

Selection of F₄ progenies of ornamental peppers (*Capsicum annuum* L.) using multivariate methods¹

Maria do Perpetuo Socorro Damasceno Costa^{2*} , Elizanilda Ramalho do Rêgo² ,
Priscila Alves Barroso³ , Michelle Gonçalves de Carvalho⁴ , Mailson Monteiro do Rêgo⁴ 

¹ This paper is part of the doctoral thesis of the first author

² Universidade Federal da Paraíba, Centro de Ciências Agrárias, Departamento de Ciências Fundamentais e Sociais, Areia, Paraíba, Brazil. maria.damasceno@insa.gov.br; elizanilda@cca.ufpb.br

³ Universidade Federal do Piauí, Campus Professora Cinobelina Elvas, Laboratório de Melhoramento e Análise de Dados, Bom Jesus, Piauí, Brazil. pa.barroso@ufpi.edu.br

⁴ Universidade Federal da Paraíba, Centro de Ciências Agrária, Departamento de Ciências Biológicas, Areia, Paraíba, Brazil. carvalho.areia@hotmail.com; mailson@cca.ufpb.br

*Corresponding author: maria.damasceno@insa.gov.br

Editors:

Thiago Vargas

Danielle Fabíola da Silva Pereira

Submitted: March 27th, 2024.

Accepted: September 4th, 2024.

ABSTRACT

Although peppers show genetic diversity, there are few ornamental cultivars in Brazil. The purpose of this study was to evaluate the genetic diversity between progenies from F₄ populations of peppers. Ten progenies were evaluated, each with 45 plants, and 4 additional control with 15 plants. Sixteen quantitative plant and fruit descriptors were used. The data were subjected to multivariate analysis of variance, and relative importance was determined using Singh's method. Canonical variable analysis and the Scott-Knott test were used to evaluate the association between characteristics and/or individuals. In addition, non-metric multidimensional scaling was applied. The multivariate analysis of variance for the quantitative characters showed that there were significant differences. The Singh method determined that six of the fifteen characteristics contributed with more than 80.00% of the genetic divergence, while nine characteristics contributed with only 18.70%. In the analysis of canonical variables, the first two canonical variables explained 70.42 % of the discrimination between families and using the Scott-Knott test the progenies were grouped into 8 groups. The non-metric multidimensional scaling method separated the progenies from the control. Progenies that showed the desirable characteristics for potted ornamentals were 4, 8, 9 and 10. Selection within these progenies is recommended to continue the ornamental pepper breeding program.

Keywords: *Capsicum*; ornamental plants; genetic variability.

INTRODUCTION

Breeding programs for ornamental peppers are based on hybridization, which is an essential process for improving the desired characteristics of peppers (*Capsicum*). This crop has a marked diversity in terms of size, crown shape, foliage and fruit color.^(1,2) Due to these variations, coupled with their durability and adaptability to pot-growing environments, peppers have been gaining ground in the ornamental plant market.^(3,4) However, even with this diversity, the availability of cultivars for ornamental purposes in Brazil is still limited.⁽⁵⁾

A key characteristic of peppers is the fact that they are autogamous, which means they have the ability to self-fertilize. This autogamy has a direct impact on breeding programs, influencing how genetic diversity is exploited to obtain new cultivars with ornamental potential.⁽⁶⁾ Hybridization plays a crucial role in these programs, allowing the combination of proven genetic characteristics through genetic recombination.⁽⁷⁾ Consequently, this practice results in hybrids with effects with more pronounced heterotic effects in their progeny, increasing the chances of developing superior genotypes in segregating generations.^(8,9)

However, to obtain new lines of peppers with desirable ornamental characteristics, several cycles of self-fertilization are required.^(10,11) This process is particularly challenging for ornamental peppers, which require a significant number of cycles - usually 7 to 8 - to achieve homozygous lines.⁽¹²⁾ Given this complexity, assessing genetic diversity emerges as a crucial factor for selecting the most promising genotypes in *Capsicum* segregating populations.

The assessment of genetic diversity is often carried out through morphological characterization,^(13,14,15) which makes it possible to understand the genetic variability between the different genotypes available, providing essential information to guide breeding programs.⁽¹⁶⁾

The careful selection of these genotypes requires the application of biometric models supported by multivariate techniques such as cluster analysis, principal components, canonical discriminant variables^(5,17,18) and non-metric multidimensional scaling.^(8,17,19) Thus, the purpose of this study was to evaluate the genetic diversity among 10 F₄ progenies of ornamental peppers (*Capsicum annuum* L.) using multivariate approaches, considering the influence of autogamy in this process.

