14 cm and 24.33 cm average diameters (Table 3).

The selection of smaller-sized plants is one of the main objectives in the breeding of ornamental peppers, besides the selection of plants with a greater stem width which is of paramount importance to prevent the plant from lodging in the pot. The greatest stem width was shown by hybrids HS1×L2 (1.05 cm), L6×L4 (1.02 cm), and L6×L7 (1.63 cm), which made them the hybrids of interest for this trait.

Traits referring to leaves also showed variability (Table 3). Two classes were formed for cotyledonary leaf width, whose mean values varied

Table 2. Beared fruits (%) and number of fruits per interspecific cross in *Capsicum* spp. Areia, UFPB, 2014.

Hybrids	Species	Formed fruits (%)	Seeds/ fruit	Germination (%)
L4 x L1*	*C. annum x C. annum*	100	42	80
HS1×L2	*C. annuum x C. chinense*	10	23	100
HS1×L7	*C. annuum xC. frutescens*	30	27	50
L1×L7	*C. annuum xC. frutescens*	25	20	30
L2×L5	*C. chinense x C. annuum*	29	16	30
L2×L6	*C. chinense x C. baccatum*	50	19	80
L6×L4	*C. baccatum x C. annuum*	50	26	30
L6×L7	*C. baccatum xC. frutescens*	20	25	30

*Intraspecific hybrids used as control (the incompatibility was not due to the crosses, but the species used in them).

Table 3. Mean values for parents and interspecific hybrids referring to traits in peppers. Areia, UFPB, 2015.

Genotypes	CLL	CLW	PH	CW	HFB	SD	LL	LW	CL	FIL	FW	FL	FD
HS1	0.85d	0.28b	37.66d	28.68b	13.90f	0.50d	9.98b	2.76d	1.52a	0.57c	0.81c	1.92b	0.55d
L1	1.72b	0.57a	37.66d	25.66b	12.66f	0.49d	4.80c	1.83e	1.36b	0.55c	0.52c	1.14d	0.85c
L2	1.27c	0.59a	58.66c	33.00b	52.66a	0.60d	9.18b	7.37a	1.22c	0.53c	1.61a	2.62a	1.04b
L4	1.77b	0.69a	15.33d	14.00d	10.66f	0.48d	4.57c	2.23e	1.56a	0.70b	1.32b	2.47a	0.98b
L5	1.28c	0.53a	29.00d	19.66d	10.00f	0.55d	6.00c	2.66d	1.60a	0.60c	1.18b	2.18b	0.94b
L6	1.01d	0.65a	19.66d	23.33c	15.66e	0.44d	9.24b	7.23a	1.38b	0.47d	0.52c	1.95b	0.92b
L7	1.27c	0.48b	25.00d	17.66d	20.33e	0.46d	6.33c	2.66d	1.54a	0.60c	0.34c	2.10b	1.09b
HS1×L2	1.24c	0.70a	77.00b	47.33b	27.00d	1.05b	14.66a	6.57b	1.42b	0.58c	0.56c	1.29d	1.00b
HS1×L7	1.14c	0.38a	25.33d	24.33c	11.66f	0.79c	5.56c	1.83e	1.62a	0.78a	1.26b	2.56a	0.98b
L1×L7	1.12c	0.42b	31.66d	24.33c	16.66e	0.74c	5.13c	2.30e	1.20c	0.57c	0.53c	1.63c	0.82c
L2×L5	1.24c	0.62b	74.66b	51.53b	32.96c	0.58d	8.00c	4.63c	1.42b	0.64c	1.46a	1.48c	1.42a
L2×L6	1.81b	0.69a	65.33c	42.66b	46.00b	0.82c	10.86b	5.50c	1.74a	0.53c	1.67a	1.53c	1.45a
L6×L4	1.84b	0.59a	94.33a	95.00a	2.50h	1.02b	10.70b	2.96d	1.56a	0.36e	0.91c	1.69c	1.12b
L6×L7	2.06a	0.47b	101.33a	56.00b	7.50g	1.63a	12.66a	5.06c	1.16c	0.36e	0.68c	1.92b	0.79c
DP	0.37	0.14	28.85	21.47	14.49	0.32	3.23	2.01	0.09	0.11	0.47	0.47	0.24

