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Genetic diversity of pepper genotypes for use as ornamental plants

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Abstract

Determining the genetic diversity of pepper plants with potential use for ornamentation through the formation of groups is of great importance in breeding programs, as it represents important information in the selection of parents. Therefore, the objective of this work was to quantify the genetic diversity through morpho-agronomic characteristics. Were used fourteen quantitative characteristics and seven qualitative characteristics related to plant, flower and fruit were evaluated in 29 pepper (*Capsicum annuum*) genotypes and was used the mixed model methodology and analysis of genetic diversity, The genotypes were divided into seven groups of genetic similarity in terms of quantitative characteristics, three in terms of qualitative characteristics and five groups considering the characteristics together. It is concluded that the genotypes of *C. annuum* evaluated have potential for use with ornamental purposes, with greater genetic variability in terms of quantitative morph-agronomic characteristics, when compared to qualitative characteristics.

Keywords: *Capsicum annuum*, cluster analysis, morpho-agronomic characterization

Introduction

The demand for vase ornamental peppers has grown in both domestic and international markets (Finger et al., 2015). In addition to their importance in food, peppers have great potential for ornamentation due to a set of characters of high aesthetic value, such as plant architecture; reduced size; shape, color, position and quantity of fruits produced; ease of cultivation; fruit durability and the ability to grow in vases as a perennial plant (Neitzke et al., 2010). The sale of ornamental pepper is an important source of income and its use in decoration and consumption adds value to the product, therefore increasing the financial return to the producer (Rêgo & Rêgo, 2018).

Due to its small size and the large variability of shapes and colors of the fruits, *Capsicum annuum* is one of the most used species in vase planting (Finger et al., 2012). However, few cultivars are used for ornamentation in the country (Vasconcelos et al., 2012). The market of ornamental plants lacks novelties and new products add competitiveness to the sector and considerably increase the profit margin. The diversity of the *Capsicum* genus, associated with the few ornamental peppers available on the market, stimulated pepper breeding programs in search of plants with ornamentation potential (Costa et al., 2019).

The study of genetic diversity is an important tool for understanding the variability between individuals (Vasconcelos et al., 2012). The formation of is of great importance in breeding programs, as it represents important information in the selection of parents (Sudré et al., 2010). In addition to allowing the identification of hybrid combinations with greater heterotic effect and greater heterozygosis (Cruz et al., 2012). The morpho-agronomic characterization provides a series of information regarding the genetic variability of the

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studied genotype. Thus, based on these data, it is possible to assess the potential for using genotypes in breeding programs, which makes it possible to identify individuals with genes of interest and insert them into the program (Marim et al., 2009).

The objective of this work was to quantify the genetic diversity through morpho-agronomic characteristics

Material and Methods

Plant materials

The experiment was conducted in a greenhouse, in the Plant Science Department using 29 genotypes of *C. annuum*, selected for their potential for ornamentation. 15 genotypes were obtained from New Mexico, three from the UFV germplasm bank (BAG-UFV) and 11 were cultivars (Table 1). A completely randomized design was used, with 29 treatments (genotypes) and five replications, where the experimental unit consisted of one plant per vase. Sowing was carried out in 120-cell polystyrene trays containing commercial substrate. Seedlings with four pairs of permanent leaves were transplanted in 800-ml vases and thinning was performed one week later. Cultural treatments such as irrigation, fertilization, weed control were carried out whenever it was necessary.

