MARIA EDUARDA DA SILVA GUIMARÃES

AVALIAÇÃO DE GENÓTIPOS DE PIMENTA (*Capsicum annuum*) PARA FINS ORNAMENTAIS

Tese apresentada à Universidade Federal de Viçosa, como parte das exigências do Programa de Pós-Graduação em Genética e Melhoramento, para obtenção do título de *Doctor Scientiae*.

Orientador: Fernando Luiz Finger

Coorientadores: Ariana Mota Pereira
Pedro Crescêncio Souza Carneiro

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Assentimento:

Maria Eduarda da Silva Guimarães
Autora

Fernando Luiz Finger
Orientador

Ao meu amado companheiro, esposo e amigo Julio César,
aos meus queridos pais Joaquim e Vitória
ao meu querido irmão Maxuel e
aos meus preciosos amigos e irmãos em Cristo,
DEDICO.

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RESUMO

GUIMARÃES, Maria Eduarda da Silva, D.Sc., Universidade Federal de Viçosa, outubro de 2020. **Avaliação de genótipos de pimenta (*Capsicum annuum*) para fins ornamentais**. Orientador: Fernando Luiz Finger. Coorientadores: Ariana Mota Pereira e Pedro Crescêncio Souza Carneiro.

O objetivo do presente estudo foi estimar a variabilidade genética de genótipos de *Capsicum annuum* e selecionar os genótipos com maior o potencial para ornamentação, com base em características morfo-agronômicas. Foram avaliadas 14 características morfo-agronômicas quantitativas e 7 qualitativas em 29 genótipos de *C. annuum,* no delineamento inteiramente casualizado, com 5 repetições. Para avaliar a diversidade genética dos genótipos foi realizada uma análise de agrupamento pelo método de Tocher. Foi avaliada a importância relativa de caracteres pelo método de Singh. Com base em 12 características quantitativas, foi realizada a análise fatorial e determinação dos escores dos fatores obtidos. Utilizando 11 características quantitativas, foi caculado o índice de seleção baseado em análise fatorial e ideótipo-design (FAI-BLUP), em que a cultivar Calypso foi utilizada como ideótipo. Com base na análise de agrupamento, observou-se a formação de 7 grupos de similaridade genética em termos de características quantitativas, 3 em termos de características qualitativas e 5 grupos considerando as características em conjunto. Os caracteres comprimento do fruto e do caule, número de sementes/fruto, número de frutos/planta e diâmetro da copa destacaram-se na explicação da dissimilaridade entre os genótipos avaliados. As 12 características avaliadas foram resumidas em 3 fatores: "qualidade de fruto", "porte da planta" e a "arquitetura de planta". Com a determinação dos escores dos fatores os genótipos do Novo México: NuMex Conquistador 1, Espanola Improved 2, Joe E Parker 2, New México 6-4 2, Sandia 2, Sweet 1 e os brasileiros BGH 1039, Jamaica Yellow, Pimenta Doce Italiana, Pimenta Doce Comprida, Picante para Vaso e Vulcão, foram indicados como os de maior potencial para ornamentação, de acordo com os fatores obtidos. Através do índice FAI-BLUP os genótipos NuMexs Big Jim 2, Espanola Improved 1, Sandia 2 e Sweet 1 e os genótipos BGH 1039 e 7073, Pimenta Amarela Comprida, Picante para Vaso e Vulcão foram os mais próximos ao ideótipo e, portanto, os de maior potencial para ornamentação. Os genótipos selecionados apresentaram ganhos genéticos para a maioria dos caracteres, com exceção apenas do diâmetro do caule e espessura de pericarpo.

Palavras-chave: Análise de agrupamento. Análise fatorial. Diversidade genética. Ideótipo. Índice FAI-BLUP.

ABSTRACT

GUIMARÃES, Maria Eduarda da Silva, D.Sc., Universidade Federal de Viçosa, October, 2020. **Evaluation of pepper genotypes (*Capsicum annuum*) for ornamental purposes**. Adviser: Fernando Luiz Finger. Co-advisers: Ariana Mota Pereira and Pedro Crescêncio Souza Carneiro.

The aim of the present study was to estimate the genetic variability of Capsicum annuum genotypes and to select the genotypes with the greatest potential for ornamentation, based on morpho-agronomic characteristics. 14 quantitative and 7 qualitative morpho-agronomic traits were evaluated in 29 C. annuum genotypes, in a completely randomized design, with 5 replications. To assess the genetic diversity of the genotypes, a cluster analysis was performed using the Tocher method. The relative importance of characters was evaluated using the Singh method. Based on 12 quantitative characteristics, factor analysis and determination of the scores of the factors obtained were performed. Using 11 quantitative characteristics, the selection index based on factor analysis and ideotype-design (FAI-BLUP) was calculated, in which the cultivar Calypso was used as an ideotype. Based on the cluster analysis, it was observed the formation of 7 groups of genetic similarity in terms of quantitative characteristics, 3 in terms of qualitative characteristics and 5 groups considering the characteristics together. The characters length of the fruit and stem, number of seeds / fruit, number of fruits / plant and canopy diameter stood out in the explanation of the dissimilarity between the evaluated genotypes. The 12 characteristics evaluated were summarized in 3 factors: “fruit quality”, “plant size” and “plant architecture”. With the determination of factor scores the genotypes of New Mexico: NuMex Conquistador 1, Espanola Improved 2, Joe E Parker 2, New Mexico 6-4 2, Sandia 2, Sweet 1 and the Brazilians BGH 1039, Jamaica Yellow, Italian Sweet Pepper, Sweet Long Pepper, Spicy for Vase and Volcano, were indicated as those with the greatest potential for ornamentation, according to the factors obtained. Through the FAI-BLUP index, the NuMexs Big Jim 2, Espanola Improved 1, Sandia 2 and Sweet 1 genotypes and the BGH 1039 and 7073 genotypes, Long Yellow Pepper, Spicy for Pot and Volcano were the closest to the ideotype and, therefore, greater potential for ornamentation. The selected genotypes showed genetic gains for most of the characters, with the exception of just the stem diameter and pericarp thickness.

Keywords: Cluster analysis. Factor analysis. FAI-BLUP index. Genetic diversity. Ideotype.

SUMÁRIO

1 INTRODUÇÃO GERAL

O cultivo de pimentas (*Capsicum* spp.) tem grande importância socioeconômica mundial. Compõem um importante segmento do mercado de hortaliças frescas no Brasil, pela alta rentabilidade e por empregar elevada mão de obra no setor agrícola e comercial (HAVERROTH; NEGREIROS, 2011).

Além da importância da pimenta na indústria alimentícia, na farmacologia, na culinária e na medicina, as pimenteiras têm sido comercializadas no mercado de plantas ornamentais. O setor de flores e plantas ornamentais vem se destacando expressivamente no agronegócio brasileiro nos últimos anos. No ano de 2016, o mercado de flores e plantas ornamentais no Brasil atingiu o faturamento anual de R$ 6,7 bilhões, com expectativa de crescimento de 6 a 8% no ano de 2017 (IBRAFLOR, 2016).

As pimenteiras ornamentais usualmente são cultivadas em vasos, contudo, têm sido utilizadas também como planta de corte na composição de arranjos florais (WIEN; MAZOUREK, 2013). O uso na ornamentação se deve ao porte reduzido das plantas; frutos e folhas de diferentes colorações e formatos; frutos eretos e vistosos, com diferentes cores nos diferentes estágios de maturação; durabilidade dos frutos e folhas e a capacidade de crescer em recipientes como planta perene (NEITZKE et al., 2010; NASCIMENTO et al., 2013).

Capsicum annuum é uma das espécies mais utilizada no plantio em vaso, devido ao pequeno porte e a grande variabilidade de formas e cores dos frutos (RÊGO et al., 2011; FINGER et al., 2012). Apesar da grande variabilidade existente do gênero *Capsicum* e da espécie *C. annuum*, apenas uma parte tem sido explorada. O que vem estimulando o desenvolvimento de programas de melhoramento com foco em variedades mais produtivas, resitentes a pragas e doenças e com potencial uso na ornamentação (MEDEIROS et al., 2014; LEITE et al., 2016; COSTA et al., 2019).

O estudo de características morfo-agronômicas está diretamente ligado à utilização destes materiais em programas de melhoramento genético (SIGNORINI et al., 2013; BIANCHI et al., 2016). A caracterização morfológica enseja a coleta de uma série de dados que possibilitam a identificação e o estudo da variabilidade genética de determinado genótipo (RAMOS; QUEIROZ, 1999). O estudo da diversidade genética é uma importante ferramenta para o conhecimento da variabilidade entre indivíduos (VASCONCELOS et al., 2012) e pode ser realizada utilizando várias características agronômicas, morfológicas e moleculares (NASCIMENTO et al., 2015; COSTA et al., 2016; LEITE et al., 2016).