	PL	PT	PLL	FFM	DMC	SYF	FYP	Y	DFL	DFR	VITC	TSS
HS1	2.67a	0.14c	0.52b	0.58c	14.00c	19.66d	20.00c	16.38d	65.00b	89.00e	94.83b	7.26c
L1	1.63c	0.13c	0.67b	0.34d	21.06c	42.33b	20.00c	10.44d	55.66c	85.00f	109.69b	6.66c
L2	2.39a	0.12c	1.38a	0.38d	35.95a	10.00e	16.00d	25.61c	65.33b	125.33a	115.01b	6.50c
L4	2.27a	0.18c	1.22a	0.83b	29.38b	51.00a	20.00c	26.51c	63.00b	92.00d	144.46a	7.50c
L5	2.02b	0.12c	0.91a	0.97b	18.56c	32.00c	20.00c	23.65c	63.00b	96.00c	153.04a	7.00c
L6	2.03b	0.11c	1.07a	0.27d	29.01b	9.66e	11.66d	6.09d	76.00a	124.00a	132.79b	6.33c
L7	1.21d	0.09c	1.29a	0.24d	41.12a	13.33d	20.66c	7.15d	62.33b	124.66a	110.86b	6.83c
HS1×L2	2.07b	0.15c	0.44b	0.51c	22.84c	7.33e	18.33c	10.16d	62.33b	122.33b	181.12a	6.73c
HS1×L7	2.48a	0.15c	1.16a	0.76c	26.87b	55.33a	25.00b	31.51b	65.00b	125.00a	108.82b	9.50b
L1×L7	2.20a	0.16c	0.92a	0.40d	20.00c	35.33c	26.33b	14.18d	62.33b	119.00b	122.22b	6.86c
L2×L5	2.51a	0.23b	0.64b	1.42a	19.69c	4.33e	28.33b	41.62b	67.00b	127.00a	167.20a	11.00a
L2×L6	1.94b	0.22b	0.48b	1.56a	18.73c	3.66e	24.66b	41.21b	59.66c	119.66b	155.45a	12.66a
L6×L4	2.09b	0.30a	0.90a	0.89b	26.67b	1.66e	56.33a	51.60a	65.00b	126.33a	109.82b	7.03c
L6×L7	2.72a	0.16c	1.01a	0.54c	24.20c	9.33e	54.66a	37.31b	68.00b	122.33b	115.01b	9.30b
DP	0.43	0.06	0.35	0.42	8.05	18.45	13.11	14.90	8.99	15.52	28.54	2.26

Cotyledonary leaf length (CLL, cm), cotyledonary leaf width (CLW, cm), plant height (PH, cm), canopy width (CW, cm), height at the first bifurcation (HFB, cm), stem width (SD, cm), leaf length (LL, cm), leaf width (LW, cm), corolla length (CL, cm), filament length (FIL, cm), fruit weight (FW, cm), fruit length (FL, cm), fruit diameter (FD, cm), Peduncle length (PL, cm), pericarp thickness (PT, cm), placenta length (PLL, cm), fruit fresh matter (FFM, g), dry matter content (DMC, g), seed yield per fruit (SYF), fruit yield per plant (FYP, g), yield (Y, g/plant), days to flowering (DFL), days to fructification (DFR), vitamin C (VITC, %) and total soluble solids (TSS, %). Equal letters in columns do not differ statistically, Scott-Knott test, 5% probability.

from 0.28 to 0.70 cm in hybrids HS1 and HS1×L2, respectively. The latter would be the hybrid of interest, since genotypes with faster initial development can be transplanted to pots in less time, a highly desirable property, because it may provide time and costs reduction to form seedlings (Barroso *et al*., 2012).

