Genetic parameters and simultaneous selection using traits of ornamental interest in pepper plants

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ABSTRACT

Pepper plants of the genus *Capsicum* are widely grown worldwide. The *Capsicum annuum* species shows ornamental potential; nevertheless, in the state of Piauí, there has been a lack of studies on its performance, related to quality traits needed to meet market demand. The aim of this study was to estimate the genetic parameters and associations between traits of ornamental interest in *C. annuum* in order to indicate, by simultaneous selection of traits, accessions to start an ornamental pepper breeding program in Piauí. We evaluated 16 accessions of *C. annuum* under plastic house conditions at Universidade Federal do Piauí. Number of days to flowering, number of days to fruit maturation, plant height, number of fruits per plant, fruit persistence, fruit length, fruit width, leaf length and fruit weight were evaluated. A significant difference (p≤0.01) between accessions for all traits was noticed. Coefficient of genetic variation / coefficient of experimental variation [*Cvg/Cve* (%)] ratios were greater than 1 and the genotypic determination coefficient (*H²*) values were all greater than 89.95%. The estimates of the genotypic correlations were higher in relation to phenotypic correlations in most of the traits, however, according to path analysis, an effect of residual variable (0.59) was verified. According to the results, the accessions BAGC 98, 199, 207 and 236 can be used as parents to start an ornamental pepper breeding program in Piauí.

Keywords: *Capsicum annuum*, ornamental ideotype, genotypic determination coefficient.

RESUMO

Parâmetros genéticos e seleção simultânea utilizando caracteres de interesse ornamental em pimenteiras

As pimenteiras do gênero *Capsicum* são amplamente cultivadas em todo mundo. A espécie *Capsicum annuum* apresenta potencial ornamental, porém o estado do Piauí ainda carece de estudos sobre o seu desempenho em relação às características de qualidade necessárias para suprir a demanda de mercado. O objetivo desse trabalho foi estimar os parâmetros genéticos e as associações entre os caracteres de interesse ornamental em *C. annuum* visando indicar, por seleção simultânea de caracteres, acessos para iniciar um programa de Melhoramento de Pimentas Ornamentais no Piauí. Foram avaliados 16 acessos em condições de telado na Universidade Federal do Piauí. Avaliaram-se as características: número de dias para o florescimento, número de dias para maturação de frutos, altura da planta, comprimento da folha, número de frutos por planta, persistência dos frutos, comprimento do fruto, largura do fruto e peso do fruto. Houve diferença significativa (p≤0,01) entre os acessos para todas as características. As razões coeficiente de variação genético e coeficiente de variação experimental [*Cvg/Cve* (%)] foram superiores a 1 e os valores do coeficiente de determinação genotípico (*H²*) foram todos maiores que 89,95%. As estimativas das correlações genotípicas foram superiores em relação às fenotípicas na maioria das características, porém de acordo com a análise de trilha houve efeito da variável residual (0,59). Diante dos resultados, os acessos BAGC 98, 199, 228, 207 e 236, podem ser utilizados como genitores para iniciar um programa de Melhoramento de Pimentas Ornamentais no Piauí.

Palavras-chave: *Capsicum annuum*, ideótipo ornamental, coeficiente de determinação genotípico.

Peppers of the genus *Capsicum* are widely grown all over the world. The fruit is mainly consumed *in natura*, as dehydrated spice, or as jelly and sauces (Finger & Pereira, 2016). The species of this genus have gained more and more space in the flower and ornamental plant business (Rêgo & Rêgo, 2018), a sector which has grown an average of 10% per year in Brazil, from 2012 to 2018 (Ibraflor, 2019).