MATERIAL AND METHODS

The study was carried out in the plant nursery of the Plant Biotechnology Laboratory at the Agriculture Sciences Center (CCA) of the Federal University of Paraíba (UFPB), in Areia - PB, at an altitude of 618 m, located at 06°57'48" S and 35°41'30" W.

The plant material consisted of 10 progenies from an F₄ generation [1 (55.50), 2 (56.8), 3 (56.26), 4 (17.15), 5 (47.26), 6 (17.33), 7 (17.18), 8 (30.22), 9 (30.16), and 10 (55.45)]⁽²⁰⁾ resulting from self-pollination of the F₃ generation, derived from the first generation cross between the parents UFPB77.2 and UFPB134 (Table 1). Selections were made using the genealogical method; each population analyzed in this study consisted of 45 individuals, along

Table 1: Means of the quantitative traits of parents and hybrids of ornamental peppers (*Capsicum annuum* L.)

Genotypes	Traits							
	PH	CD	HFF	SD	LL	LW	FW	FL
UFPB134	21.60	20.47	9.07	0.57	2.55	1.02	0.78	1.62
UFPB77.2	35.81	24.53	16.61	0.61	5.72	1.65	0.34	1.24
77.2x134	61	43.33	11.83	0.65	7.66	2.27	0.78	1.48
Pirâmide	23.07	23.10	9.03	0.72	4.82	2.04	2.30	1.92
Etna	33.63	34.80	16.33	0.60	3.27	1.41	0.38	1.06
Genotypes	Traits							
	LFD	SFD	PT	PL	NSF	NFP	DMC	
UFPB134	0.95	0.44	0.08	1.15	30.00	38.93	18.62	
UFPB77.2	0.67	0.42	0.08	0.93	18.47	37.07	13.17	
77.2x134	0.76	0.46	0.07	1.06	13.00	40.00	15.00	
Pirâmide	1.64	0.73	0.10	1.53	28.40	18.80	15.07	
Etna	0.67	0.41	0.07	0.72	19.47	30.47	24.56	

PH (plant height); CD (crown diameter); HFF (height of first fork); SD (stem diameter); LL (leaf length); LW (leaf width); FW (fruit weight); FL (fruit length); LFD (largest fruit diameter); SFD (smallest fruit diameter); PT (pericarp thickness); PL (placenta length); NSF (number of seeds per fruit); NFP (number of fruits per plant); DMC (dry matter content).

with four controls: the parental lines UFPB 77.2 and UFPB 134, and the commercial varieties Etna and Pirâmide; each control had 15 replicates.

The seeds were sown in expanded polystyrene trays with 200 cells filled with commercial Plantmax HT® substrate. Thirty-five days after sowing, when the seedlings had three pairs of definitive leaves, they were transplanted into plastic pots with a volumetric capacity of 900 ml containing commercial Plantmax HT® substrate.

Daily irrigation and weekly fertigation with nutrient solution were carried out.⁽¹¹⁾ Phytosanitary treatments were carried out when necessary throughout the cycle in order to minimize damage caused by pests and diseases. When the plants were ready for marketing, with at least 50% fully ripe fruits, the characterizations were carried out. Morpho-agronomic characterization was carried out according to the guidelines contained in the descriptor of the *Capsicum* genus proposed by IPGRI⁽²¹⁾, using a caliper (Western®) and a semi-analytical scale (Bel engineering®).

A total of 15 morphological descriptors were used, covering plant and fruit characteristics. Regarding plant variables, height, crown diameter, height of the first fork, stem diameter, leaf length and leaf width were assessed. As for the fruit-related variables, fruit weight, total fruit length, largest and smallest fruit diameter, pericarp thickness, placenta length, number of seeds, number of fruits and dry matter content were considered.

The experiment was carried out in a completely randomized design and the experimental unit consisted of one plant per pot. Data were subjected to multivariate analysis of variance (MANOVA) to verify the difference between

progenies. Singh⁽²²⁾ criterion was used to quantify the relative contribution of the characteristics to genetic divergence, based on the generalized Mahalanobis distance matrix.