A predição da divergência genética pode ser realizada por métodos de agrupamentos baseados em medidas de dissimilaridade, estimadas previamente. A separação dos acessos em grupos permite a verificação da máxima homogeneidade dentro do grupo e a máxima heterogeneidade entre grupos (SOUSA et al., 2012). É possível, ainda, dividir um grupo original de observações em vários grupos, seguindo um critério de similaridade ou dissimilaridade (CRUZ et. al, 2012). Dos métodos de agrupamento, os mais utilizados são os hierárquicos e os de otimização (CRUZ et al., 2011).

Por meio da análise de agrupamento é possível obter avaliar os genitores e identificar as combinações híbridas de maior efeito heterótico e maior heterozigose, informações de grande importância em programas de melhoramneto (SUDRÉ et al., 2010; CRUZ et. al, 2012). A variabilidade genética pode ser analisada por métodos específicos ou combinações de métodos, que incluem variáveis quantitativas e qualitativas (BARBÉ et al., 2010). Estudos de divergência, envolvendo caracteres morfoagronômicos, por meio de métodos aglomerativos, têm sido realizados em pimentas do gênero *Capsicum* (FARIA et al., 2012; SILVA et al., 2017; ARAÚJO et al., 2018) incluindo aquelas destinadas a ornamentação (NEITZKE et al., 2010; RÊGO et al., 2010).

Como na analise de agrupamento, a utilização de métodos multivariados viabiliza a combinação de diversas informações e facilita a caracterização dos genótipos com base em um complexo de variáveis (CRUZ; REGAZZI, 1994). A Análise de Fatores (AF) é um método estatístico multivariado que vem sendo aplicado em estudos agronômicos, com várias finalidades, inclusive no melhoramento (GRANATE et al., 2001). Por meio da análise fatorial é possível avaliar a estrutura de variabilidade de um conjunto de variáveis visando reduzir a informação contida em um número menor de variáveis (variáveis latentes ou fatores).

Os fatores podem ser denominados de acordo com o conhecimento do pesquisador e não apresentam correlação entre si, todavia, as características agrupadas dentro do fator são altamente correlacionadas. A análise de fatores tem sido utilizada na redução da dimensionalidade de conjuntos de dados com o intuito de verificar a estrutura empírica de diversas características (SILVA et al., 2011; SILVA et al., 2014; TEIXEIRA, et al., 2015) contudo, estudos com pimentas ainda são incipientes. Após a identificação e interpretação dos fatores, as variáveis latentes podem ser preditas através dos escores (TEIXEIRA, et al., 2015). Os escores podem ser utilizados em análises posteriores, como por exemplo, no cálculo de índices de seleção (FERREIRA et al., 2005; SILVA et al., 2018; WOYANN et al., 2019).

Os índices de seleção permitem a seleção para mais de uma característica de forma simultânea, o que aumenta a chance de sucesso de um programa de melhoramento. O índice é formado pela combinação linear ótima de um conjunto de características de interesse (BERNARDO, 2002; CRUZ; CARNEIRO, 2003). Vários índices foram propostos, porém a existência de multicolinearidade na matriz de covariância compromente a análise e interpretação dos resultados (ROCHA et al., 2018).

Com o intuito de contornar os problemas de multicolinearidade, Rocha et al. (2018) propuseram o índice FAI-BLUP (Factor analysis and ideotype-design) que combina múltiplas características e pode ser facilmente adaptado para incorporar várias gerações e múltiplas características simultaneamente. Esse índice considera as correlações genéticas entre as características-alvo e o ideótipo de interesse, livres de multicolinearidade e sem a necessidade de pesos econômicos. Além disso, esse índice permite a seleção de genótipos com características mais próximas ao do ideótipo, que reúne um conjunto de características desejáveis para o mercado, determinado pelo melhorista de acordo com a cultura.

Diante do exposto, o objetivo do presente estudo, foi estimar e avaliar a variabilidade genética de genótipos de *Capsicum annuum* e selecionar os genótipos com maior o potencial para ornamentação, com base em características morfo-agronômicas.

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CAPÍTULO 1:

Genetic diversity of pepper genotypes for use as ornamental plants

ABSTRACT

The commercialization of ornamental pepper trees constitutes an important source of income for the agricultural populations. Despite the great variability that exists, in Brazil few commercial varieties are used for this purpose. The presence of genetic diversity is the main criterion for a successful selection and progress in a breeding program. The objective of this study was to quantify the genetic diversity among pepper genotypes, aiming at their use in ornamentation, through the description of morpho-agronomic characteristics. 14 quantitative characteristics and seven qualitative characteristics related to plant, flower and fruit were evaluated in 29 pepper (*Capsicum annuum*) genotypes. Using the mixed model methodology and analysis of genetic diversity, genetic variability was verified between the genotypes. 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. Thus, the genetic variability of the genotypes can be exploited to produce superior combinations while.

Key words: *Capsicum annuum*. Clustering. Morpho-agronomic characterization.

RESUMO

A comercialização de pimenteiras ornamentais constitui importante fonte de renda para as populações agrícolas. Apesar da grande variabilidade existente, no Brasil poucas variedades comerciais são destinadas a esse fim. A presença de diversidade genética é o principal critério para uma seleção e progresso bem-sucedidos em um programa de melhoramento. O objetivo deste estudo foi quantificar a diversidade genética entre genótipos de pimenta, visando seu uso na ornamentação, através da descrição de características morfo-agronômicas. 14 características quantitativas e sete características qualitativas relacionadas a plantas, flores e frutos foram avaliadas em 29 genótipos de pimenta (*Capsicum annuum*). Utilizando a metodologia do modelo misto e a análise da diversidade genética, verificou-se a variabilidade genética entre os genótipos. Os genótipos foram divididos em sete grupos de similaridade genética em termos de características quantitativas, três em termos de características qualitativas e cinco grupos

considerando as características em conjunto. Assim, a variabilidade genética dos genótipos pode ser explorada para produzir combinações superiores.

Palavras-chave: Análise de agrupamento. *Capsicum annuum.* Caracterização morfo-agronômica.

1 INTRODUCTION

The demand for pot 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 containers 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 pot planting (FINGER et al., 2012). However, few commercial varieties 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 greater production, resistance to diseases and pests, fruit quality and 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 clusters 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 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 aim of this study was to quantify the genetic diversity among pepper genotypes, aiming at their use in ornamentation, through the description of morpho-agronomic characteristics.

2 MATERIAL AND METHODS

2.1 Plant materials

29 genotypes of *Capsicum annuum* (Table 1), selected for their potential for ornamentation, was evaluate. The experiment was conducted in a greenhouse, in the Department of Plant Science, in the Federal University of Viçosa. The experiment was installed in a completely randomized design, with 29 treatments and five replications. The experimental unit was composed of one plant per pot. Sowing was carried out in 120-cell polystyrene trays containing commercial substrate. Two seeds were used per cell being made thinning, if necessary, after germination. When the plants reached the stage of four pairs of definitive leaves were transplanted into 800-ml pots, being a plant per pot. Whenever necessary, the cultural treatments recommended for the culture.

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

2.2 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).

14 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; immature fruit color intermediary fruit color; ripe fruit color. The evaluations of the listed characteristics were visual.

2.3 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) (RESENDE, 2007):

$$y = Xu + Zg + e$$

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 (neighbor joining), using the R program (R DEVELOPMENT CORE TEAM, 2015).

3. RESULTS AND DISCUSSION

3.1 Genetic variability

Significant clone 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.

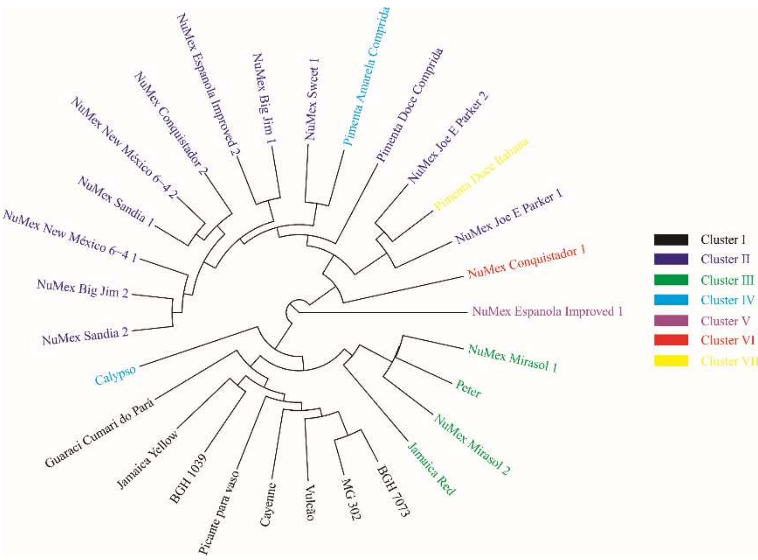
Likelihood ratio test, using the chi-squared test with one degree of freedom.

3.2 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 group I: 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.

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.



Fonte: Guimarães, 2020, p. 26.

The genotypes NuMex Mirasol 1, NuMex Mirasol 2, Jamaica Red and Peter form the group III. Numex Mirasol plants have erect size and fruits and can be indicated for making bouquets. 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 group IV 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 pot. In comparison to the cultivar Calypso, Pimenta Amarela Comprida presents larger and heavier fruits, in addition to greater plant height.