Most pepper plants can be classified as an ornamental potted plant (Rêgo & Rêgo, 2018). In this market, the plant architecture and number of fruits are the main traits used as quality standard for commercialization. The expected ideotype for ornamental pepper plants includes: (i) harmony between the plant (plant height, canopy width and foliage position) and the pot size, (ii) showy, upright and colorful fruits, with a suitable number for each pot size and (iii) resistance to pests, diseases and

ethylene (Rêgo & Rêgo, 2018; Veilling Holambra, 2018).

The genetic diversity of genus *Capsicum,* considering a small number of ornamental pepper varieties available in the market and registered at Ministry of Agriculture, Livestock and Supply (MAPA), has stimulated the development of pepper breeding programs. Considering the Northeast part of Brazil, the inferior quality of the marketed ornamental pepper plants turns out to be an aggravating factor, due to the distance from the largest potted plant producing center, located in São Paulo (Ibraflor, 2019). The main damages observed in these plants are related to the effect of ethylene released during transport, with an emphasis on the absence of flowers, fruits and leaves (Lima *et al.*, 2017; Ribeiro *et al.*, 2019).

Piauí has several peculiar edaphoclimatic conditions throughout its extensive territory (Andrade Júnior *et al.*, 2004; Santos *et al.*, 2011). This state is known for its grain production. The example of pepper and other ornamental species breeding programs developed in Paraiba State (Rêgo & Rêgo, 2016), shows favorable conditions to exploit this new market niche in Piaui State.

Universidade Federal do Piauí has been proposing actions to conduct breeding programs, aiming to strengthen and diversify the production of ornamental plants in the region. These actions are based on new bills, such as Instituição da Política Nacional de Incentivo à Cultura de Flores e de Plantas Ornamentais de Qualidade (Institution of the National Policy to Encourage the Crop of Quality Flowers and Ornamental Plants) newly approved at Comissão de Agricultura e Reforma Agrária (PL 6912-2017) (Agriculture and Agrarian Reform Commission). These actions are based on selecting pepper accessions with ornamental potential; these accessions have been collected (Costa *et al.*, 2019) and stored at the *Capsicum* Germplasm Bank of the Institution (BAGC/UFPI) (Monteiro *et al.*, 2010).

Searching for new genotypes is facilitated when the correlations between the traits used for selection are already known. Knowing these traits is quite relevant when it is related to late-expressed phenotype, such as number of fruits in pepper plants, or for medium-low heritability variables (Moreira *et al.*, 2018). The correlations show the direction and degree of association between a pair of traits and whether the interrelation is due to genetic factors (pleiotropy or genetic link) or environmental factors (Ramalho *et al.*, 2012). Associated with the trail analysis (Wright, 1921) can also indicate the direct and indirect effects of other variables on the correlation between a pair of traits under study.

Associations between traits are not always favorable. The negative correlation between two traits of economic importance can hinder the selection of genotypes of interest to the breeder. In these cases, genetic-statistical procedures can be applied, such as selection indexes. These indexes allow to obtain simultaneous gains even for traits which have adverse effects, enabling the selection of superior genotypes regardless of the existence or not of correlation (Rangel *et al.*, 2011; Cruz *et al.*, 2012, 2014).

Obtained data will be the base for choosing more appropriate methods to conduct segregating populations, assisting in obtaining and recommending ornamental pepper cultivars for Piauí, as well as to provide information for crop researchers. In this context, the aim of this study was to estimate genetic parameters and associations between traits of ornamental interest in *Capsicum annuum* in order to suggest, using simultaneous trait selection, accessions to begin an Ornamental Pepper Breeding Program in Piauí.

MATERIAL AND METHODS

The experiment was carried out in a plastic house, installed in the Department of Phytotechnics, at Centro de Ciências Agrárias da Universidade Federal do Piauí, in Teresina (05°05'05''S, 42°05'W, 73 m altitude) from February to November, 2017. The local climate is Aw type, tropical climate with dry winter, according to Köppen classification, 1349 mm rainfall distributed from November to May, 27.6°C average annual temperature.

