Quantitative descriptors that contribute to variability in the F₃ population of ornamental pepper

Descritores quantitativos que contribuem para a variabilidade na população F₃ de pimenteira ornamental

Descripores cuantitativos que contribuyen a la variabilidad en la población F3 de pimiento ornamental

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ABSTRACT
The diversity of peppers from the *Capsicum* genus has always enriched global cuisine and is currently driving the growth of the ornamental plants market. In this sense, breeding programs with ornamental peppers play a crucial role in the evolution of the ornamental market. Therefore, the objective of this study was to evaluate genetic variability in an F₃ population of ornamental pepper through principal component analysis (PCA) based on quantitative descriptors of ornamental interest and identify correlations between them through Pearson's correlation coefficient analysis. In the F₃ generation of a genetic improvement program with ornamental pepper plants at the State University of Montes Claros, 200 genotypes were conducted. In these, four quantitative descriptors were evaluated: plant height (PH), fruiting stages (FS), production (PD) and average fruit mass (AFM). The data were subjected to normality and homogeneity of variance tests (p<0.05) and, subsequently, to principal component analysis (PCA) to evaluate genetic diversity between genotypes. Analyzes were performed using PAST software. The PCA results demonstrated that the variables PD and PH were the ones that contributed most to PCA I, while for PCA II it was FS. In the Pearson correlation coefficient, it was observed that the most significant correlation occurred between the PH and PD variables. AFM and PD were negatively correlated, indicating that the greater the average fruit mass, the lower the number of fruits produced. The results of this study will open up opportunities for the development of new cultivars of ornamental peppers, which are cultivated mainly by small producers or family farmers.


RESUMO
A diversidade das pimentas do gênero *Capsicum* sempre enriqueceu a culinária mundial e, atualmente, impulsiona o crescimento do mercado de plantas ornamentais. Neste sentido, programas de melhoramento genético com pimenteiros ornamentais desempenham um papel crucial na evolução do mercado ornamental. Por isto, o objetivo deste estudo foi avaliar a variabilidade genética em uma população F₃ de pimenta ornamental através da análise de componentes principais (PCA) com base em descritores quantitativos de interesse ornamental e identificar correlações entre eles através da análise do coeficiente de correlação de Pearson. Na geração F₃ do programa de melhoramento genético com pimenteiros ornamentais da Universidade Estadual de Montes Claros foram conduzidos 200 genótipos. Nestes foram avaliados quatro descritores quantitativos: altura de plantas (AP), estádios de frutificação (FS), produção (PD) e massa média de frutos (AFM). Os dados foram submetidos aos testes de normalidade e
homogeneidade das variâncias (p<0,05) e, posteriormente, à análise de componentes principais (PCA) para avaliar a diversidade genética entre genótipos. As análises foram realizadas no software PAST. Os resultados da ACP demonstram que as variáveis PD e PH foram as que mais contribuíram para a ACP I, enquanto para a ACP II foi a FS. No coeficiente de correlação de Pearson observou-se que a correlação mais significativa ocorreu entre as variáveis HP e PD. AFM e PD correlacionaram-se negativamente, indicando que quanto maior a massa média dos frutos, menor o número de frutos produzidos. Os resultados deste estudo abrirão oportunidade para o desenvolvimento de novas cultivares de pimentas ornamentais, que são cultivadas principalmente por pequenos produtores ou agricultores familiares.


RESUMEN
La diversidad de pimientos del género Capsicum siempre ha enriquecido la cocina mundial y actualmente impulsa el crecimiento del mercado de plantas ornamentales. En este sentido, los programas de mejora genética con pimiento ornamental juegan un papel crucial en la evolución del mercado ornamental. Por lo tanto, el objetivo de este estudio fue evaluar la variabilidad genética en una población F3 de pimiento ornamental mediante análisis de componentes principales (PCA) basado en descriptores cuantitativos de interés ornamental e identificar correlaciones entre ellos mediante análisis de coeficientes de correlación de Pearson. En la generación F3 del programa de mejoramiento genético con plantas ornamentales de pimiento de la Universidad Estadual de Montes Claros se realizaron 200 genotipos. En estos se evaluaron cuatro descriptores cuantitativos: altura de planta (AP), estados de fructificación (FS), producción (PD) y masa promedio de fruto (AFM). Los datos fueron sometidos a pruebas de normalidad y homogeneidad de varianza (p<0,05) y, posteriormente, a análisis de componentes principales (PCA) para evaluar la diversidad genética entre genotipos. Los análisis se realizaron utilizando el software PAST. Los resultados del ACP demostraron que las variables PD y PH fueron las que más contribuyeron al ACP I, mientras que para el ACP II fue FS. En el coeficiente de correlación de Pearson se observó que la correlación más significativa ocurrió entre las variables HP y PD. AFM y PD se correlacionaron negativamente, lo que indica que cuanto mayor es la masa promedio de fruto, menor es el número de frutos producidos. Los resultados de este estudio abrirán oportunidades para el desarrollo de nuevos cultivares de pimiento ornamental, los cuales son cultivados principalmente por pequeños productores o agricultores familiares.