Table 1 – List of 29 evaluated *Capsicum annuum* genotypes.

genotypes	origin
NuMex Big Jim 1	New Mexico
NuMex Big Jim 2	New Mexico
NuMex Conquistador 1	New Mexico
NuMex Conquistador 2	New Mexico
NuMex Espanola Improved 1	New Mexico
NuMex Espanola Improved 2	New Mexico
NuMex Joe E Parker 1	New Mexico
NuMex Joe E Parker 2	New Mexico
NuMex Mirasol 1	New Mexico
NuMex Mirasol 2	New Mexico
NuMex New México 6-4 1	New Mexico
NuMex New México 6-4 2	New Mexico
NuMex Sandia 1	New Mexico
NuMex Sandia 2	New Mexico
NuMex Sweet 1	New Mexico
BGH 1039	BAG-UFV
BGH 7073	BAG-UFV
MG 302	BAG-UFV
Calypso	Commercial
Cayenne	Commercial
Guaraci Cumari do Pará	Commercial
Jamaica Red	Commercial
Jamaica Yellow	Commercial
Peter	Commercial
Pimenta Doce Italiana	Commercial
Pimenta Doce Comprida	Commercial
Pimenta Amarela Comprida	Commercial
Picante para Vaso	Commercial
Vulcão	Commercial

Morpho-agronomic characterization

For the morpho-agronomic characterization of the genotypes, the ornamental potential associated with characters of interest for consumption was taken into account, considering that pepper plants can have dual purposes. The descriptors established by the International Plant Genetic Resources Institute for the genus *Capsicum* were taken as a base (IPGRI, 1995).

Fourteen quantitative characteristics were evaluated: Plant height (cm); stem length (cm); stem diameter (mm); canopy diameter (cm); leaf size (cm); diameter of the corolla (mm); fruit weight (grams); fruit length (mm); fruit diameter (mm); thickness of the pericarp (mm); fresh matter (grams); dry matter (grams); number of seeds/fruit (direct count), number of fruits per plant (direct count). The measurements related to dimensions were measured with the use of a digital caliper, and the weight data were taken on an analytical scale. Seven qualitative characteristics were evaluated: branch density; leaf shape; corolla color; fruit shape; and immature, intermediary and ripe fruit color. The evaluations of the listed characteristics were visual, according to the notes for capsicum qualitative descriptors, established by the International Plant Genetic Resources Institute (IPGRI, 1995).

Statistical analyses

Was adopted the mixed model statistical analyses via REML/BLUP (restricted residual maximum likelihood and best linear unbiased prediction). For the deviance analysis, the model for a completely randomized design was used (model 83):

$$Y = Xu + Zg + e$$

Where: Y = data vector; u = scalar referring to the overall mean (assumed as fixed); g = vector of genotypic effects (assumed as random); e = vector of residue (random). The uppercase letters X and Z, represent the incidence matrices for these effects.

For the random effects of the model, the significance for the Like-lihood ratio test (LRT) was tested using the chi-square test with onedegree of freedom. BLUP (Best Linear Unbiased Prediction) meanswere estimated for each of the 29 genotypes based on the 14 quantitative traits evaluated.

The Tocher clustering method (Rao, 1952) was used in the quantification of the genetic diversity among 29 genotypes of *Capsicum annuum*, based on the genetic dissimilarity matrix, obtained by the mean standardized Euclidean distance of the BLUP means, for the quantitative characteristics. For qualitative, multi-categorical characteristics, the genetic dissimilarity matrix was obtained by complementing the simple compatibility index. For estimates of the BLUP means and dissimilarity matrix were obtained using the software Selegen-REML/BLUP (Resende, 2007).

The relative importance of the traits, quantitative and qualitative, in quantifying genetic divergence was estimated based on the method proposed by Singh (1981), using the GENES software (Cruz, 2013). To show the genetic diversity of genotypes, graphical analysis dendrograms (graphical analysis) were constructed based on the hierarchical methodology of single linkage (Nearest Neighbor Method) (neighbor joining), using the R program (R Development Core Team, 2015).

Results and Discussion

Genetic variability

Significant genotypes effects (p<0,01) were detected by the joint deviance analysis in for the quantitative traits (Table 2). These results indicate elevated genetic variability among 29 genotypes of the *Capsicum annuum*. Variability is a precondition for establishing any breeding program (Blind et al., 2018).