We evaluated 16 accessions of *Capsicum annuum* from eight Brazilian states (Table 1). The experiment was conducted in a completely randomized design, with four replicates, considering one plant per plot. Under plastic house conditions (50% shading screen). The accessions were sown in expanded polystyrene trays of 128 cells, filled with the commercial substrate Plantmax®. The seedlings showing six to eight definitive leaves were transplanted to polystyrene pots, size 13, containing soil organic matter/humus substrate at a 2:5 ratio. The seedlings were irrigated daily, on mild sunny hours (8 am or 5 pm), and planting fertilization was done with 2 g of ammonium sulfate, 17 g of simple superphosphate and 2.5 g of potassium chloride, according to recommendation of Alcântara & Ribeiro (2008) and fertilization, every 30 days after planting, using Nutriverde NPK 13-13-15 fertilizer with micronutrients.

Morpho-agronomic characterization of the accessions was carried out according to the descriptors established by *International Plant Genetic Resources Institute* (IPGRI, 1995) for genus *Capsicum* and Ornamental Pepper Classification Criteria of the Veiling Holambra Cooperative, which are quality standards nationally established by Instituto Brasileiro de Floricultura (Ibraflor, 2020).

The authors evaluated number of days for flowering (NDF), which refers to number of days since sowing, up to 50% of plants showing at least one opened flower; number of days for maturation (NDM), measured since sowing, up to 50% of plants showing at least one ripe fruit; plant height (ADP), in cm, observed when 50% of plants showed the first fuits in the beginning of ripening; number of fruits per plant (NFP), according to the average of total number of fruits per accession; fruit persistence (PSF), considering the number of the days when the first ripe fruits appeared up to the last one; Fruit length (CDF), in mm, referring to average length of 10 ripe fruits, taken at random; fruit width (LDF), in mm, measured at the widest point of 10 ripe

fruits, taken at random; leaf length (CDFol), in mm, which corresponds to the average length of 10 leaves, also taken at random; fruit weight (PDF), referring to the average weight of 10 ripe fruits, taken at random, in grams.

Obtained data were submitted to individual variance analysis. Effects of the accessions were considered fixed. Multicollinearity diagnose was based on the number of condition (NC), considering the ratio between the highest and lowest eigenvalue of the matrix. For NC<100, multicollinearity is considered weak and it does not represent a problem for the analysis; 100≤NC≤1000, multicollinearity is considered moderate to strong and NC≥1000 is considered severe (Cruz *et al.*, 2012). When the authors observed moderate to severe multicollinearity, the variables were discarded; this fact contributed to the presence of multicollinearity.

Genotypic and phenotypic correlations were estimated for all trait combinations after multicollinearity diagnosis. The significance of these combinations was estimated using t test with n^{-2} degrees of freedom, in which n corresponds to the number of evaluated genotypes.

Unfolding of correlations into direct and indirect effects was performed using path analysis (Wright, 1921), in which number of fruits per plant ((NFP) was the base variable. This variable was chosen since it is a later variable, and the other traits were considered explanatory variables.

The accessions were classified using genotype-ideotype distance selection indexes (Schwarzach, 1972 cited by Wricke & Weber, 1986) and the sum of ranking (Mulamba & Mock, 1978). An equal economic weight was attributed to each evaluated trait. Spearman's correlation coefficient (1904) was used for the correlation between the results of the indexes. All statistical analyses were performed using Genes software (Cruz, 2013).

RESULTS AND DISCUSSION

A significant difference (p≤0.01)

among the accessions for all evaluated traits was verified, showing genetic variability among them. Variability is important for establishing plant breeding programs. An efficient selection of superior genotypes depends on genetic and environmental parameters for traits of interest, though (Blind *et al.*, 2018).

Coefficients of experimental variation ranged from 5.09%, for number of days for fruit maturation (NDM) to 44.87%, for number of fruits per plant (NFP). This coefficient, relatively high, may be associated with the germplasm used in this study, since this genetic material is still in process of pre-breeding, presenting unevenness in the number of fruits, even within the same accession.