1 INTRODUCTION

The diversity of peppers within the *Capsicum* genus not only enriches global cuisine but also drives the rise of the ornamental market. In this ornamental sector, plant diversity takes center stage, and the released cultivars are not only focused on palatability but also feature a unique aesthetic in their architectures.

Breeding programs with ornamental peppers play a crucial role in the evolution of the market, as they are focused on creating materials that meet the sector’s expectations and the constant changing preferences of consumers (Ribeiro *et al*., 2020). To obtain materials that meet these requirements, genetic diversity within the programs is essential, as it enables the exploration of unique characteristics and promotes adaptability of these plants in different environmental conditions (Costa *et al*., 2019).

To analyze sources of variability within the programs, the Principal Component Analysis (PCA) serves as a tool. PCA is based on a mathematical procedure that transforms a set of variables into a smaller number of uncorrelated variables called principal components (Chatfield; Collis, 1980). According to Singh *et al*. (2020), this reduction of a complex data set reveals what is sometimes hidden, allowing it to be interpreted through simplified structures. This analysis is frequently used to determine and interpret variability within *Capsicum* spp. breeding programs, due to its efficiency for this type of study (Sunday *et al*., 2021; Rahevar *et al*., 2021; Taş & Balkaya, 2021; Custódio *et al*., 2023).

From variables evaluated within a study, correlation analysis methods can be used to assess the relationship between the characteristics of interest for the breeding program. Correlation is an estimate that indicates the direction and degree of association between a pair of traits, and it can be used for indirect selection (Moreira *et al*., 2018; Moreira *et al*., 2022). Among the available methods, there is the analysis of Pearson's correlation coefficient, which estimates the degree of magnitude and direction of the association between two characters (Olivoto *et al*., 2017). Information like this can support future advances in the field of plant genetic improvement and the practicality of indirect selection of variables, carried out earlier (Neri, 2021).
Therefore, the objective of this study is to detect the existing variability in an F3 population of ornamental pepper through Principal Component Analysis (PCA) of quantitative descriptors of ornamental interest. Additionally, the study aims to identify correlations between descriptors using Pearson correlation.

2 MATERIAL AND METHODS

The stages of this plant genetic improvement program were conducted in a greenhouse covered by 50% shade cloth, in the experimental area of the State University of Montes Claros (UNIMONTES), Janaúba Campus, in the city of Janaúba, Minas Gerais, Brazil. The local altitude is 533 meters, with a latitude of 15°48'09" S and a longitude of 43°18'32".

The breeding program was carried out in six cycles over four consecutive years, using the SSD (Single Seed Descent) method to handle the segregating populations. The selected parents were two pepper accessions, UNI01 (Capsicum annuum var. annuum) and UNI05 (C. annuum var. glabriusculum), with contrasting qualitative traits, belonging to the Pepper Germplasm Bank (BAG) of UNIMONTES (Pimenta et al., 2020).

In Stage I, a cross was made between the male parent UNI01 and the female parent UNI05 to obtain the F1 generation. In Stage II, self-fertilization of the F1 was ensured by protecting the flowers during pre-anthesis to obtain seeds of the F2 generation. In Stage III, the genotypes of the F2 generation were grown in 3-liter plastic pots filled with a mixture of clayey soil, coarse sand, and bovine manure in a 1:1:1 ratio, with two genotypes per pot. After fruit formation and maturation, the seeds were extracted, dried at room temperature, and stored under refrigeration for sowing the next generation (F3).