Table 2. Joint deviance analysis for the 14 quantitative traits evaluated in 29 genotypes of *C. annuum*.

traits	reduced model	complete model	likelihood ratio test	mean
Plant height	921.15	864.6	56.55**	55.61
Stem length	813.89	738.16	75.73**	28.42
Stem diameter	71.45	-5.2	76.65**	5.91
Canopy diameter	761.02	708.58	52.44**	38.49
Leaf size	423.01	346.31	76.70**	11.94
Corolla diameter	639.21	529.92	109.29**	21.83
Fruit weight	901.73	719.45	182.28**	15.28
Fruit length	1216.24	1026.88	189.36**	71.64
Fruit diameter	802.32	575.89	226.43**	22.24
Pericarp thickness	86.98	-8.71	95.69**	1.83
Number of seeds /fruit	1168.65	1148.52	20.13**	47.86
Fresh mass	891.05	703.63	187.42**	14.50
Dry mass	301.36	152.9	148.46**	2.04
Number of fruits /plant	988.05	759.13	228.92**	13.08

Chi-squared tabulated: 6.63 for level of significance of 1%.

** significant to 1%, by the chi-squared test.

Likelihood ratio test, using the chi-squared test with one degree of freedom.

Quantitative traits clustering

Considering the variability of the quantitative morpho-agronomic traits evaluated in the 29 genotypes, the formation of seven clusters was observed by using the Tocher method (Figure 1). Eight genotypes were allocated to the first group: BGH 1039, BGH 7073, MG 302, Cayenne, Guaraci Cumari do Pará, Jamaica Yellow, Picante para Vaso and Vulcão. With the exception of the genotypes BGH 1039, BGH 7073 and MG 302, the other genotypes are marketable. These genotypes are particularly similar in relation to the plant characters: plant height, canopy diameter, stem length and diameter.

The following 12 genotypes were allocated in group II: NuMex Big Jim 1, NuMex Big Jim 2, NuMex Conquistador 2, NuMex Espanola Improved 2, NuMex Joe E Parker 1, NuMex Joe E Parker 2, NuMex New Mexico 6-4 1, NuMex New México 6-4 2, NuMex Sandia 1, NuMex Sandia 2, NuMex Sweet 1 and Pimenta Doce Comprida. Aside from Pimenta Doce Comprida, all genotypes in this group originate from New Mexico. They are genotypes that are similar due to their fruit characteristics, presenting fruits with higher weight, length, diameter, thickness of pericarp, number of seeds, fresh weight and dry weight than those of group I genotypes.

The genotypes NuMex Mirasol 1, NuMex Mirasol 2, Jamaica Red and Peter form the third group. Numex Mirasol plants have erect size and fruits and can be indicated for making bouquets. For this purpose, fruits with larger and erect peduncles should be selected, as fruits with longer peduncles stand out more in relation to the foliage (Melo et al., 2014). In the development of 'NuMex Mirasol', the selection was made for various horticultural characteristics, in which the most important was vertical fruits, fruit size and color, number of fruits per branch and the number of branches per plant (Bosland & Gonzalez, 1994).

The fourth group was formed by the cultivars Calypso and Pimenta Amarela Comprida. They present similar values for canopy diameter, leaf size, stem diameter, number of fruits per plant, pericarp thickness, dry weight, fruit diameter and number of seeds per fruit. Calypso is a cultivar intended for the ornamentation market because it has desirable characteristics such as: small size; edible fruits of medium size, with upright position, contrasting with the foliage and with different colors before, during and after ripening; harmonic plant architecture (balance between plant height, stem diameter and canopy diameter) and good adaptability in vase. In comparison to the cultivar Calypso, Pimenta Amarela Comprida presents larger and heavier fruits, in addition to greater plant height.