For length and width of the adult leaves, however, three and five classes were formed, respectively. Plants with shorter leaves have great potential in breeding programs of ornamental peppers (Nascimento *et al*., 2012b, Rêgo & Rêgo, 2016; Pessoa *et al*., 2018), as well as greater facility to adapt to pots, being more attractive to the consumers. Thus, hybrid L1×L7 should be selected, since its length was 5.13 cm and width was 2.30 cm.

Three and five classes were formed for the flower-related traits corolla length and filament length, respectively. The mean values for corolla length varied from 1.16 cm, in hybrid L6×L7, to 1.74 cm, in hybrid L2×L6 (Table 3), which was the hybrid of interest, because larger flowers give beauty to the plant, since more attractive and pleasant to consumers, the higher are the chances of it being purchased (Santos *et al*., 2013).

Regarding the response shown by the filament, the mean values varied between 0.78, in hybrid HS1×L7, and 0.36, observed in hybrids L6×L4 and

L6×L7 (Table 3); the latter were those of interest when aiming to have a reduction in filament length. A shorter filament would help in the successful fixation of the crossings, as well as in reducing contact with it at the moment of the crossing, which is of extreme importance, because any contact beyond necessary with the filament results in a deformed fruit, with consequent reduction in seed yield.

Variability was also observed for the morpho-agronomic traits analyzed in the fruits. Recently, ornamental peppers have had a double purpose, i.e., in addition to their use in the decoration indoors and in gardens, their fruit can and should be consumed or used in the making of teas or spices (Finger *et al*., 2012). Three classes also were formed for fruit weight, whose mean values varied from 0.34 to 1.67 g. Line L7 was the lightest, and hybrid L2×L6, the heaviest. Analyzing fruit length, four classes were formed, wherein genotype L1 had fruits with the smallest length (1.14 cm), and L2 had the largest ones (2.62 cm). For fruit diameter, means varied between 0.55 cm (HS1) and 1.67 cm (L2×L6) (Figure 2).

Table 4. Grouping of parents and interspecific hybrids according to Tocher's method. Areia, UFPB, 2015.

Group	Genotype
1	L4, L5, HS1, L1×L7, HS1×L7, L1, L7, L6×L7, L2×L5
2	L2, L2×L6, L6
3	HS1×L2
4	L6×L4

Table 5. Relative contribution of 27 quantitative traits to diversity between parents and interspecific hybrids of *Capsicum* spp., by Singh method (1981). Areia, UFPB, 2015.

Trait	Relative contribution (%)
Fruit yield per plant	20.78
Leaf width	18.12
Yield	12.69
Days to fructification	9.06
Fruit fresh matter	6.62
Leaf length	6.35
Fruit length	4.35
Seed yield per fruit	4.12
Fruit diameter	2.46
Pericarp thickness	2.13
Fruit weight	1.78
Days to flowering	1.76
Plant height	1.48
Vitamin C	1.41
Cotyledonary leaf width	1.30
Stem width	1.19
Peduncle length	0.97
Filament length	0.80
Canopy width	0.79
Placenta length	0.45
Corolla length	0.32
Titratable acidity	0.27
Dry matter content	0.27
Anther length	0.16
Total soluble solids	0.11
Height at the first bifurcation	0.11
Cotyledonary leaf length	0.01

The dimensions of ornamental pepper fruits should be smaller so that there is balance with the plant architecture. These traits are correlated negatively with fruit yield per plant. It is noteworthy that the average fruit weight can be changed according to the fruit yield per plant (Rêgo *et al*., 2011). Two hybrids obtained the lowest values for fruit weight, length, and diameter, L1×L7 and HS1×L2, so they should be selected for ornamental purposes.

The peduncle length formed three classes, with mean values varying between 1.21 and 2.72 cm, which corresponded to genotypes L7 and L6×L7, respectively. For ornamental purposes, it is interesting to select fruits with longer peduncles so that they are prominent on the leaf, and facilitate harvesting.