In Stage IV, where the data for this study were collected, 200 genotypes were grown in two replicates (full-siblings) of the F3 generation, totaling 400 evaluated plants. The implementation and management were similar to the previous generation. Throughout all stages, the plants received cultural treatments recommended for conventional cultivation (Filgueira et al., 2012), with adaptations for protected and potted cultivation.
Four quantitative variables were considered for evaluation: plant height (PH), fruiting stages (FS), production (PD) and average fruit mass (AFM). PH was measured using a graduated ruler. FS was determined by counting of months from sowing to the first fruit maturity. PD was assessed by counting the number of fruits produced by each genotype. AFM was determined by evaluating five fruits per plant and obtaining their average.

The data were subjected to tests of normality of data (Lilliefors) and homogeneity of variances (Bartlett), at p<0.05. Principal component analysis (PCA) was used to evaluate the genetic diversity between genotypes, considering the number of principal components enough to explain at least 90% of the data variability. Subsequently, Pearson correlations were estimated in order to demonstrate the associations between the studied characters. The analyzes were carried out using the PAST software (Hammer et al. 2003).

3 RESULTS AND DISCUSSION

Of the four principal components, the first two were significant for the study, explaining 99.17% of the total variation in the dataset (Figure 1). Principal Component 1 (PCA I) and Principal Component 2 (PCA II) contributed 64.52% and 34.65%, respectively, to the remaining variance. According to Regazzi and Cruz (2020), it is recommended to retain components that explain more than 80% of the cumulative total variance. Therefore, in the present study, it is possible to satisfactorily explain the variability manifested by the genotypes.
The variables that contributed the most to PCA I were production and plant height, as they were farther from the intersection point of the x and y axes. The fruiting stage variable, despite being close to the intersection point of the axes, contributed the most to PCA II (Figure 1). Custódio et al. (2023), using the PCA method for seven quantitative variables, evaluated in a population of ornamental pepper trees (*C. annuum* L.), obtained two components responsible for 96.9% of the variability between the studied characteristics. These authors found that the flowering cycle had the greatest influence (62.15%) on the observed variability, followed by the plant height variable (34.8%).

Several studies highlight that plant height is among the variables contributing to genetic variability in *Capsicum* spp., demonstrating that this characteristic is effective in explaining dissimilarity among genotypes (Pessoa *et al.*, 2018; Singh *et al.*, 2020). Thus, plant height is an important characteristic in divergence studies in pepper plant materials and should be prioritized in them.

In the graphical dispersion, most genotypes were grouped near the origin, indicating similarity for the principal components. The few genotypes that are distant from the origin have a greater influence on the variables, plant height, and
fruit production (Figure 1). These results demonstrate that the majority of evaluated genotypes exhibit low values for fruit production and plant height.

In ornamental peppers, plant height is what determines whether the species can be marketed in a pot or for landscaping purposes. Although most ornamental pepper plants are potted due to consumer preference for compact, low-sized plants, some can be used as decorations for gardens and outdoor areas (Fortunato et al., 2019). The cooperative Veiling Holambra (2020) establishes that plants grown in 13, 14 and 15 cm pots must be between 14 and 32 cm tall to maintain quality standards. Thus, the genotypes of the population evaluated in the present study, which are shorter in height, are good candidates in this breeding program, which aims to pot materials.

The low production of genotypes can be explained by the reduction in the canopy and consequently its productive branches. The reduction in vegetative growth is associated with a change in the pattern of photoassimilate distribution towards reproductive development (Khalil; Aly, 2013). However, the low variability observed in genotypes, due to their proximity to the origin, indicates a certain standardization of production within the population. In this sense, if the production pattern is suitable for commercial purposes, the genotypes could be selected as candidates for new cultivars at the end of the program. The commercial standard, established by Veiling Holambra (2020), is that ornamental pepper plants should be marketed with ten or more fruits per plant.

In the Pearson correlation coefficient (r), the plant height variable (PH) showed a moderately positive correlation with the production variable (PD) (r = 0.30) and a weak positive correlation with the average fruit mass (AFM) (r = 0.16) (Figure 2). With the fruiting stages (FS) variable, the correlation was negative and weak (r = -0.02). PD presented relevant correlation values only with PH.
Figura 2. Graphical dispersion of the Pearson correlation matrix of the quantitative descriptors plant height, production, fruiting stages and medium weight, obtained from genotypes of ornamental pepper (*C. annuum* L.) in F$_3$ generation, Janaúba-MG, Unimontes, 2023.