Then, canonical discriminant variables were constructed, whose average scores for each progeny were presented on the two-dimensional plane using the biplot technique.⁽²³⁾ Scott Knott criterion was used to classify the progenies based on the scores of the first canonical Variable.⁽²⁴⁾ Non-metric multidimensional scaling (nMDS) was also used to graph the distance matrices in two-dimensional space.⁽²⁵⁾

All analyses were carried out using the R software version 4.2.1.⁽²⁶⁾

RESULTS AND DISCUSSION

There is variability among *C. annuum* progenies, as demonstrated by the multivariate analysis of the quantitative characters ($p \leq 0.01$). Therefore, including these characters in the diversity studies will be efficient for discriminating and selecting progenies with ornamental characters.

Evaluating the contribution of the traits using Singh's method⁽²²⁾ for the 10 populations of ornamental peppers, it was found that six of the fifteen traits contributed with more than 80% of the variability found between families, with the greatest representation for fruit weight (35.2%), leaf length (15.30%), placenta length (12.80%), fruit length (6.20%), plant height (5.80%) and number of fruits per plant (5.50%) and (Figure 1). These results indicate that these characteristics are more efficient in explaining dissimilarity between the progenies studied, and could help in the selection of these populations based on these variables.

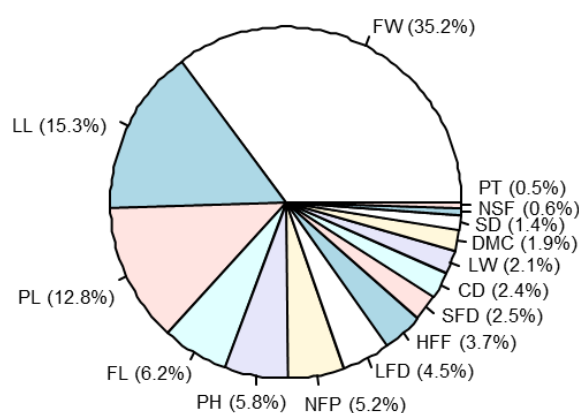


Figure 1: Relative contribution of morphological descriptors with the calculation of Mahalanobis distances, according to Singh's criterion in 10 progenies of ornamental peppers (*C. annuum* L.). Areia-PB. UFPB, 2024. FW (fruit weight); LL (leaf length); PL (placenta length); FL (fruit length); PH (plant height); NFP (number of fruits per plant); LFD (largest fruit diameter); HFF (height of first fork); SFD (smallest fruit diameter); CD (crown diameter); LW (leaf width); DMC (dry matter content); SD (stem diameter); NSF (number of seeds per fruit); PT (pericarp thickness).

Plant height is one of the main characteristics that should be observed when selecting ornamental plants. Marketing standards require a relationship between plant height and pot size. Some authors report that the ideal size for plant height is between 22.5 and 26.5 cm.^(27,28) The pots used in this study were 16 cm and 13 cm high. Considering this criterion, several strains can be selected from genetic diversity studies. This trait contributed with 7.40% of the diversity, showing that even in F_4 there is still a lot of variability that should be considered when discriminating between progenies.

The other traits contributed with 18.70% (Figure 1). At this stage of the breeding program, a greater number of variables are expected to contribute little to diversity. An advanced degree of homozygosity for many traits by population factor is at F_4 . Therefore, the use of Singh's method in advanced generations allows to identify which variables should weigh in the selection, where mainly the lines (progenies) differ, not to discard variables, as is recommended in earlier generations.^(2,29)

In the analysis of the canonical variables, genetic diversity was detected among the progenies, and the first three variables explained 79.29% of the total variance (Table 2). The results of the canonical variables were satisfactory and should be used to assess the variability of these progenies, considering that total variations of more than 70% were obtained in the first three variables (Table 2), allowing group analysis of the progenies using the scatter plot. Similar

results were observed by Nascimento *et al.*⁽³⁰⁾ and Carvalho *et al.*⁽³¹⁾ in studies of genetic divergence with segregation of ornamental pepper progenies, noting that the first three canonical variables explained more than 70% of the total variation. According to Bento *et al.*⁽³²⁾, when the first three canonical variables explain more than 70% of the variation, the data fits into a three-dimensional format, allowing the separation of progenies and can be used as a strategy to select divergent genotypes.