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 group VI 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.

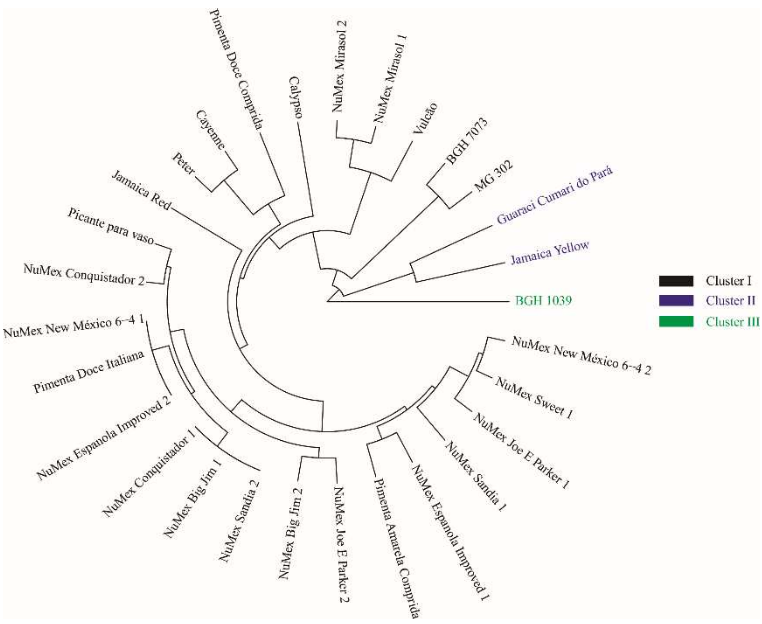
When considering the variability of the qualitative characteristics evaluated in the 29 genotypes, it was possible to distinguish a smaller number of clusters when comparing to the quantitative characteristics. Only three groups were formed using Tocher's optimization method. Out of 89.66% of the genotypes were concentrated in the group I. 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 cluster criterion is given by the maximum value (θ) of the dissimilarity measure found in the cluster 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.

3.3 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 clusters by the Tocher optimization method. Sixty 89,66% of the accessions were concentrated in the group 1, 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).

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.



Fonte: Guimarães, 2020, p. 28.

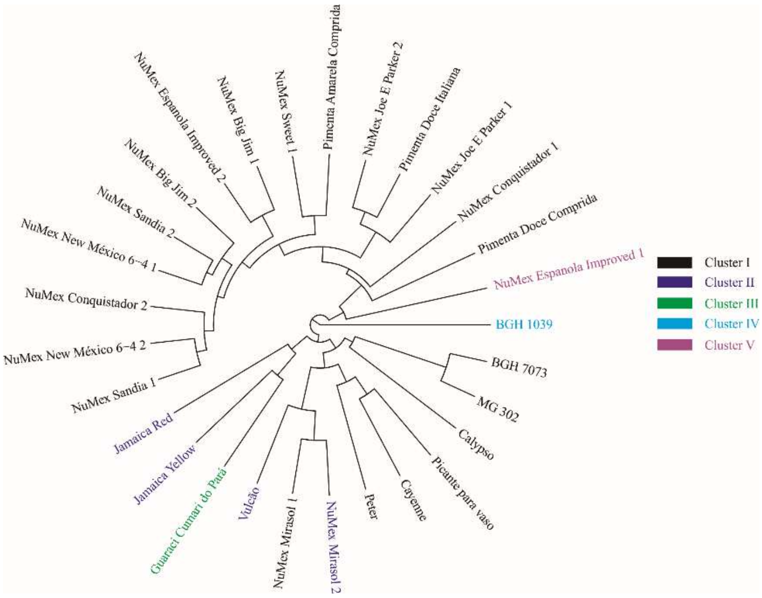
The genotypes of New Mexico were all grouped in group I, it is observed that there is low variability in relation to qualitative characters. Mainly in relation to the growth habit characters, leaf shape, branch density and fruit shape that showed little or no variation in classification. The opposite was observed by Bento et al (2007) who, using Tocher's method, based on quantitative variables, observed that the 29 accessions of Capsicum spp. analyzed were divided into only two groups. In the analysis of qualitative variables, the formation of seven groups was observed. Sudré et al. (2006) when studying the phenotypic divergence between 59 accessions of Capsicum spp. using 15 qualitative descriptors, they obtained the formation of eight groups by the Tocher method.

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.

3.4 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 clusters, 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 clusters.

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.



Fonte: Guimarães, 2020, p. 29.

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. 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. They 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.

3.5 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/plant (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 genotypes.

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 (9.78%), canopy width (9.73%) and corolla length (9.092%) were the main contributors to the divergence. The characters that contributed less were fresh weight (0.69%), larger fruit diameter (0.54%) and stem diameter (0.54%).

4. CONCLUSION

1. 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.
2. The traits: Fruit length, number of seed/fruit, number of fruits/plant, stem length and canopy diameter, are the most efficient in explaining the dissimilarity between genotypes.

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CAPÍTULO 2:

Determination of factors in pepper characteristics for ornamental purposes

ABSTRACT

The aim of the present work was to use factor analysis to describe the variability structure of morpho-agronomic characteristics of pepper genotypes (Capsicum annum) and to evaluate the ornamental potential of these genotypes. For that, 12 quantitative traits were evaluated in 29 pepper genotypes (Capsicum annuum), in a completely randomized design, with five replications. Of the created factors, 3 presented practical interpretation, grouping a total of 12 variables in factors related to “fruit quality” (8 variables), “plant size” (2 variables) and “plant architecture” (2 variables). Based on the score values of the 3 factors found, the genotypes NuMex Conquistador 1, NuMex Espanola Improved 2, NuMex Joe E Parker 2, NuMex New Mexico 6-4 2, NuMex Sandia 2, NuMex Sweet 1, BGH 1039, Jamaica Yellow, Italian Sweet Pepper, Long Sweet Pepper, Spicy for Vase and Volcano presented greater potential for ornamentation and were indicated for incorporation in future breeding programs.

Key words: *Capsicum annuum.* Factor analysis. Morpho-agronomic characterization.

RESUMO

O objetivo do presente trabalho foi utilizar a análise de fatores para descrever a estrutura de variabilidade de características morfo-agronômicas de genótipos de pimenta (*Capsicum annum*) e avaliar o potencial ornamental destes genótipos. Para isso 12 características quantitativas foram avaliadas em 29 genótipos de pimenta (*Capsicum annuum*), no delineamento inteiramente casualisado, com cinco repetições. Dos fatores criados, 3 apresentaram interpretação prática, agrupando um total de 12 variáveis em fatores relacionados a “qualidade de fruto” (8 variáveis), “porte da planta” (2 variáveis) e a “arquitetura de planta” (2 variáveis). Com base nos valores de escores dos 3 fatores encontrados, os genótipos NuMex Conquistador 1, NuMex Espanola Improved 2, NuMex Joe E Parker 2, NuMex New México 6-4 2, NuMex Sandia 2, NuMex Sweet 1, BGH 1039, Jamaica Yellow, Pimenta Doce Italiana, Pimenta Doce Comprida, Picante para Vaso e Vulcão apresenaram maior potencial para ornamnetação e foram indicados para incorporação em futuros programa de melhoramento.

Palavras-chave: Análise de fatores. *Capsicum annuum.* Caracterização morfo-agronômica.

1 INTRODUCTION

Pepper is an economically important crop worldwide. In addition to their importance in food, pharmacology, dentistry and medicine, peppers have great potential for ornamentation. Among pepper species, *Capsicum annuum* is the most used in planting with ornamental purposes, due to its small size and the great variability of fruit shapes and colors (FINGER et al., 2012). Despite the great variability that exists, few commercial varieties are used for ornamentation in the country (VASCONCELOS et al., 2012).

The ornamentals market lacks novelties and new products add competitiveness to the sector and considerably increase the profit margin (COSTA et al., 2019). The study of morphological and agronomic characteristics of cultivated plants is important to understand the genetic divergence of the set of germplasm available for use in a breeding program (ELIAS et al., 2007).

The study of the morphological characters can be carried out individually or simultaneously. Simultaneous analysis allows to conclude for more than one variable and thus better interpret the relationship between them. Multivariate statistics allows the study of complex phenomena, as it performs the treatment of several variables simultaneously (JOHNSON; WICHERN, 2007).

Among the multivariate techniques, factor analysis allows to reduce the dimension of the analyzed variables. It makes it possible to group correlated variables into unobservable factors (latent variables), defined through the correlation between variables. After the identification and interpretation of the factors, the latent variables can be predicted and their values used in later analyzes (SILVA et al., 2014).

Given the above, this study aimed to verify the empirical structure of morpho-agronomic characteristics of *Capsicum annuum* genotypes, so that correlated variables are grouped into a smaller number of latent (interpretable) variables, reducing the dimensionality of the data set. In addition to estimating the factor scores and according to them, evaluate the genotypes with the greatest potential for ornamentation.