![Correlation Matrix](image)

Source: Own authorship.

The variables that showed the most significant correlation in this study were PH and PD, reported in various studies as characteristics of interest for the cultivation of ornamental peppers (Costa *et al*., 2021; Nascimento *et al*., 2019). Monge *et al*. (2021) reported a high positive correlation ($r = 0.66$) for plant height and production in *C. annuum*, corroborating with the present study. These results demonstrate the possibility of selecting more productive *C. annuum* plants based on their height.

The Pearson correlation coefficient is a numerical measure that expresses the correlation between two continuous quantitative variables, where values close to 1 or -1 indicate a more strongly correlated relationship (Lu *et al*., 2023). In *Capsicum* breeding programs, using variables that are related to the traits of interest can contribute to indirect gains in the selection process (Brilhante *et al*., 2021). In this sense, correlating characteristics associated with the plant’s architecture and aesthetics can assist in selections within pepper breeding programs for ornamental purposes. Plant height and characteristics linked to the fruits are important parameters to be evaluated in the development of new ornamental pepper materials. Shorter plants, with colorful fruits and an adequate number of fruits...
at the time of commercialization make up the ornamental pattern and are preferred by consumers (Veiling Holambra, 2018; Soares et al., 2020).

For PH and AFM, Bianchi et al. (2020) obtained a weak positive correlation \( r = 0.08 \) for *C. chinense* accessions, which corroborates the results obtained in the present study. However, when analyzing PH with FS, the same authors reported a positive correlation \( r = 0.26 \), which differs from the results observed in this study. In any case, the results elucidate the low possibility of selecting these descriptors indirectly, within this population. The opposite would be interesting because, in addition to the essentiality of height for ornamental pepper plants, the number of days until the maturation of the first fruit represented by FS is also important because it represents the precocity of the plant.

AFM was negatively correlated, with weak magnitude, with FS \( r = -0.06 \). Ali et al. (2020), evaluating accessions of *C. chinense*, obtained similar results, with a negative correlation value of -0.11. These low magnitude correlations indicate that the number of days until fruit maturity, that is, the precocity of maturation, has very little influence on the average mass and production of *Capsicum* fruits.

In the present study, despite the variables AFM and PD not showing significant correlations, it is observed that they are negatively correlated (Figure 2). SYUKUR et al. (2023), evaluating *C. annuum*, observed a moderate negative correlation \( r = -0.47 \) for the same variables. These results demonstrate that, for *C. annuum*, the greater the average fruit mass, the lower the number of fruits produced by the pepper plant. This possibly occurs because, during the production phase, there is competition between the fruits for the photoassimilates produced by the plant. Therefore, the greater the number of fruits per plant, the lower the availability of compounds from photosynthesis for each fruit and, consequently, the smaller the fruit size (Silva et al., 2023).

In ornamental pepper plants with dual aptitude, ornamentation and consumption, the average fruit mass is even more relevant, and larger fruits are the most targeted. However, for the ornamental sector, considering the compact size of pepper trees, the fruits cannot be large enough to cause lodging or disproportionate aesthetics, which would harm the commercialization of the materials.
4 CONCLUSIONS

The information obtained in this study serves to adequately guide the development of this genetic improvement program with ornamental pepper plants, aiming at the development of new cultivars at the end of this. This is because there is variability in the F3 population of ornamental pepper evaluated, detected in the Principal Component Analysis (PCA) carried out with quantitative descriptors of ornamental interest. Therefore, the first two main components satisfactorily explained the variability between the genotypes studied.

The most relevant variables for PCA I were production and plant height, while fruiting stage was prominent in PCA II. The variables plant height and production were positively correlated, with moderate magnitude.

The results of this study will open an opportunity for the development of new cultivars of ornamental peppers, given that peppers (Capsicum spp.) are cultivated mainly by small producers, the present study provides subsidies to expand the materials available on the market for this class. The cultivation and sale of ornamental pepper trees can be a great option for family farming, directly impacting the socioeconomic development of these families.

The limitation of this study is the way in which the plants are conducted, as it was carried out in a greenhouse, and, if this continues until the end of this genetic improvement program, management adjustments may be necessary for the production of future cultivars in spaces opened by small producers. For future studies, it is recommended to include more quantitative assessments and evaluation of important aspects in horticulture, such as tolerance to pests and diseases.
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