Three classes were formed for pericarp thickness, whose mean values were 0.09 cm, corresponding to parent L7, and 0.30 cm, corresponding to hybrid L6×L4, which was the one of interest, given that selection of peppers with thicker pericarp is positively correlated with increased production (Rêgo *et al*., 2011); moreover, fruits with thicker walls are more resistant to damage during transportation.

A lower variability was observed for the placenta length trait, wherein only two classes were formed, which varied between 0.44 cm (HS1×L2) and 1.38 cm (L2). It is important to quantify the placenta length, as this is where the greatest amounts of capsaicinoids are found (Zewdie & Bosland, 2001), substance responsible

Figure 1. Formed groups, according to Scott Knott's criterion (p≤0.05) for plant architecture. Areia, UFPB, 2015.

for the pungency characteristic of fruits, rich in antioxidant agents (Rêgo & Rêgo, 2016).

The formation of four classes was observed for the trait fruit fresh matter, whose mean values varied between 0.24 cm (L7) and 1.56 cm (L2×L6). This trait is positively correlated with fruit weight (Rêgo *et al*., 2011), and for ornamental purposes, fruits may not remain erect at the plant, thus not being attractive to the consumer.

Three classes were formed for dry matter content trait. The lowest content was observed in genotype HS1 (14%), and the greatest was observed in genotype L7 (41.12%). Greater dry matter contents, as well as greater pericarp thicknesses, have a direct influence on fruit firmness (Ferrão *et al*., 2011).

Five classes were formed for the trait seed yield per fruit, which varied on average, from 1.66 for hybrid L6×L4 to 41.12 cm, in parent L7. The use of interspecific hybridization in breeding programs of *Capsicum* spp. is widely restricted, especially due to the low viability and number of hybrid seeds obtained (Nascimento *et al*., 2012a). Thus, although the interspecific hybrids evaluated here were not superior to some parents (L1, L4, and L5), it is worth stressing that the combination HS1×L7 obtained around 26 seeds per fruit; this same hybrid obtained the smallest size and dimensions of fruit, which indicates that it is a promising combination to continue the breeding program of peppers for ornamental purposes.

The other traits related to productivity such as fruit yield per plant and yield formed four classes. For these, the lowest mean value was observed in parent L6, with approximately 11 fruits per plant, and a yield of around 6 g. The highest mean was observed in hybrid L6×L4, which showed around 56 fruits per plant, having an average production of around 51 g. Olszewska *et al*. (2010) characterized interspecific hybrids of *C. frutescens* × *C. chinense* and reported a lower variability for both traits, observing the formation of only two groups for them.

Regarding the traits seed yield per fruit, fruit yield per plant, yield, fruit color, flower size, and plant architecture, the hybrid L6×L4 should be selected as garden cultivar.

The precociousness traits days to flowering, and days to fructification had three and six classes, respectively. Parent L1 was the most precocious, as it flowered at 55 days and fructified at 85 days, both counts made after transplantation (Table 3). Among the evaluated interspecific hybrids, L2×L6 was the most precocious, flowering at 59 days and fructifying 119 days after transplantation. For these traits, similar variability was observed by Thul *et al.* (2009), evaluating genetic diversity in 24 accessions of *Capsicum* spp.

Two classes were formed for the trait vitamin C. Fruits with a high nutritional quality can be used in functional gardens. Cultivating peppers with good-quality fruits allows the consumer to exert an occupational therapy of high value to mental and dietary health (Finger *et al*., 2012). For vitamin C, the means varied from 94 mg in parent HS1, to 181.12 mg, in hybrid combination HS1×L2. According to Patrick *et al.* (2016), the vitamin C content found in pepper surpasses that of orange. Rêgo *et al.* (2012) reported values in *C. chinense* of 99 mg; around 28 g of pepper are required to provide the daily amount of vitamin C that an adult human needs (60 mg). Then this hybrid has potential to continue the

Figure 2. Genotype with lowest fruit diameter (HS1) (A),and highest fruit diameter (L2xL6) (B). Areia, UFPB, 2015.