The variability retained by the first canonical variable was 48.50% (Table 2), and included NSF, FW, FL, SFD and PL (Table 3). The second canonical variable retained 22.00% of the variability observed between the populations, and the traits that contributed most were PH, HFF, SD, LL, and DMC (Table 3). These traits are important in the breeding of ornamental plants, as the height of the first smaller forked plant reduces the size of the plant, which is desirable for plants grown in pots.⁽²⁷⁾

Therefore, the discriminant analysis was able to identify variation between the progenies of ornamental peppers (Figure 2). Genetic variability is the raw material for genetic improvement and is necessary for the practice of selection in the progression of segregating generations.^(8,17)

The canonical discriminant analysis showed that, in general, the characteristics associated with the fruit (PH, LL, NFP, FW, DMC) contributed the most to the distance between ornamental pepper populations. Therefore, progenies can be selected according to fruit characteristics.

Table 2: Estimates of variances (eigenvalues) associated with the canonical variables for morpho-agronomic characteristics in progenies of ornamental peppers (*C. annuum* L.)

Canonical variables	Eigenvalues	Eigenvalues %	% Accumulated
CV1	7.392	48.456	48.456
CV2	3.351	21.966	70.423
CV3	1.348	8.838	79.291
CV4	1.078	7.071	86.333
CV5	0.775	5.085	91.418
CV6	0.523	3.432	94.850
CV7	0.363	2.380	97.231
CV8	0.230	1.509	98.741
CV9	0.087	0.755	99.316
CV10	0.056	0.392	99.708
CV11	0.033	0.217	99.926
CV12	0.009	0.063	99.990
CV13	0.001	0.010	100.00
CV14	0.000	0.000	100.00
CV15	0.000	0.000	100.00

The results obtained through canonical discriminant analysis highlighted significant distinctions between *Capsicum annuum* progenies, especially in relation to dry of fruit matter content, size and magnitude of fruit. These characteristics give the progenies remarkable superiority, aligning them with the marketing standards of the Brazilian Institute of Floriculture (Ibraflor)⁽³³⁾ and reinforcing their potential in breeding programs.

Analyzing the additional Control 12, 14 and 11, a distinction was made in relation to the progenies, revealing a negative correlation in the fruit characteristics (PH, NFP e FL). However, the Control show different variables from the progenies; the latter, in turn, show superior variables, especially regarding to ornamental characters. It should be noted that the F₄ generation already shows superior characteristics when compared to the cultivars currently available on the market. This observation highlights the feasibility of selecting ornamental characteristics among segregating populations, as mentioned by Carvalho et al.⁽³¹⁾ The importance of selecting advanced populations is emphasized in order to obtain pure and superior lines, especially in relation to desirable agronomic characters. Finally, it is recommended to carry out distinguishability, homogeneity and stability (DHS) tests among the progenies, observing if the target characteristics have been fixed and if the lines are truly distinct from each other, playing a fundamental role in

the selection and registration of new varieties.

The Scott-Knott test at 5% probability divided the 14 populations analyzed into eight distinct groups (Figure 3). These results show the presence of genetic variability between the populations for the characteristics evaluated, allowing for the selection of these populations with superior characteristics for ornamental purposes.

Analyzing the groups formed, it is worth highlighting the distinction of additional Control 14, which was grouped differently from the other progenies (Figure 4), as shown in the analysis of the canonical discriminant variables.

Notably, despite forming the same group, progenies 7 and 2 differed from families 6 and 5, while progenies 7 and 2 did. Progenies 7 and 2 do not have interesting characteristics for ornamental pepper trees because they have larger fruit and a smaller stem diameter. These characteristics are unfavorable, as larger fruits are more suitable for outdoor environments. In addition, plants with a smaller stem diameter are not interesting for selecting plants for ornamental purposes, as the plants can fluff up in the pot and may lose their commercial value.⁽²⁸⁾ On the other hand, progenies 6 and 5 had short stature and smaller leaves, which are highly desirable characteristics for ornamental purposes.

Group 3 was made up of populations 3 and the additional Control 11, while progenies 1, 4 and 13 formed group 4. In this context, family 4 stood out for its smaller size

Table 3: Weighting coefficients (eigenvectors) associated with the canonical variables of the sixteen traits evaluated from 10 progenies of ornamental peppers (*C. annuum* L.)