All evaluated traits showed higher values of genetic variance when compared with values for environmental variance, showing predominance of genetic effects over environmental effects. The values of coefficient of genetic variation and experimental coefficient of variation ratios [Cvg/Cve(%)] ranged from 1.59% for NDM to 5.79% for LDF. Values higher than or equal to the unit showed the existence of great genetic variability to be used in breeding (Cruz *et al.*, 2014).

The evaluated traits indicated high values for coefficient to genotypic determination coefficient, which ranged from 89.95% for PSF to 99.26% for LDF. Thus, the phenotypic values of these treatments have high correlation with genotypic values, which means, the studied germplasm showed heritable phenotypic variability. Moreira *et al.* (2015), working with inbred lines of *C. annuum,* found similar values for coefficient of genotypic determination (H²) ranging above 82.29 for fruit-related traits.

Considering the nine evaluated variables, the diagnosis of multicollinearity showed NC = 432.80, indicating a moderate to strong collinearity. In order to deal with this strong multicollinearity, first, the authors used the methodology proposed by Carvalho *et al.* (1999), called Crest Path Analysis, where a constant (k) was added to the diagonal elements of the X'X matrix. However, this methodology was not efficient to reduce the multicollinearity. Hence, the authors excluded the variables. To choose the variables to be discarded, we observed the ones which presented high correlation among themselves. So, we excluded ADP (plant height) and

Table 1. Accessions of *Capsicum annuum*, their respective collection sites and traits. Teresina, UFPI, 2017.

BAGC	Common name	State	Average height (cm)
236	"Pimenta-de-mesa"	Piauí	20.75
98	Ornamental orange pepper	Piauí	20
224	Ornamental red pepper	Maranhão	23
199	Ornamental purple pepper	Ceará	20.75
207	Ornamental yellow pepper	Ceará	21.5
228	Yellow-sweet pepper	Ceará	21.75
180	Red bell pepper	Rio Grande do Norte	42.5
150	Not identified	Pernambuco	40.5
202	Long Cayenne	Paraíba	49
203	"Pimenta-de-mesa"	Paraíba	45.5
220	Red pepper	Paraíba	18.25
229	Jalapeño	Paraíba	36.25
230	Cayenne pepper	Paraíba	33.5
149	Yellow bell pepper	Alagoas	40.25
145	Sweet pepper	Sergipe	41.5
148	Red bell pepper	Sergipe	31

PDF (fruit weight). After discarding these two variables, a new diagnosis of multicollinearity was performed, in which NC was 48.82, finalizing matrix adjustment.

The authors observed positive and significant genotypic correlation (0.5037) between NDF x NDM and negative correlation for NDF x PSF (-0.5263) (Table 2). These correlations are important in ornamental peppers, as the shorter the period of days for flowering, for maturation and greater persistence of fruits in plants, the more interesting and attractive it will be for the consumer.

We verified negative correlations for NFP and CDFol. The values observed for phenotypic and genotypic correlations were -0.4163 and -0.5039, respectively (Table 2). Thereby, in accessions with shorter leaves, the amount of fruit will be greater. This correlation can be used to shorten the time of breeding programs which aim to work with number of fruits per plant, since the indirect selection can be carried out in vegetative phase.

Using the path analysis, NFP as base variable, the authors observed a high residual effect (0.59) (Table 3), showing that the set of variables used in this study does not totally explain the number of fruits in ornamental pepper plants, since the values of the residual exceeded, except CDFol. Thus, the range observed in number of fruits occurred probably due to other traits which were not mentioned in this study, being able to be evaluated in further studies, though.