2 MATERIAL AND METHODS

2.1 Plant materials

The experiment was conducted in a greenhouse, in the Department of Plant Science, in the Federal University of Viçosa, using 29 genotypes of *C. annuum*, selected for their potential for ornamentation. A completely randomized design was used, with 29 treatments (genotypes) and five replications, where the experimental unit consisted of one plant per pot. Sowing was carried out in 120-cell polystyrene trays containing commercial substrate. Seedlings with four pairs of permanent leaves were transplanted in 800-ml pots 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

Number of genotypes	Common name
1	NuMex Big Jim 1
2	NuMex Big Jim 2
3	NuMex Conquistador 1
4	NuMex Conquistador 2
5	NuMex Espanola Improved 1
6	NuMex Espanola Improved 2
7	NuMex Joe E Parker 1
8	NuMex Joe E Parker 2
9	NuMex Mirasol 1
10	NuMex Mirasol 2
11	NuMex New México 6-4 1
12	NuMex New México 6-4 2
13	NuMex Sandia 1
14	NuMex Sandia 2
15	NuMex Sweet 1
16	BGH 1039

17	BGH 7073
18	MG 302
19	Calypso
20	Cayenne
21	*Guaraci Cumari do Pará*
22	Jamaica Red
23	Jamaica Yellow
24	Peter
25	*Pimenta Doce Italiana*
26	*Pimenta Doce Comprida*
27	*Pimenta Amarela Comprida*
28	*Picante para Vaso*
29	*Vulcão*

2.2 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). 12 characteristics of plant, flower and fruit were evaluated: FW-fruit weight (grams); FL-fruit length (mm); FD-fruit diameter (mm); TP-thickness of the pericarp (mm); NS/FR-number of seeds/fruit; FM- fresh matter (grams); DM – Dry matter (grams); CORD-diameter of the corolla (mm); PH-Plant Height (cm); SL-stem length (cm); CAD-canopy diameter (cm); SD-stem diameter (mm).

2.3 Statistical analyses

The factorial model adopted for an observable X_i variable, with mean μ_i can be represented by the (JOHNSON & WICHERN, 2007):

$$X_i - \mu_i = l_{i1}F_1 + l_{i2}F_2 + \cdots + l_{im}F_m + \varepsilon_i$$

Where: X_i represents the observable variables with mean μ_i, i=1,2,...,p e m ≤ p, and m ≤p, in which p is the number of observable variables; The elements l_{ij} refer to the factor loads associated with the ith variable X_i and the jth common factor; $F_{j,,}$ j = 1,2, ... m. Fj corresponds to common unobservable latent factors; ε_i are the random errors associated with the ith variable X_i.

To measure the adequacy of the analysis, the Kaiser-Meyer-Olkin (KMO) criterion and Bartlett's sphericity test were used (FERREIRA, 2011). The number of factors was defined using two criteria. The first criterion was the analysis of the proportion of the total explained variance. An explanation percentage of 70% of the total variability was considered, which according to Ferreira (2011) is sufficient to satisfactorily reduce the data.

The second criterion used was the eigenvalue criterion or Kaiser criterion in which the number of factors will be equal to the number of eigenvalues greater than or equal to 1 (KAISER, 1958). In addition to the criteria used, the choice of the number of factors (m) took into account the interpretability of the factors and the principle of parsimony (MINGOTI, 2005).

The relationship between variables and common factors was made through loadings (l_{ij}), or factorial loads, which represent the correlation between each variable and the respective factors. The loadings values, as well as the simple correlation, vary between -1 and 1 and, the higher the factor load (in module) the greater the correlation between the variable and the respective factor. Making it possible to name the factors based on those variables that are most related to them.

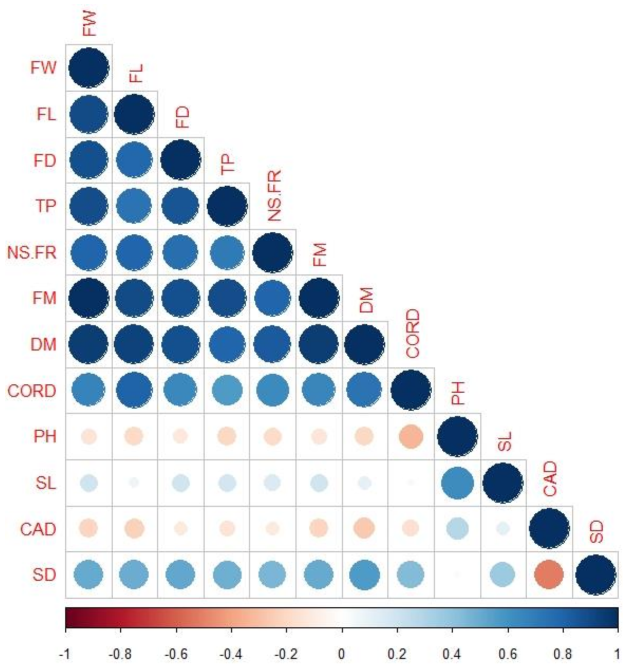
For a better interpretation of the distribution of variables in the respective factors, varimax rotation was used. To evaluate the proportion of each variable explained by the factor to which it belongs and the proportion explained by the random error, the values of commonality were calculated. After identifying and interpreting the factors, the values of the scores for each factor were calculated. Through the scores it is possible to predict the values for each sample unit and use these latent variables (factors) in later analyzes. The R software (R Development Core Team 2015) was used for the analysis.

3 RESULTS AND DISCUSSION

3.1 Correlation analysis

In order to assess the association structure between the variables, the correlation matrix was calculated. The existence of a correlation between the variables in the data set is of great importance for factor analysis, since this technique aims to identify relationships between variables. This relationship only exists in the presence of a correlation between them (CORRAR et al., 2009). To improve the visualization and interpretation of the correlations between the variables, a correlogram was created (Figure 1). The correlogram graph represents the bivariate correlations so that the positive correlations are blue, with stronger tones for the higher correlations. Negative correlations are in pink, with stronger tones for higher correlations. (SILVA et al., 2014).

Figure 1 - Graph of the sample correlations of the 12 variables referring to the 29 genotypes of *Capsicum annuum* evaluated. FW-fruit weight (grams); FL-fruit length (mm); FD-fruit diameter (mm); TP-thickness of the pericarp (mm); NS/FR-number of seeds/fruit; FM- fresh matter (grams); DM – Dry matter (grams); CORD-diameter of the corolla (mm); PH-Plant Height (cm); SL-stem length (cm); CAD-Canopy diameter (cm); SD-stem diameter (mm).



Fonte: Guimarães, 2020, p. 41.

It is observed that there are strong and positive correlations between the variables FW, FL, FD, TP, NS/FR, FM, DM e CORD, and between variables PH e SL. In addition to a very strong and negative correlation between the variables CAD e SD. As most of the variables showed high correlations with each other, it can be assumed that the use of factor analysis will be promising.

3.2 Factor analysis

According to the KMO index (0.74), considered satifastory by criteria of Pallant (2007), which suggests 0.60 as a reasonable value, and with Bartlett's sphericity test, which showed statistical significance ($\rho < 0.01$), it was found that the data are adequate for factor analysis. To determine the number of factors to be used in the factor analysis, it is necessary to calculate the eigenvalues of the correlation matrix. Eigenvalues are numbers that reflect the importance of the factor, and divided by the sum of all eigenvalues indicate the proportion of the total variability of the data that is explained by the factor (SILVA et al., 2014).

Table 1 shows the eigenvalues and the accumulated variance of the 12 main components obtained from the genetic correlation matrix. Only the first three components are associated with eigenvalues that are greater than one. Thus, according to Kaiser's criteria (KAISER, 1958), the data can be condensed into three factors. The accumulated variance of the first three components was greater than 80%, indicating that these three factors are sufficient because they represent 84.46% of all variability. Mingoti (2005) suggests that the number of factors to be retained should reflect a value greater than 70% of the original data variability.

Table 1 – Eigenvalue estimates by principal components analysis and the variance proportion explained by them

Eigenvalue	Eigenvalue (%)	Accumulated variance (%)
7.14	59.48	59.48
1.78	14.85	74.33
1.22	10.13	84.46
0.53	4.42	88.88
0.42	3.47	92.35
0.30	2.51	94.86

0.26	2.20	97.06
0.16	1.31	98.37
0.11	0.96	99.33
0.053	0.44	99.77
0.027	0.229	99.99
0.0002	0.01	100

The Varimax rotation method was used to give factors greater potential for interpretability, making the factorial solution simpler and more meaningful (JOHNSON; WICHERN, 2007). After varimax rotation (Table 2), it was observed that the first factor (F1) was made up by variables related to fruit characteristics (FW, FL, FD, TP, FM, DM, CORD). This result indicates that the variables related to fruits are highly correlated with each other, which makes it possible to denote this factor as "fruit quality". It is observed that all variables have positive correlation values, that is, the higher the value of these variables, the higher the value of the scores of the new variable formed.