Traits	CAN1	CAN2	CAN3
PH	-0.0102706	0.52176960	0.3894380
CD	0.1067349	-0.0079494	0.1025382
HFF	0.1933780	0.2135853	0.3269931
SD	0.0038141	-0.2672554	0.3269931
LL	-0.4473207	0.5243668	-0.1777415
LW	-0.1102567	0.0482739	0.2317160
FW	-0.8052784	-0.4584953	0.5324481
FL	0.6172606	0.4325079	-0.7695105
LFD	0.1068123	-0.1847471	0.1010800
SFD	-0.1464540	-0.0178315	-0.0083270
PT	-0.0548958	0.0984600	-0.0633896
PL	-0.5384536	-0.1409557	0.1989124
NSF	0.2963437	0.0690634	-0.2088302
NFP	0.2357521	-0.1362834	0.5692512
DMC	0.0868724	-0.3227919	0.1187178

PH = plant height; CD = crown diameter; HFF = height of first fork; SD = stem diameter; LL = leaf length; LW = leaf width; FW = fruit weight; FL = fruit length; LFD = largest fruit diameter; SFD = smallest fruit diameter; PT = pericarp thickness; PL = placenta length; NSF = number of seeds per fruit; NFP = number of fruits per plant; DMC = dry matter content. Areia-PB. UFPB, 2024.

compared to progenies 1 and 13. However, these latter had fewer desirable characteristics for ornamental purposes, such as high forking and tall size, indicating their preference for growing outdoors.⁽³⁴⁾

Finally, genitor 12 and progenies 8, 9 and 10 (Figure 4) formed individual groups (groups 5, 6, 7 and 8, respectively). Each group had unique characteristics: smaller leaves, smaller fruit diameter and higher dry matter content. Progenies with these characteristics are considered aesthetically valuable and are suitable for pot cultivation and indoor decoration.⁽³⁵⁾

Progenies 4, 8, 9, and 10 were selected due to their greater number of ornamental characteristics, such as

shorter stature, smaller leaves, smaller fruits, and a higher number of fruits. These traits are important for the ornamental plant market. Progenies with both characteristics may be suitable for selection. It is therefore recommended to select these progenies in order to continue the *Capsicum* breeding program.

This Scott-Knott grouping based on the first canonical variable provided a different grouping to the previous method (canonical variable methods), better separating the populations, and presenting groups with only one population, in the case of genotypes with greater dissimilarity.⁽³⁶⁾ This method is used in conjunction with other methods to complement the results and help to better distinguish the groups formed.

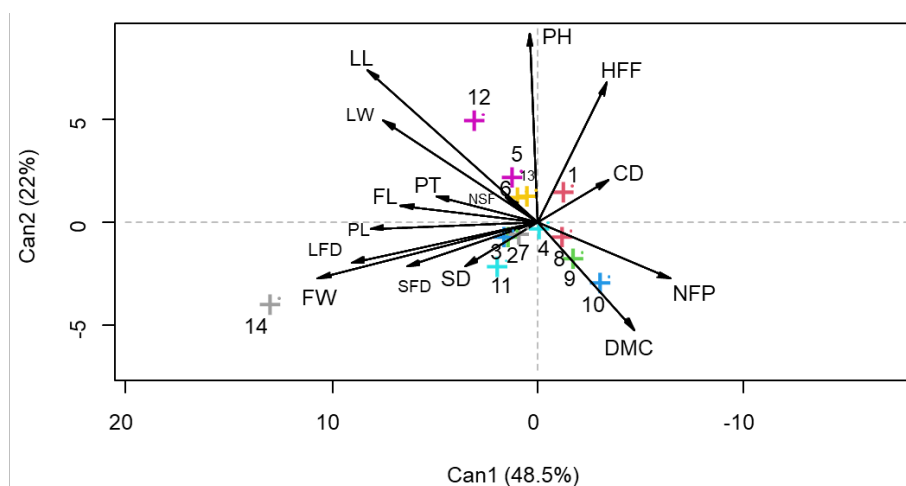


Figure 2: Dispersion of scores of the first two canonical variables (Can1 and Can2) obtained from the morpho-agronomic characteristics of 10 progenies of ornamental peppers (*C. annuum* L.). 1 (55.50.), 2 (56.8), 3 (56.26), 4 (17.15), 5 (47.26), 6 (17.33), 7 (17.18), 8 (30.22), 9 (30.16), 10 (55.45), 11 (UFPB 134), 12 (UFPB 77.2), 13 (Etna) and 14 (Pirâmide). Areia-PB. UFPB, 2024. (+) score obtained for each of the progenies based on the first two canonical variables.