Low values of coefficient of determination (0.37) and high values of residual variable (0.79) were also obtained by Cabral *et al.* (2011), using path analysis for number of seeds per plant in beans (*Phaseolus vulgaris*). Salla *et al.* (2015) also obtained low values of coefficient of determination (0.12) and high values for residual effect (0.93) studying jabuticaba fruit traits (*Plinia cauliflora*). Blind *et al.* (2018) verified that secondary traits, such as average length and fruit circumference and maximum fiber thickness were not effective in determining the variation in number of fruits ($R^2 = 0.288$) and fiber production ($R^2 = 0.238$) in vegetable loofah (*Luffa cylindrica*).

Even taking these results into consideration, the explanatory variables should not be totally discarded due to the low direct effect on the main variable. In these cases, the use of selection indexes would be a good alternative to be used in breeding programs. These indexes may provide favorable and simultaneous gains in many traits (Cruz *et al.*, 2014).

Selection indexes of Mulamba & Mock (1978) and Genotype-Ideotype (Schwarzach, 1972 cited by Wricke & Weber, 1986) were used in order to identify promising accessions based on vegetative and reproductive traits, simultaneously. Among the studied 16 accessions, the indexes indicated BAGC 236, BAGC 207, BAGC 199, BAGC 98 and BAGC 228 as the most promising materials, changing only the order within each index. This corresponded to a coincidence of 0.92 ordering the accessions according to Spearman's correlation coefficient (Table 4).

The indexes were efficient for indicating earlier accessions, with

Table 2. Estimate of phenotypic correlation (and genotypic correlation coefficients of seven agronomic traits in 16 pepper accessions (*Capsicum annuum*) with ornamental potential. Teresina, UFPI, 2017.

Variables	r	NDM[2]	NFP[3]	PSF[4]	CDF[5]	LDF[6]	CDFol[7]
NDF[1]	r_f	0.4628**	-0.2424	-0.5263**	-0.1434	0.1558	0.1563
	r_g	0.5037**	-0.1289	-0.6665**	-0.3044	0.1121	0.3022
NDM	r_f		-0.2806	0.0358	0.0863	0.0254	-0.2551
	r_g		-0.4015*	0.2022	0.2622	0.0898	-0.4197*
NFP	r_f			0.1256	0.2935	-0.028	-0.4163*
	r_g			0.1832	0.3831*	0.0462	-0.5039**
PSF	r_f				-0.4614**	0.0197	0.3563*
	r_g				-0.5652**	-0.0089	0.4745**
CDF	r_f					-0.1546	0.8162**
	r_g					-0.2186	0.8634**
LDF	r_f						0.4577**
	r_g						0.4771**

**Significant at 1% and 5% probability by F test, respectively; [1]Number of days for flowering; [2]Number of days for maturation; [3]Number of fruits per plant; [4]Fruit persistence; [5]Fruit length; [6]Fruit width; [7]Leaf width.

Table 3. Estimate of the direct (diagonal in bold) and indirect (off-diagonal) effects of six agronomic traits on the number of fruits per plant in pepper (*Capsicum annuum*) with ornamental potential. Teresina, UFPI, 2017.

Variables	NDF[1]	NDM[2]	PSF[3]	CDF[4]	LDF[5]	CDFol[6]	Total
NDF	**-0.2938**	-0.1733	0.0840	0.1306	-0.0123	-0.2712	-0.7042
NDM	-0.2013	**-0.2530**	-0.0582	0.0213	-0.0055	-0.0459	-0.5427
PSF	0.2059	0.1228	**0.1198**	-0.1514	0.0069	0.1724	0.4766
CDF	-0.0981	-0.0137	0.0463	**0.3912**	-0.0138	-0.5748	-0.3557
LDF	-0.1403	-0.0542	-0.0321	0.2090	**-0.0259**	-0.4892	-0.5328
CDFol	-0.1169	-0.0170	-0.0303	0.3300	-0.0185	**-0.6814**	-0.5344
Determination coefficient							0.6401
Effect of residual variable							0.5998

[1]Number of days for flowering; [2]Number of days for maturation; [3]Fruit persistence; [4]Fruit length; [5]Fruit width; [6]Leaf length.