Table 2 – Factorial loadings after varimax rotation and communalities

	Fruit quality	Plant size	Plant architecture	Commonality
FW	**0.96**	0.0	0.15	0.94
FL	**0.92**	-0.07	0.16	0.88
FD	**0.91**	0.08	0.10	0.85
TP	**0.88**	0.04	0.11	0.79
NS/FR	**0.86**	0.01	0.07	0.75
FM	**0.96**	0.06	0.15	0.94
DM	**0.95**	-0.03	0.22	0.94
CORD	**0.76**	-0.19	0.15	0.64
PH	-0.19	**0.88**	-0.16	0.83
SL	0.15	**0.91**	0.10	0.86
CAD	-0.05	0.21	**-0.92**	0.89
SD	0.45	0.27	**0.74**	0.82

FW-fruit weight (grams); FL-fruit length (mm); FD-fruit diameter (mm); TP-thickness of the pericarp (mm); NS/FR-number of seeds/fruit; FM- fresh matter (grams); DM – Dry matter (grams); CORD-diameter of the corolla (mm); PH-Plant Height (cm); SL-stem length (cm); CAD-Canopy diameter (cm); SD-stem diameter (mm).

The second factor (F2) was composed of variables related to the plant length (PH, SL), denominate “plant size”. As in the previous factor for all variables, the loadings were positive, thus, the value of the score for this factor will increase according to the increase in the variables belonging to it. The third factor (F3) can be referred to as “plant architecture” since it grouped two characteristics related to diameter (SD, CAD) that are part of the determination of the architecture and harmony of the plant.

For all variables belonging to the factors that have a practical interpretation, mentioned above, the values of commonality (h_2> 0.60) were acceptable. According to Figueiredo Filho (2010) the values of commonality must be greater than 0.5. The commonality are proportion of variance (or correlation), of each variable explained, by common factors. They can also be interpreted as indexes attributed to the original variables that express, in percentage terms, how much of the variability of each variable is explained by the model adopted. Thus, the higher the commonality values, the better the adjustment of the factorial model (SILVA et al., 2014).

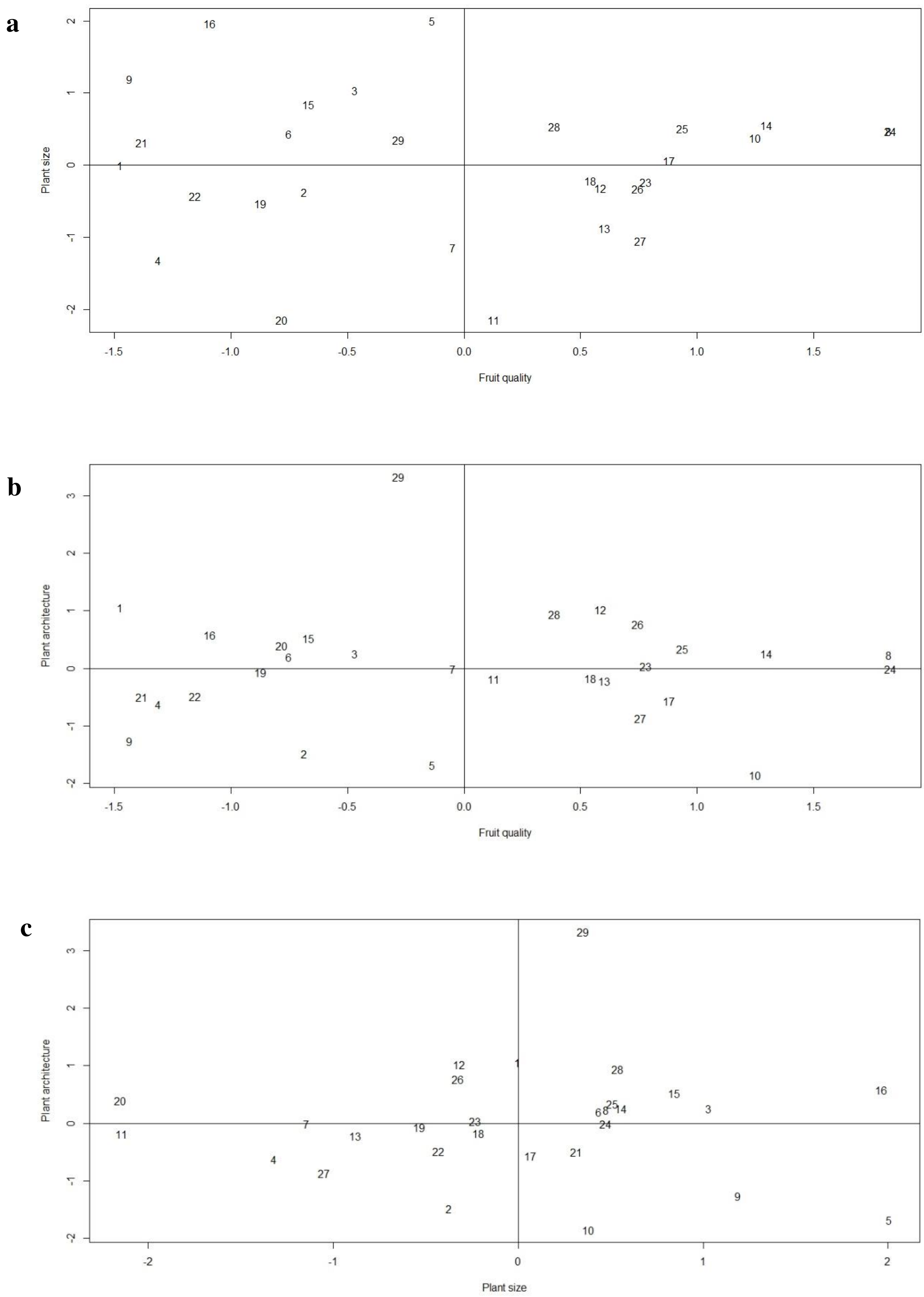
3.3 Estimation of factor scores

After factor analysis, the scores of the interpretable latent variables were estimated and their values were presented in two-dimensional graphs. This procedure allows to verify which genotypes are more related to the determined factors (SILVA et al., 2014). As the vast majority of variables showed positive loadings, the genotypes can be classified according to quadrants.

In the first quadrant, there are the genotypes that stand out positively in relation to the two factors evaluated in the graph. In the second quadrant are the genotypes that have high values of the characteristic of the Y axis and low values on the X axis. The opposite of what happens in the fourth quadrant, in which individuals have high scores for the variable of the X axis and low scores for the variable the Y axis. In the third quadrant, genotypes do not stand out in any of the variables.

According to figure 2 (a, b and c), as expected, there is a lack of association between the factors defined given the hypothesis for the construction of the factor analysis (FERREIRA, 2011).

Figure 2 - Dispersion graph between the scores of the factors “plant size” and fruit quality” (a), “plant architecture” and fruit quality” (b) and “plant architecture” and “plant size” (c).



Fonte: Guimarães, 2020, p. 45.

According to Figure 2a, genotypes 3, 5, 6, 9, 15, 16, 21, 29 have higher values of scores for "plant size" and "fruit quality". The genotypes 8, 10, 14, 17, 24, 25, 28 have higher values for “plant size” and lower values for “fruit quality”. The “plant size” factor is composed of the characters length of the stem and the height of the plant, these are of great importance in the ornamental Market. The aforementioned genotypes are not suitable for planting in small pots, as they have high values of height and stem length.

Small plants are suitable for cultivation in small pots, larger plants can be grown in larger pots or suitable for cultivation in the open environment, such as squares and streets. For ornamental peppers, it is recommended that the accessions should have a crown diameter and plant height of 1.5 to 2 times greater than the size of the pot (BARBOSA et al., 2003; BARROSO et al., 2012). The genotypes 11, 12, 13, 18, 23, 26, 27 (Figure 2a) have lower values for “plant size” and higher values for “fruit quality”, being more suitable for planting in small pots.

The genotypes 1, 3, 6, 15, 16, 20, 29 have higher values of scores for the factors “plant architecture” and “fruit quality” (Figure 2b). In the second quadrant noted the genotypes (8, 12, 14, 23, 25, 26, 28) with the highest scores for “plant architecture”, in contrast in the fourth quadrant are the genotypes 10, 11, 13, 17, 18, 27 that present higher scores for “fruit quality”. Ornamental pepper fruits are of great value mainly for their dual purpose and can be used for consumption, in addition to giving beauty to ornamental plants (RÊGO; RÊGO, 2016).

The different shapes, sizes and colors of the fruits make the plants more attractive to consumers (CARVALHO et al., 2006). The fruits with smaller diameters they are generally small and less heavy. Genotypes with small fruits are recommended for use in the improvement of pepper with ornamental purpose, because they stand out in the foliage (SILVA et al., 2015). Large and long fruits are generally more attractive to the fresh pepper market (CARDOSO et al., 2018).