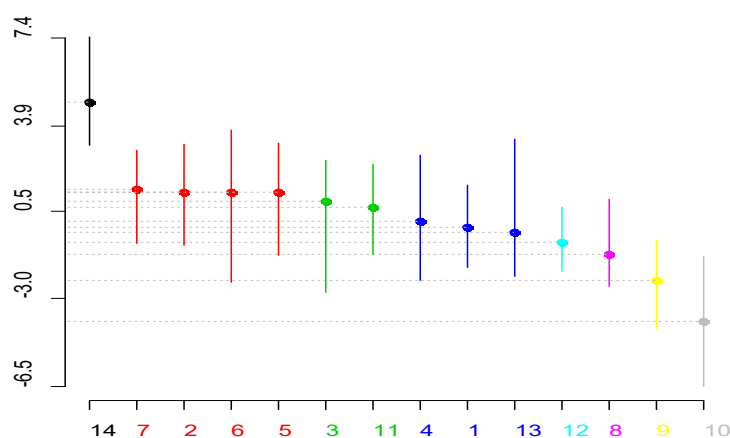


Figure 3: Grouping according to the Scott-Knott criterion for 10 progenies of ornamental peppers (*Capsicum annuum*) and 4 additional Control, based score for each access assumed by the weighting coefficients for the first canonical variable. Areia-PB. UFPB, 2024. Group 1-black color = 14 (pyramid), group 2-red color = 7 (47.26) 2 (56.8) 6 (17.33) 5 (17.18), group 3-green color = 3 (56.26) 11 (UFPB 134), group 4-blue color 4 (17. 15) 1 (55.50) 13(Etna), group 5-light blue = 12 (UFPB 77.2), group 6-purple color = 8 (30.22), group 7-yellow color = 9 (30.16), and group 8-gray color = 10 (55.45).

The non-metric multidimensional scaling analysis made it possible to separate the progenies on the graph with a stress value of 2.58% (Figure 5). The lower the stress value, the more reliable the position of the points in the image generated, representing the calculated distances, with little distortion in the data as the dimensions reduced.⁽³⁷⁾ These values are considered acceptable for representing the distances of the individuals on the graph,⁽³⁸⁾ which indicates a desired and efficient ordering of the distances of the individuals in the population using this type of analysis.

Based on this analysis, it can be seen that there is sig-

nificant variability between the populations and cultivars in comparison to the genitors (Figure 5). It is noteworthy that, in this analysis, no significant variations were observed between progenies, which were visually grouped together, indicating marked similarities in the fruit characteristics evaluated. It is also worth noting that these results contrast with studies carried out with *Capsicum* segregating populations.^(8,17,19)

On the other hand, genitors showed a notable disparity in the graphs, indicating substantial differences in relation to the traits studied. This shows that genitors have different

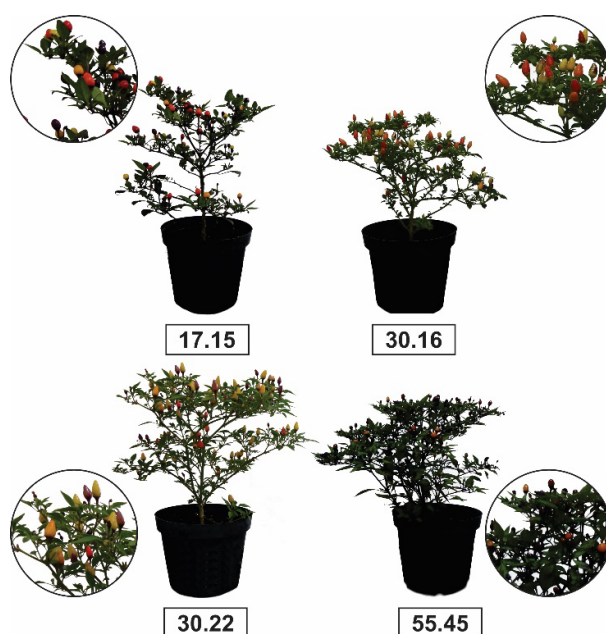


Figure 4: Progenies of ornamental peppers (*Capsicum annuum*) with ornamental potential. 17.15 (4), 30.16(9), 8(30.22) and 10 (55.45). Areia-PB. UFPB, 2024.