Table 4. Ranking using the Mulamba & Mock non-parametric selection index (1978) and Genotype-Ideotype distance based on agronomic traits, evaluated in 16 pepper accessions (*Capsicum annuum*) with ornamental potential from different states. Teresina, UFPI, 2017.

Accessions	NDF[1]	NDM[2]	NFP[3]	PSF[4]	CDF[5]	LDF[6]	CDFol[7]	MM[8]	GI[9]
BAGC 236	44.75	102.25	81.75	89.25	1.09	0.49	1.36	1°	2°
BAGC 98	49.25	107.25	14.00	82.00	3.51	1.86	6.00	4°	4°
BAGC 224	66.00	118.25	15.00	83.00	2.95	1.87	5.36	7°	6°
BAGC 199	61.00	107.00	27.50	90.00	2.70	1.96	3.88	3°	3°
BAGC 207	57.25	109.75	80.25	90.00	2.00	1.04	4.61	2°	1°
BAGC 228	63.50	107.00	28.50	84.00	3.51	0.82	3.81	5°	5°
BAGC 180	70.50	108.50	7.75	79.50	15.21	3.96	12.15	9°	14°
BAGC 150	73.50	127.00	6.75	96.50	4.22	3.80	7.09	10°	10°
BAGC 202	87.25	132.50	6.75	61.00	4.70	2.64	4.57	16°	16°
BAGC 203	74.00	119.00	21.50	68.00	11.94	2.29	8.07	11°	12°
BAGC 220	73.75	114.25	8.50	85.00	1.49	1.14	4.8	6°	7°
BAGC 229	74.50	113.75	20.00	75.00	3.88	0.54	5.97	8°	8°
BAGC 230	71.00	131.50	4.25	74.50	3.89	2.41	6.16	13°	11°
BAGC149	80.75	112.00	8.50	68.00	6.13	5.35	7.88	14°	13°
BAGC 145	85.00	131.50	4.25	64.50	4.90	1.64	4.54	15°	15°
BAGC 148	80.25	112.00	7.25	72.50	5.24	3.26	8.1	12°	9°

[1]Number of days for flowering; [2]Number of days for maturation; [3]Number of fruits per plant; [4]Fruit persistence; [5]Fruit length; [6]Fruit width; [7]leaf length; [8]Mulamba & Mock Index; [9]Genotype-Ideotype Index.

greater number of fruits per plant and greater fruit persistence. The accessions recommended ranged from 70.5 to 44.75 for NDF and 27.5 to 81.75 for NFP. These accessions produced fruits which persisted up to 90 days in plants (Table 4). This is important since the ornamental value of the peppers is directly related with permanence of the fruits in the plant. The results for NDF are in accordance with the results obtained by Nascimento *et al.* (2019) working with 6 generations of ornamental pepper plants, which showed values from 38.65 to 95. Silva *et al.* (2015) found results similar to these ones in this study, except for one accession which produced 137.3 fruits; these authors also obtained accessions of NDF ranging from 41.7 to 80. The values of NDF obtained by Nascimento *et al.* (2019) ranged between 15 and 70 days. The studies cited, as well as the results obtained in this experiment, are within the quality standards for commercialization, NFP≥10 (Veilling Holambra, 2018).

We highlight that even the plant height not being used in the selection index, the indicated accessions (BAGC 236, BAGC 207, BAGC 199, BAGC 98 and BAGC 228) presented an average height within the quality standards for commercialization, being 14 to 32 cm, for the pot size used in this experiment (Veilling Holambra, 2018). Therefore, such accessions, which have an average height between 20 and 21.75 cm (Table 1), are suitable for ornamental purposes and can be used to start crosses in the Ornamental Pepper Breeding Program in the state of Piauí.

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