In Figure 2c, observed higher score values for the factors “plant architecture” and "plant size" for the genotypes 1, 12, 20, 23, 26. The genotypes 3, 6, 8,14,15, 16, 25, 28, 29 present higher score for “plant architecture”, while the genotypes 5, 9, 10, 17, 21, 24 present higher score for the "plant size". Canopy and stem diameters are important features in the composition of the plant's architecture. Barroso et al. (2012) state that the harmony between the architecture of the plant and the size of the pot is important for determining the quality of an ornamental pepper. This character is important in the selection of genotypes, since the diameter of the stem must be sufficient to support the weight of the plant and fruits (FERREIRA et al., 2015).

Due to the small size of the pot, plants with more compact canopy are preferred. As the correlation between stem and crown diameter is negative when selecting genotypes with higher scores for plant architecture, they have higher values for stem thickness and smaller crown diameter, resulting in more compact plants.

The genotypes 3, 6, 8, 12, 14, 15, 16, 23, 25, 26, 28 and 29 have low values of scores for "fruit quality" and "plant size" and high values of scores for the “plant architecture”. Considering the selection of small, compact plants with small fruits, with potential use in ornamentation and also for consumption, the genotypes mentioned above can be used for crossbreeding and obtaining hybrids in future breeding programs. Hybridization, an improvement method, is widely used in peppers in the development of new cultivars (NASCIMENTO et al., 2015).

After identifying and estimating the scores for each factor, the latent variables can be used in later analyzes. One of the applications of factor analysis is for the calculation of selection indexes as it allows the elimination of multicollinearity. Rocha et al. (2018) proposed a new multitrait index based on factor analysis and ideotype-design (FAI-BLUP index). According to this index, the factor scores of each ideotype are projected according to the desirable and undesirable factors and the spatial probability é estimated based on genotype-ideotype distance, enabling genotype ranking.

The FAI-BLUP index was used for Silva et al. (2018) to assist the selection of hybrids of sorghum that simultaneously meet favorable traits for the production of second-generation ethanol. Rocha et al. (2019) used the FAI-BLUP index for selection of 20 inbred progenies of greater potential, toward the common bean ideotype. Already, Ferreira et al. (2005) used factor analysis to eliminate the problem of multicollinearity, which allowed the proper use of the selection index theory, for simultaneous improvement of characters from Coffea canephora var. Conilon.

4 CONCLUSIONS

1. With the analysis of factors, the 12 characteristics evaluated were reduced to only 3 factors with practical interpretation: fruit quality”, “plant size” and “plant architecture”, with a satisfactory percentage of explained variability.
2. The genotypes NuMex Conquistador 1, NuMex Espanola Improved 2, NuMex Joe E Parker 2, NuMex New Mexico 6-4 2, NuMex Sandia 2, NuMex Sweet 1, BGH 1039, Jamaica Yellow, Italian Sweet Pepper, Long Sweet Pepper, Spicy for Vase and Volcano present

desirable characteristics for ornamentation according to the factors found and can be use for crosses in future improve programs.

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CAPÍTULO 3:

Potential of pepper (*Capsicum annuum* L.) genotypes for ornamentation

ABSTRACT

Obtaining a variety that has high performance characteristics is the main focus of a breeding program. It is of interest to the breeder an ideotype plant that contains all the characteristics of interest for commercialization. With the objective of to evaluate the potential of genotypes of *Capsicum annuum* for ornamental purposes, 29 genotypes was evaluated based on eleven characteristics of plant, flower and fruit. The experiment was conducted in a greenhouse in a completely randomized design, with 29 treatments (genotypes) and five replications. The cultivar Calypso was chosen as an ideotype because it has characters that are highly desirable in the ornamentation market. Based on the analysis, high genetic variability was observed for all traits. According to factor analysis and the distance between genotype-ideotype (FAI-BLUP), nine genotypes were selected for presenting means close to those of the ideotype, for all the characteristics evaluated. The predicted genetic gain was increased for most traits, with respect to the mean of ideotype and mean of individuals.

Key words: *Capsicum annuum.* FAI-BLUP index. Ideotype. Selection gains.

RESUMO

A obtenção de uma variedade com características de alto desempenho é o foco principal de um programa de melhoramento. É de interesse do melhorista de plantas um ideótipo que contenha todas as características de interesse para comercialização. Com o objetivo de avaliar o potencial dos genótipos de *Capsicum annuum* para ornamentação, foram avaliados 29 genótipos com base em onze características de plantas, flores e frutos. O experimento foi conduzido em casa de vegetação no delineamento experimental inteiramente casualizado, com 29 tratamentos (genótipos) e cinco repetições. A cultivar Calypso foi escolhida como ideótipo por possuir caracteres altamente desejáveis no mercado de ornamentação. Alta variabilidade genética foi observada para todas as características. De acordo com a análise fatorial e na distância entre o genótipo-ideótipo, nove genótipos foram selecionados por apresentarem médias próximas às do ideótipo, para todas as características avaliadas. Observou-se ganho genético predito para a maioria das características, com relação à média do ideótipo e média dos indivíduos.

Palavras-chave: *Capsicum annuum***.** Ganhos por seleção. Índice FAI-BLUP. Ideótipo.

1 INTRODUCTION

Pepper trees stand out for their diversified use. They are widely used in the food industry as a raw material in the manufacture of dyes, flavorings, oleoresins, condiments, sauces and seasonings. They are also highly valued in cooking, pharmacology, dentistry and medicine. The fruits of such tree are a source of vitamin compounds and natural antioxidants such as vitamin C, vitamin E, B vitamins and carotenoids (PINTO et al., 2013). 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 containers as a perennial plant (NEITZKE et al., 2010).

Capsicum annuum is one of the most used species in pot planting for ornamental purposes, due to the large number of small cultivars and the great variability of shapes and colors of the fruits (FINGER et al., 2015). Despite the great variability of the *Capsicum* genus (NEITZKE et al., 2010) the market of ornamental plants lacks novelties and new products that add competitiveness to the sector and a considerably raise in the profit margin (COSTA et al., 2019). The morpho-agronomic characterization enables the assessment of the presence of variability in the population, which is the basic premise for obtaining gains from selection. In this sense, estimates of genetic parameters are an important tool for plant breeders (CARDOSO et al., 2018a).

The study of the morphological characters can be carried out individually or simultaneously. Through simultaneous analysis, it is possible to better interpret the relationship between variables. However, obtaining high-performance genotypes based on simultaneous character selection is not always an easy task. In the genetic improvement of plants, it is sought an ideotype that has favorable phenotypes for all characteristics of agronomic interest aimed by both producers and consumers (ROCHA et al., 2018).

Selection indexes, established by the linear combination of several characters, allow simultaneous selection to be carried out more efficiently (CRUZ, 2013). However, multicollinearity conditions compromise the adequate interpretation of the results. The multiple characteristics index based on factor analysis and ideotype-design (FAI-BLUP), proposed by Rocha et al. (2018), is based on the structural equation models by joining the factor analysis technique (exploratory factor analysis) with the ideotype design (confirmatory factor analysis) and is not influenced by multicollinearity, allowing the selection of genotypes in a more appropriate way than traditional indices.

In light of the aforementioned, this study proposes was to evaluate the potential of pepper genotypes of *Capsicum annuum*, with desirable ornamentation characteristics.

2 MATERIAL AND METHODS

2.1 Plant materials

The experiment was conducted in a greenhouse, in the Department of Plant Science using 29 genotypes of *C. annuum*, selected for their potential for ornamentation. The first 15 were from New Mexico, the next three from the UFV germplasm bank (BAG-UFV) and the remaining 11 were commercial varieties (Table 1). A completely randomized design was used, with 29 treatments (genotypes) and five replications, where the experimental unit consisted of one plant per pot. Sowing was carried out in 120-cell polystyrene trays containing commercial substrate. Seedlings with four pairs of permanent leaves were transplanted in 800-ml pots 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 the 29 evaluated genotypes of *Capsicum annuum*

Number of genotypes	Common name	Origin
1	NuMex Big Jim 1	New México
2	NuMex Big Jim 2	New México
3	NuMex Conquistador 1	New México
4	NuMex Conquistador 2	New México
5	NuMex Espanola Improved 1	New México
6	NuMex Espanola Improved 2	New México
7	NuMex Joe E Parker 1	New México
8	NuMex Joe E Parker 2	New México
9	NuMex Mirasol 1	New México
10	NuMex Mirasol 2	New México
11	NuMex New México 6-4 1	New México
12	NuMex New México 6-4 2	New México

13	NuMex Sandia 1	New México
14	NuMex Sandia 2	New México
15	NuMex Sweet 1	New México
16	BGH 1039	BAG-UFV
17	BGH 7073	BAG-UFV
18	MG 302	BAG-UFV
19	Calypso	Commercial
20	Cayenne	Commercial
21	*Guaraci Cumari do Pará*	Commercial
22	Jamaica Red	Commercial
23	Jamaica Yellow	Commercial
24	Peter	Commercial
25	*Pimenta Doce Italiana*	Commercial
26	*Pimenta Doce Comprida*	Commercial
27	*Pimenta Amarela Comprida*	Commercial
28	*Picante para Vaso*	Commercial
29	*Vulcão*	Commercial

For the morphological 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). 11 characteristics of plant, flower and fruit were evaluated: PH-plant height (cm); SL-stem length (cm); SD-stem diameter (mm); CAD-canopy diameter (cm); CORD-diameter of the corolla (mm); FW-fruit weight (grams); FL-fruit length (mm); FD-fruit diameter (mm); TP-thickness of the pericarp (mm); FM- fresh matter (grams); DM - Dry matter (grams).