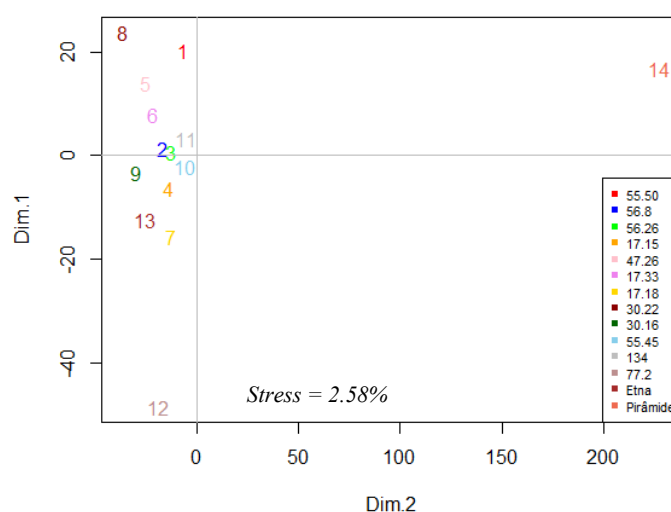


Figure 5: Non-metric multidimensional scaling of qualitative data from 10 progenies of ornamental peppers (*Capsicum annuum*) and 4 additional controls. Areia-PB. UFPB, 2024.

attributes from progenies, with lesser characteristics in relation to size, which is an important characteristic in ornamental peppers. This characteristic is one of the most attractive and relevant in the context of this study. It can thus be seen that the combination of these contrasting genitors has resulted in remarkable performance over the course of the *Capsicum* segregating generations, facilitating the selection of desirable characteristics in future generations.

CONCLUSIONS

There is genetic diversity among the F_4 progenies of *Capsicum annuum* evaluated.

The Scott-Knott grouping method based on the first canonical variable is recommended for assessing diversity in F_4 progenies of ornamental peppers as it shows greater variability for the different characters assessed.

Progenies 4, 8, 9 and 10 are recommended for selection due to their superior ornamental characteristics for pot cultivation in comparison to the other progenies evaluated. Therefore, selection within these progenies is recommended to continue the breeding program of ornamental peppers for pot cultivation.

ACKNOWLEDGEMENTS AND CONFLICT OF INTERESTS

The authors are thankful to CAPES and CNPq by grant of their research fellowship. Authors have declared that no competing interests exist.