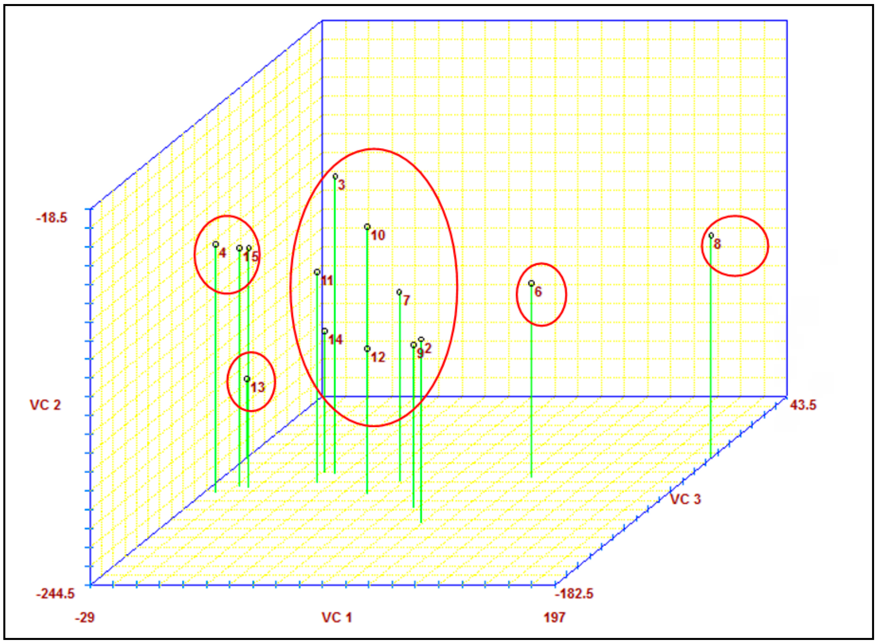

Figure 3. Graphic dispersion of scores relative to the axes representing the canonical variables (VC1, VC2 and VC3) for 27 traits studied in parents and interspecific hybrids of *Capsicum* ssp. Identification of genotypes: 1= HS1; 2= L1; 3= L2; 4= L4; 5= L5; 6= L6; 7= L7; 8= HS1×L2; 9= L2×L6; 10= HS1×L7; 11= L1×L7; 12= L2×L5; 13= L6×L4; 14= L6×L7. Areia, UFPB, 2015.

breeding program for fruit quality.

The total acidity was lowest in genotype L6 (0.43 g) and highest in hybrid L6×L7 (1.31 g). Ornamental peppers can and should have their fruit consumed fresh, and so, the total titratable acidity influences most the flavor of these fruits, in addition to being an important parameter in the appreciation of the preservation state of a food product (Rêgo *et al*., 2011).

For total soluble solids, three classes were formed, in which the means varied from 6.33% (L6) to 12% (L2×L6). Total soluble solids content is positively correlated with pericarp thickness (Lannes *et al*., 2007; Rêgo *et al*., 2011); fruits with thicker pericarp are more resistant to damages during transportation, which provides them with fresher appearance for longer period (Schuelter *et al*., 2010). In addition, fruits with high levels of total soluble solids have less water to be removed during drying, in addition to reduced contamination by fungi and pathogenic bacteria (Rêgo *et al*., 2011).

Genetic divergence

Analyzing the genetic divergence, according to Tocher's methodology based on generalized Mahalanobis distance, the parents and interspecific hybrids were clustered in four groups (Table 4), which demonstrates that there is variability among them for the evaluated traits. In this method, individuals belonging to a same group are more homogeneous than individuals from distinct groups (Cruz *et al*., 2011), which would explain the greater variation of group one, composed of five of the seven evaluated parents, four of which belong to the same *C. annuum* species (HS1, L1, L4, and L5), and one to *C. frutenscens* (L7), as well as their offspring in hybrid combinations L1×L7 and HS1×L7 (*C. annuum* × *C. frutescens*), L6×L7 (*C. baccatum* × *C. frutescens*) and L2×L5 (*C. chinense* × *C. annuum*) (Table 4).