2.2 Statistical analyses:

2.2.1 Estimates of genetic parameters

The statistical analyses were processed using the SELEGEN-REM/BLUP software (RESENDE, 2007). The mixed 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.

2.2.2 Multitrait index based on factor analysis and genotype-ideotype distance (FAI-BLUP index).

This method combines factor analysis and proposition of ideotypes in order to explore the covariance between the characteristics. The ideotype is defined based on the combination of desirable factors in the selection (ROCHA et al., 2018). With the objective of designing the specific ideotype for ornamentation, the standard values were for the means of the Calypso variety (genotype 19 - see Table 1), which is a very popular among ornamental peppers, grown in Brazil and other countries (FINGER et al., 2015).

Calypso is indicated as a potential ornamental pepper ideotype, as it presents characteristics of interest such as vigorous seedling, small size, large flowers, small fruits and large pedicels, which are important characteristics as large pedicels highlights the flowers and fruits among the leaves (MELO et al., 2014). In addition to having edible fruits, with an 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 pot.

After ideotypes were determined, the distances from each genotype according to ideotypes (genotype-ideotype distance) were estimated and converted into spatial probability, enabling the genotype ranking. The following algorithm was used:

$$P_{ij} = \frac{\frac{1}{d_{ij}}}{\sum_{i=1;j=1}^{i=n;j=m} \frac{1}{d_{ij}}}$$

In which: Pij = Probability of the ith genotype (i = 1, 2,. . ., n) to be similar to the jth ideotype (j = 1, 2,. . ., m); dij = Genotypeideotype distance from the ith genotype to the jth ideotype - based on standardized mean Euclidean distance.

The R software (R DEVELOPMENT CORE TEAM, 2015) was used for the factor analysis and genotype-ideotype distances (spatial probability).

2.2.3 Predicted genetic gain related to the mean of the genotypes:

The gain considering the mean of the selected individuals, using the FAI-BLUP index, in relation to the mean of all genotypes. For the calculation, the following formula was used:

$$GS_{Gen}\% = \frac{\bar{X}_S - \bar{X}_{Gen}}{\bar{X}_{Gen}} \times 100$$

In which: $GS_{Gen}\%$ = predicted genetic gain, in relation to the mean of the genotypes, in percentage terms; $\bar{X}_S$ = the mean of the selected individuals, using the FAI-BLUP index, considering selection intensity of 30%; $\bar{X}_{Gen}$ = the mean of the genotypes.

2.2.4 Predicted genetic gain related to the mean of the calypso variety (ideotype):

The gain considering the mean of the selected individuals, using the FAI-BLUP index, in relation to the mean of Calypso variety. The following formula was used:

$$GS_{Calypso}\% = \frac{\bar{X}_S - \bar{X}_{Calypso}}{\bar{X}_{Calypso}} \times 100$$

In which: $GS_{Calypso}\%$ = predicted genetic gain, in relation to the mean of the Calypso variety, in percentage terms; $\bar{X}_S$ = the mean of the selected individuals, using the FAI-BLUP index, considering selection intensity of 30%; $\bar{X}_{Calypso}$ = the mean of Calypso variety.

3 RESULTS AND DISCUSSION

3.1 Estimates of genetic parameters

Significant genotypes effect ($P < 0.05$) was detected by the joint deviance analysis in the for all morpho-agronomic characteristics (Table 2). These results indicate high genetic variability among the 29 *C. annuum* genotypes, allowing the exploitation of this variability in pepper improvement programs. Knowledge about population variability allows the selection of superior genotypes and, consequently, an increase in the favorable allelic frequency (GONÇALVES et al., 2008).

Table 2 – Estimates of Vg: genotypic variance, Ve: residual variance, Vf: individual phenotypic variance, $h^2g = h^2$: heritability of individual plots in the broad sense, that is, of the total genotypic effects, CVg%: coefficient of genotypic variation, CVe%: coefficient of residual variation, CVr% = CVg/CVe: coefficient of relative variation. For plant, flower and fruit characters of the 29 genotypes of *C. annuum* evaluated

Genetic components	PH	SL	SD	CAD	CORD	FW	FL	FD	PT	FM	DM
V_g	117.78*	64.22*	0.37*	37.32*	22.31*	164.01*	1471.86*	86.71*	0.46*	153.43*	2.38*
V_e	98.71	38.79	0.22	33.84	8.40	26.86	224.02	9.11	0.21	23.82	0.56
V_f	216.49	103.01	0.59	71.16	30.71	190.87	1695.88	95.82	0.67	177.25	2.94
h^2_g	0.54	0.62	0.63	0.52	0.73	0.86	0.87	0.90	0.69	0.87	0.81
Accuracy	0.74	0.79	0.79	0.72	0.85	0.93	0.93	0.95	0.83	0.93	0.89
CV_{gi}%	19.51	28.19	10.32	15.87	21.64	83.79	53.55	41.87	36.90	85.41	75.58
CV_e%	17.87	21.92	7.96	15.11	13.28	33.91	20.89	13.57	24.78	33.65	36.70
CVr%	1.09	1.30	1.29	1.05	1.30	2.47	2.56	3.08	1.49	2.54	2.06
Overall mean	55.61	28.42	5.91	38.49	21.826	15.28	71.64	22.24	1.83	14.50	2.04

PH-plant height (cm); SL-stem length (cm); SD-stem diameter (mm); CAD-canopy diameter (cm); CORD-diameter of the corolla (mm); FW-fruit weight (grams); FL-fruit length (mm); FD-fruit diameter (mm); TP-thickness of the pericarp (mm); FM- fresh matter (grams); DM - Dry matter (grams).

Heritability values ranged from 52% to 90% (Table 2). For the characters FW, FL, FD, FM and DM, the heritability values were very high (> 80%). High heritability values indicate that most of the observed phenotypic diversity is of genetic origin (FORTUNATO et al., 2015). When evaluating morpho-agronomic traits in 16 pepper genotypes, Rosmaina et al. (2016) obtained estimates of heritability in a broad sense ranging from 54.35% for stem diameter to 99.63% for fruit length. The authors observed very high values of heritability (> 80%) for plant height, stem length, canopy width, length, diameter and weight of the fruit. Similar results were obtained by Neto et al. (2014) when analyzing 10 morpho-agronomic characters of a base population of ornamental pepper trees (*Capsicum annuum* L.). High heritability values were found for plant height (92.87%), canopy diameter (96.14%), stem length (94.05%), stem diameter (99.49%) and length of the corolla (85.61%).

Selective accuracy reflects the quality of information and procedures used to predict genetic values. The higher the value of the accuracy of the genotype, the greater the confidence in the evaluation and in the predicted genetic value of the individual (PIMENTEL et al., 2014). The results of corolla diameter (CORD), fruit weight (FW), fruit length (FL), fruit diameter (FD), thickness of the pericarp (TP), dry matter (DM) and fresh matter (FM) stand out with expressive values of accuracy and heritability.

The coefficients of genetic variation (CVg) ranged from 10.32% to 85.41%. In particular, FW (83.79%) and FM (85,41%) showed high CVg values. This coefficient quantifies the magnitude of the genetic variation available in the selection, where high values are desirable. Variability is a precondition in the establishment of any genetic improvement program; however, the efficiency of the selection of superior genotypes will depend on genetic and environmental parameters related to the characters of interest (BLIND et al., 2018).

The CVr values obtained in the experiment were greater than 1 in most characters, which indicates that the genetic variation between the genotypes is greater than the environmental variation (PIMENTEL et al., 2014). Nascimento et al. (2012) when evaluating 11 quantitative morpho-agronomic characteristics of 55 *C. annuum* genotypes, observed CVe values between 3.30% (canopy width) and 86.81% (leaf length), CVg between 8.35% (corolla length) and 28.65% (stem diameter), and CVr values, mostly, greater than 1. Rêgo et al. (2011) in a study with Capsicum baccatum found CVg/CVe values greater than 1 for all evaluated characteristics. High coefficients of genetic variation and heritability are the main requirements for genetic gain and greater response to the selection of individuals (FALCONER; MACKAY, 1996).

3.3 Selection of genotypes using the FAI-BLUP index

By using the values referring to the means of the characteristics of the cultivar Calypso, chosen in the present study as an ideotype for ornamentation, and the scores of the factor analysis, the FAI-BLUP index was calculated allowing the classification of the genotypes. Based on the genotype-ideotype distance, nine genotypes (2, 5, 14, 15, 16, 17, 27, 28 e 29 - see Table 1) were selected for showing means closer to those of the Calypso ideotype, for all evaluated characteristics.