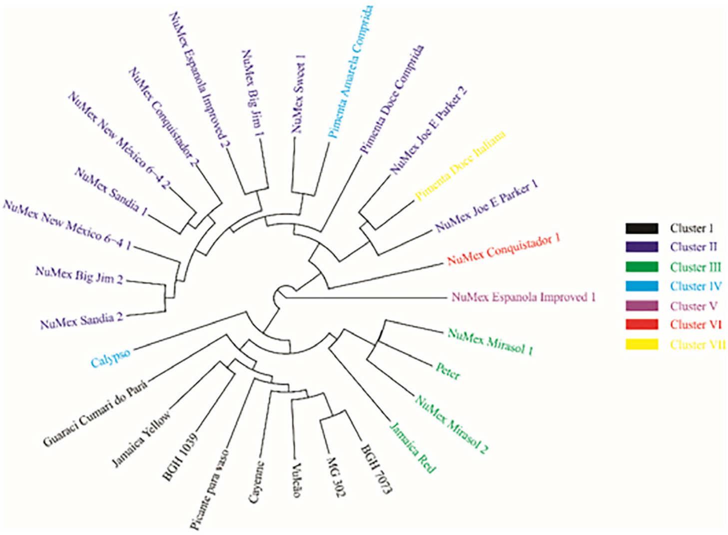

Figure 1. Dendrogram of 29 genotypes of *C. annuum* of, based on the neighbor joining method, obtained from BLUP means of quantitative morpho-agronomic traits. Different colors represent the clusters of similar accessions formed using the Tocher clustering method.

The other groups allocated only one genotype each. Group V with NuMex Espanola Improved 1 which has lower means for plant height, stem length and higher values for number of fruits per plant. In the sixth group is the NuMex Conquistador 1 genotype, whose mean for canopy diameter is lower than the others. Finally, in group VII is the Pimenta Doce Italiana, which stands out for having large fruits, with higher means than those of the other genotypes.

When considering the variability of the qualitative characteristics evaluated in the 29 genotypes, it was possible to distinguish a smaller number of groups when comparing to the quantitative characteristics. Only three groups were formed using Tocher's optimization method. Out of 89.66% of the genotypes were concentrated in the first group. Those showing most similarity were: *Pimenta Doce Italiana*, NuMex Espanola Improved 2, NuMex New Mexico 6-4 1, NuMex Big Jim 1, NuMex Sandia 2, Numex Conquistador 1 and Picante para Vaso and Numex Conquistador 2.

The groups criterion is given by the maximum value (θ) of the dissimilarity measure found in the groups of smaller distances that involve each pair of individuals (Rao, 1952). Thus, accessions which were extremely divergente from the others, such as NuMex Espanola Improved 1, NuMex Conquistador 1 e Pimenta doce Italiana (Figure 1), affect the Tocher clustering method. This accession showed greater relative distance than the other accessions.

Qualitative traits clustering

When considering the variability of the qualitative morpho-agronomic traits evaluated in 29 genotypes, it was possible to distinguish fewer groups when comparing the quantitative traits. It was possible to distinguish three groups by the Tocher optimization method. Sixty 89,66% of the accessions were concentrated in the first groups, among which the most similar were: Pimenta Doce Italiana, NuMex Espanola Improved 2, NuMex New México 6-4 1, NuMex Big Jim 1, NuMex Sandia 2, Numex Conquistador 1 e Picante Para Vaso e Numex Conquistador 2 (Figure 2).

According to Neitzke et al. (2010) qualitative descriptors are very important in identifying accessions that may be used in crossings to obtain ornamental pepper cultivars. The authors also highlight the color of the fruits, when immature and ripe, the shape of the fruits and the branching density as some of the most relevant qualitative descriptors, in relation to the aesthetic aspect. When assessing consumer acceptance and preference for ornamental peppers, Neitzke et al. (2016) found that qualitative characters, compared to quantitative characters, were preferred for ornamental pepper fruits and that the greatest preference was for plants with fruits with color contrasting to the foliage.