Parents L2 (*C. chinense*) and L6 (*C. baccatum*) and the hybrid combination resulting from this crossing, L2×L6, formed the second group (Table 4). These genotypes belonged to the same class, according to Scott-Knott's test probability, for seed yield per fruit, pericarp thickness, and acidity (Table 3). These traits were some of those that most contributed to genetic diversity.

Hybrid HS1×L2 (*C. annuum* × *C. chinense*), which formed group three, showed the greatest values for the traits cotyledonary leaf width (0.70 cm), leaf length (14.66 cm), and vitamin C (181.12 mg). Such values are of interest when aiming to obtain plantlets with a faster initial development, which may reduce production costs (Barroso *et al*., 2012), and generate fruits with a greater nutritional value. Greater leaf length alone is not interesting, given that, for ornamental purposes, leaves must maintain the balance with the plant, so smaller leaves are more preferable (Barroso *et al*., 2012; Pessoa *et al*., 2018).

The fourth group was formed by hybrid L6×L4 (*C. baccatum* × *C. annuum*), which showed the lowest values for height at the first bifurcation (2.50 cm) and seeds per fruit (1.66) traits. Although it is interesting that the height at the first bifurcation be low in order to reduce the size of pepper plants, this same genotype showed the greatest corona diameter (95 cm); this relationship is not desirable, because for a smaller size, plant height, height at the first bifurcation, and corona diameter must be low.

Hybrid L6×L4 also showed the highest values for the traits pericarp thickness (0.30 cm) and fruit yield per plant (56.33). These characteristics are of interest for ornamental purposes, since, according to Rêgo *et al*. (2011), the selection of peppers with a thicker pericarp is positively correlated with increased production.

The relative importance of 27 quantitative traits tested by Singh's method (1981), showed that eight of these traits contributed with 82% of the genetic diversity, whereas 19 contributed with only 18% (Table 5). The variables that most contributed to divergence were fruit yield per plant, with 21%, and leaf width, with 1%. These traits can help in the selection of superior genotypes for them, which makes them important in the breeding of ornamental peppers.

The variable that contributed the least to divergence by Singh's method was cotyledonary leaf length (0.0019%). This variable can be discarded in future divergence studies because, according to

Rêgo *et al*. (2003), traits that contributed with a very low percentage or that did not contribute at all for the detected variability can be discarded.

In the analysis of canonical variables there was phenotypic diversity among the studied genotypes, in which the first three canonical variables explained 92.02% of the total variance, the data fit to a tridimensional graphic representation. Thus, in the graphic dispersion of the genotypes, adopting the scores relative to the canonical variables, five groups were formed (Figure 3), similarly to the clustering analysis by Tocher's method (Table 4), since the separation by the two methods was the same, but graphically group 1 had greater separation, wherein genotypes HS1, L4 and L5 were placed in a different group (Figure 3).

The separation of these groups in the graph depends on the scale utilized, which shows one of the subjective aspects of this type of genetic dissimilarity analysis (Cruz *et al*., 2011).

According to the weighting coefficients, the canonical variable that contributed the least to genetic diversity was total soluble solids. This trait should be discarded in future studies because, in the analysis of canonical variables, traits that have shown the highest weighting coefficient among the accessions are discarded (Cruz *et al*., 2011), thereby saving time, labor, and financial resources in future studies.

In the conditions of this study, traits that contributed the most to the variability between parents and hybrids analyzed were fruit yield per plant and leaf width. Both are easy to obtain and are of great interest for the production of ornamental peppers. The traits with smaller contribution for diversity were cotyledonary leaf length and total soluble solids, these are difficult to measure and can be discarded in future studies with these genotypes.

Obtaining interspecific hybrids of ornamental peppers with a ideal ideotype to producers and consumers is not easy. In this work we can indicate the selection of the combinations HS1xL7, L2xL6 and HS1xL2, which presented the best performance regarding the evaluated characters and the harmony between plant height, canopy width and poor size. Beside these traits they showed larger flowers, earliness, fruit quality and yield.

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