According to Donald (1968), the ideotype can be defined as a model plant with a set of characteristics that can lead to high performance. Therefore, the creation of an ideotype focuses on several characteristics simultaneously. The genetic improvement of plants seeks an ideotype that contains all the characteristics of agronomic interest and allows the achievement of a final target for selection, replacing the trial and error method of gradually increasing the performance of the plant as a consequence (ROCHA et al., 2018). Despite the proposition of Donald that possible most plant breeding programs can be based on ideotypes, this approach has not been widely used in practice (ZHANG et al., 1999).

In order to develop new cultivars for the ornamental pepper tree market, Silva et al. (2017) selected hybrids based on an estimated ideotype. Such ideotype consisted of small plants (up to 30 cm), precocious in relation to the days until flowering and fruiting and a high number of fruits per plant. On the other hand, Hapshoh et al. (2016) when studying the qualitative inheritance of characters associated with shortening of internodes, fruit orientation and anthocyanin content, using six populations of ornamental pepper, determined an ideotype with shortened internodes that form a bouquet of flowers, with upright fruits with anthocyanins for a more attractive appearance.

3.4 Predicted genetic gain

Considering the nine individuals selected through the FAI-BLUP index, predicted gains were calculated in relation to the average of all evaluated genotypes and in relation to the average of the Calypso ideotype. As for the average of the genotypes, a negative genetic gain was observed for all traits. As a consequence, the selection for these characteristics results in their reduction. Regarding the ideotype, the gains were positive for most of the characters, except SD, CAD, FD and TP (Table 5).

Table 5 – Selection gains obtained for 11 characteristics of *C. annuum* pepper plants where X_s - Means of individuals selected using the FAI-BLUP index, considering selection intensity of 30%; X_{id} – Means of the ideotype; X_{pop} - Population means; $GS_{id}\%$ - Gains by selection, in percentage terms, of the individuals selected in relation to the ideotype; $GS_{pop}\%$ - Gain by selection, in percentage terms, of the individuals selected in relation to the population

	PH	SL	SD	CAD	CORD	FW	FL	FD	TP	FM	DM
X_s	46.52	21.78	5.66	36.87	20.81	9.27	55.01	17.75	1.64	8.77	1.35
X_{id}	30.89	12.66	6.01	37.23	17.84	3.64	26.04	19.26	2.09	3.30	0.49
X_{Gen}	55.61	28.42	5.91	38.49	21.83	15.28	71.64	22.24	1.83	14.50	2.04
$GS_{id}\%$	50.58	72.11	-5.82	-0.96	16.64	154.65	111.28	-7.83	-21.48	165.66	178.85
$GS_{Gen}\%$	-16.35	-23.37	-4.32	-4.20	-4.66	-39.34	-23.21	-20.16	-10.37	-39.56	-33.74

PH-Plant height (cm); SL-stem length (cm); SD-stem diameter (cm); CAD-canopy diameter (cm); CORD-corolla diameter (cm), FW-fruit weight (grams); FL-fruit length (cm); FD-fruit diameter (cm); TP-thickness of the pericarp (cm); FM- fresh matter (grams); DM -Dry matter (grams).

Stem length and plant height are characters of great importance in the ornamental market, since small size genotypes allow cultivation in smaller containers without compromising the growth and development of the plant. Medium to high size genotypes can be used for landscaping, cultivation in gardens such as medicinal, aromatic and condiment gardens (NEITZKE et al., 2010). In the selected individuals, there was a reduction of 8.2 cm for plant height and 6.42 cm for stem length, when compared to the average of the genotypes. Regarding the ideotype, the gain was 50.58% for plant height and 72.11% for stem length. Selection based on the ideotype would imply in higher plants, which is not interesting for ornamentation. This was because no selected genotype has a height smaller than the ideotype. The average of the selected is 46.52 cm while the Calypso ideotype is 30.89 cm.

The commercial success of ornamental plants grown in pots is mainly associated with the proportion, in volume, of the plant with the container used. According to Barbosa et al. (2002) the relationship between canopy width, plant height and pot size are important for plant harmony. The canopy (CAD) and stem (SD) diameters are relevant characteristics in the plant architecture. The SD should be sufficient to bear the weight of the plant and the fruits (FERREIRA et al., 2015), since plants with very thin stems tend to lodging and lose their commercial value (NETO et al., 2014). There was no gain in the SD due to the reduction in the diameter value, both in relation to the population (-4.32%) and in relation to the ideotype (-5.82%). Considering a more compact and harmonic plant for ornamentation, the ideal would be a reduction of the diameter of the canopy as observed in relation to the population and the ideotype.

The mean value of the corolla diameter was reduced from 21.83 mm to 20.87 mm (gain of -4.6%) regarding the mean of the genotypes. In relation to the mean of the ideotype, the gain was positive (16.64%), which would result in an increase in the CAD. According to Nascimento et al. (2013), larger flowers are preferable because they provide beauty to the plant, standing out among the foliage, looking more attractive and pleasant to the consumer. Santos et al. (2013) reported that the selection of plants with large flowers has potential for use in ornamental pepper breeding programs.

As for the weight, length and diameter of the fruit, the gains were -39.97%, -21.30% and -20.16% respectively, in relation to the population mean. In relation to the mean of the ideotype, the gains were positive for weight and length (154.65% for FW and 111.28% for FL) and negative for diameter (-7.83%). According to Bento et al. (2007), regarding the market of ornamental plants, the preference for plants with shorter length and diameter of the fruit was observed. The diameter associated with the length is important in harmonizing the fruits with the plant size. Lighter-weight and shorter- length fruits are ideal for ornamental purposes due to the small size of the plants. In addition, they indicate a greater possibility of obtaining erect fruits, more prominent in the foliage (SILVA et al., 2015). Broad and long fruits are generally more attractive to the fresh pepper market (CARDOSO, 2018b). Thus, selection to reduce these characters is more appropriate.

Ornamental pepper fruits are of great value mainly for their dual purpose. Besides, they can be used for consumption in addition to granting beauty to them. This characteristic has added value to pepper plants, configuring itself as another way to increase the financial return for the producer (RÊGO; RÊGO, 2016). In view of this, the study of fruit characters such as pericarp thickness, fresh matter and dry matter, becomes interesting.

For the characteristic thickness of pericarp, the gain was -10.37% in relation to the population and -21.48% in relation to the ideotype, therefore selection for this character results in its reduction. Thinner fruits are more suitable for industry, as they can be used in processing due to the higher content of soluble solids, in addition to requiring less energy inputs in dehydration for the production of paprika. Fruits with thick pericarp are more suitable for fresh consumption, as they are more resistant to physical damage during handling and have a fresher appearance (LANNES et al., 2007).

According to Lannes et al. (2007), there is a positive linear correlation between the thickness of the pericarp and the fresh matter content of the fruit, which is important for the selection of varieties more appropriate for the consumption of fresh fruits. Fruits with a higher dry matter content have a higher content of soluble solids, a characteristic of interest mainly for fruits consumed in their fresh form (CONTI et al., 2002). The gains for the contents of fresh matter (-39.56%) and dry matter (-33.74%) were negative in relation to the population and positive in relation to the ideotype (165.66% for FM and 178.85% for DM). Selection based on the ideotype to increase these characters is preferable, as fruits with higher dry matter and fresh matter content are more attractive for fresh consumption.

In view of the gains for most characters, the selected genotypes are the most recommended for crossing both with the evaluated genotypes and with the ideotype. Hybridization, an improvement method, is widely used in peppers in the development of new cultivars (NASCIMENTO et al., 2015). Crossing with the ideotype is the best recommendation as it allows improving and adding new characteristics and increasing variability while maintaining the existing ideal characters (ROCHA et al., 2018).

4 CONCLUSIONS

1. Variability and possibility of gains by means of selection were predicted in the desirable direction in all the measured traits.
2. Based on the FAI-BLUP index, nine genotypes with greater performance in terms of ornamental use were selected: 2, 5, 14, 15, 16, 17, 27, 28 and 29.

3. The selected genotypes showed gains for five characters in relation to the ideotype (CAD, CORD, FD, FM and DM) and six regarding the population (PH, SL, FW, FL, FD and CAD).

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CONCLUSÃO GERAL

✓ Há variabilidade genética entre os genótipos de pimenta em estudo quanto as características morfológicas avaliadas. Permitindo a escolha de genitores divergentes com potencial uso em programas de melhoramento, visando a obtenção de pimenteiras ornamentais.

✓ A análise fatorial reduziu as 12 características avaliadas em três fatores. De acordo com a representação gráfica dos escores dos fatores, 12 genótipos apresentaram maior potencial para ornamentação e podem ser utilizados para a formação de híbridos.

✓ Por meio do índice de seleção FAI-BLUP oito genótipos foram selecionados como os mais próximos ao ideótipo e, portanto, com maior potencial para ornamentação. Os genótipos selecionados apresentaram ganhos genéticos para a maioria das características avaliadas. Dessa forma, os genótipos selecionados podem ser utilizados em futuros cruzamentos com o ideótipo para obtenção de novas variedades, matendo as características desejáveis já existentes.