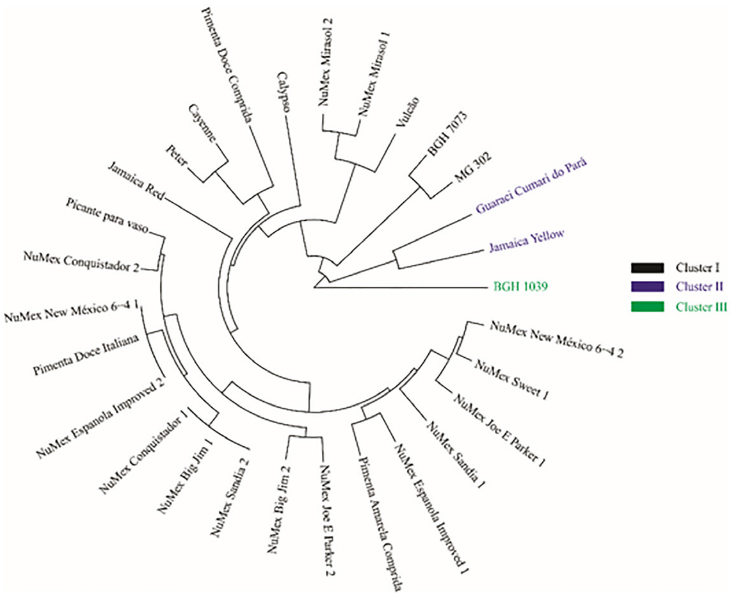

Figure 2. Dendrogram of 29 genotypes of *C. annuum*, based on the neighbor joining method, obtained from of qualitative morpho-agronomic traits data. The different colors represent the clusters of similar accessions formed using the Tocher clustering method.

Quantitative and qualitative traits clustering

The genetic diversity analysis among the 29 genotypes based on both quantitative and qualitative traits revealed the formation of five groups, and 22 genotypes were allocated in the first cluster (Figure 3). These results indicate the importance of morpho-agronomic quantitative and qualitative traits in the quantification of the genetic diversity of peppers, since they enable the efficient separation of the genetic similarity groups.

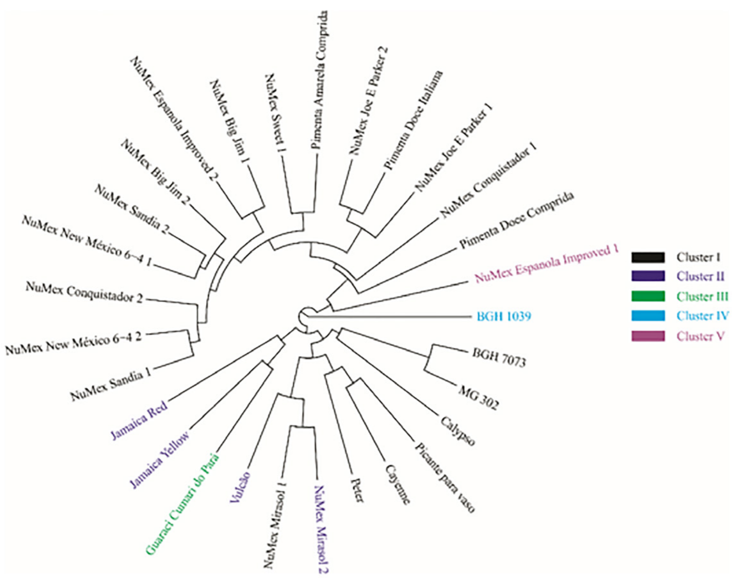

Figure 3. Dendrogram of 29 genotypes of *C. annuum,* based on the neighbor joining method, obtained from BLUP means of quantitative morpho-agronomic traits and qualitative morpho-agronomic traits data. The different colors represent the clusters of similar accessions formed using the Tocher's clustering method.

Other studies with *Capsicum* have shown variability between genotypes through the Tocher's clustering, but none of the studies have the same genotypes used in the present study. Silva Neto et al. (2014) working with a population based on ornamental pepper trees (*C. annuum* L.), reported the formation of eight clusters to study 54 genotypes. Pessoa et al. (2018) evaluated the genetic diversity of 16 *Capsicum annuum* L. genotypes, 15 accessions and the cultivar Calypso, based on 28 quantitative morpho-agronomic characteristics observed the formation of five distinct groups using the Tocher's method.

In a similar study, Nascimento et al. (2015) analyzed the genetic diversity in 324 genotypes of ornamental pepper trees (*C. annuum*), using quantitative and qualitative data. Based on the 19 qualitative characteristics, 93 groups were formed. For the 22 quantitative traits, the 324 genotypes were grouped into 50 different groups. When the quantitative and qualitative characters were analyzed together, 75 different groups were formed. According to Gonçalves et al. (2008) and Tsivelikas et al. (2009), a combined analysis of quantitative and qualitative data can provide a better understanding of genetic diversity and a more comprehensive approach to the characterization of genotypes, contributing to the determination of further breeding strategies.

Relative importance and discard of traits

The evaluation of the relative importance of the traits in the genetic diversity of the 29 genotypes of the *C. annuum*, using the Singh method (1981), indicated that the five main traits were: Fruit length (31,35%), number of seed / fruit (13,98%), number of fruits / planta (17,50%), stem length (11,79%) and canopy diameter (9,95%) (Table 3). This indicates that these characteristics are the most efficient in explaining the dissimilarity between the genotypes, and should be prioritized in studies of dissimilarity among ornamental pepper accessions.

Table 3. Relative contribution of quantitative and qualitative morph-agronomic traits, evaluated in 29 genotypes of the *C. annuum*, based on the Sigh method.

traits	S.j	relative importance (%)
Branch density	6.00	0.01
Leaf shape	362.05	0.29
Corolla color	425.80	0.34
Fruit shape	12.00	0.01
Immature fruit color	4098.42	3.35
Intermediary fruit color	281.00	0.23
Ripe fruit color	1507.84	1.23
Plant height	97.86	0.08
Stem length	14443.71	11.79
Stem diameter	348.16	0.28
Canopy diameter	12182.13	9.95
Leaf size	3359.83	2.74
Corolla diameter	1349.08	1.10
Fruit weight	587.53	0.48
Fruit length	38384.91	31.35
Fruit diameter	2532.49	2.07
Pericarp thickness	92.57	0.08
Fresh mass	2850.16	2.33
Dry mass	947.89	0.77
Number of seed /fruit	17114.96	13.98
Number of fruits /plant	21430.52	17.50

S.j, Singh statistic (1981).

The rest of the traits have lower relative importance, but should not be discarded, since the with drawal of the less important trait (average height) alters the clustering pattern of the genotypes. Thus, all of the traits used in this work were considered for the quantification of the genetic diversity of the genotypes. When the relative importance of quantitative traits was contrasted with the qualitative traits, it was observed that the latter contributed with 94.53% of the total genotypes discrimination. Therefore, it can be inferred that the genotypes of the *C. annuum* presented greater genetic variability in terms of quantitative traits, when compared with qualitative traits.

When assessing the genetic diversity of promising *Capsicum annuum* L. accessions for ornamental purposes, Pessoa et al. (2018) observed that among the characters studied, those that most contributed to the genetic divergence between accessions were: fresh fruit mass (24.38%), stem diameter (14.85%), fruit diameter (11, 68%), fruit weight (11.29%), plant height (6.67%), canopy diameter (5.24%) and number of fruits per plant (4.68%).

Among the variables that contributed the least to the divergence are leaf length, flower diameter and thickness of the pericarp. Lima et al. (2019) found that fruit weight (9,784%), canopy width (9,725%) and corolla length (9,092%) were the main contributors to the divergence. The characters that contributed less were fresh weight (0.699%), larger fruit diameter (0.544%) and stem diameter (0.540%).

Conclusions

The genotypes of *C. annuum* evaluated have potential for use with ornamental purposes, with greater genetic variability in terms of quantitative morph-agronomic characteristics, when compared to qualitative characteristics.

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