REFERENCES

- Rêgo ER, Rêgo MM. Genetics and Breeding of Chili Pepper *Capsicum* spp. In: Rêgo ER, Rêgo MM, Finger FL. (ed.). Production and Breeding of Chilli Peppers (*Capsicum* spp.). 2016;(2):1-129.
- Pessoa AM, Rêgo ER, Santos CA, Rêgo MM. Genetic diversity among accessions of *Capsicum annuum* L. through morphoagronomic characters. *Genet Mol Res*. 2018;17(1):01-15.
- Finger FL, Rêgo ER, Segatto FB, Nascimento NF, Rêgo MM. Produção e potencial de mercado para pimenta ornamental. *Informe Agropecuário*. 2012;33(267):14-20.
- Rêgo ER, Fortunato FL, Carvalho MG, Santos CA, Lima JA, Rêgo MM. Genetic control of plant size-related traits and fruit in ornamental pepper (*Capsicum annuum* L.). *Comunicata Scientiae*. 2022a;13:e3643.
- Custódio GC, Pimenta S, Júnior ND, Pimenta AM, Gomes WS, Monteiro HC, et al. Variabilidade genética e interação entre variáveis de interesse ornamental em uma população segregante de pimentão. *Contribuciones a las Ciencias Sociales*. 2023;16(13):21310-25.
- Rêgo ER, Rêgo MM, Finger FL. Genetics and breeding of chili pepper (*Capsicum* spp.). In: Finger FL, editor. Production and breeding of chilli peppers. Cham: Springer; 2016. p. 58-80.
- Gurung T, Sitaula BK, Penjor T, Tshomo D. Genetic diversity of chili pepper (*Capsicum* spp.) genotypes grown in Bhutan based on morphological characters. *Sabrao J Breed Genet*. 2020;52(4):446-64.
- Pessoa AM, Rêgo ER, Silva AP, Mesquita JC, Silva AR, Rêgo MM. Genetic diversity in F_3 population of ornamental peppers (*Capsicum annuum* L.). *Rev Ceres*. 2019;66(6):442-50.
- Costa MP, Rêgo ER, Barroso PA, Silva AR, Rêgo MM. Selection in segregating populations of ornamental pepper plants (*Capsicum annuum* L.) using multidimensional scaling. *Rev Ceres*. 2020;67(6):474-81.
- Pessoa AM, Rêgo ER, Barroso PA, Rêgo MM. Genetic diversity and importance of morpho-agronomic traits in a segregating F_2 population of ornamental pepper. *Acta Hort*. 2015;1087(1):195-200.
- Mesquita JU, Rêgo ER, Silva AR, Silva JJ Neto, Cavalcante LC, Rêgo MM. Multivariate analysis of the genetic divergence among populations of ornamental pepper (*Capsicum annuum* L.). *Afr J Agric Res*. 2016;42(11):4189-94.
- Rêgo ER, Nascimento MF, Nascimento NF, Santos RM, Fortunato FL, Rêgo MM. Testing methods for producing self-pollinated fruits in ornamental peppers. *Hortic Bras*. 2012;30(4):669-72.
- Guimarães ME, Oliveira AC, Freire AI, Pereira AM, Pantaleão AS, Santos RM, et al. Selection of pepper genotypes for ornamentation based on ideotype. *Res Soc Dev*. 2020;9(3):e79491110399.
- Gomes F, Pimenta S, Silva TJ, Matos IN, Custódio GC, Paula AG, et al. Morphological characterization and estimates of genetic parameters in peppers with ornamental potential. *J Agric Sci*. 2022;14(5):66-75.
- Rêgo ER, Freitas ND, Pessoa AM, Silva PD, Finger FL, Rêgo MM. Selection of ornamental peppers elite lines for ethylene-insensitive. *Rev Ceres*. 2022b;69(3):294-8.
- Elias HT, Vidigal MC, Gonela A, Vogt GA. Variabilidade genética em germoplasma tradicional de feijão-preto em Santa Catarina. *Pesq Agropec Bras*. 2007;42(10):1443-9.
- Costa MP, Rêgo ER, Guedes JF, Carvalho MG, Silva AR, Rêgo MM. Selection of genotypes with ornamental potential in an F_4 population of ornamental peppers (*Capsicum annuum* L.) based on multivariate analysis. *Comunicata Scientiae*. 2021;12:e3511.
- Aquino HF, Medeiros JE, Carvalho JL Filho, Ribeiro CM, Maciel MI, Dantas JR. Morpho-agronomic characterization and genetic divergence among pepper accessions. *Rev Ceres*. 2022;69(6):187-94.
- Mesquita JC, Rêgo ER, Pessoa AM, Silva AR, Neto JJ, Rêgo MM. Multidimensional scaling for divergence analysis in pepper. *Aust J Crop Sci*. 2021;15(5):622-627.
- Costa MP. Diversidade genética entre e dentro de populações F_4 de pimenteiras ornamentais (*Capsicum annuum* L.) [doctoral thesis]. Areia: Universidade Federal da Paraíba; 2018. 150 p.
- International Plant Genetic Resource Institute. Descritores para *Capsicum* spp. Roma: IPGRI; 1995. 51p.
- Singh D. The relative importance of characters affecting genetic divergence. *Indian J Genet Plant Breed*. 1981;41(2):237-45.
- Gabriel KR. The biplot graphical display of matrices with application to principal component analysis. *Biometrika*. 1971;58(3):453-67.
- Scott AJ, Knott M. A cluster analysis method for grouping means in the analysis of variance. *Biometrics*. 1974;30(3):507-12.
- Kruskal JB. Multidimensional scaling by optimizing goodness of fit to a nonmetric hypothesis. *Psychometrika*. 1964;29(1):01-27.
- R Core Team. R: A language and environment for statistical computing [software]. [Unknown]: Foundation for Statistical Computing; 2020 [cited 2022 Jun 20]. Available from: <https://www.R-project.org/>
- Barroso PA, Rêgo ER, Rêgo MM, Nascimento KS, Nascimento NF, Nascimento MF, et al. Analysis of segregating generation for components of seedling and plant height of pepper (*Capsicum annuum* L.) for medicinal and ornamental purposes. *Acta Hort*. 2012;953(1):269-75.

28. Silva JJ Neto, Rêgo ER, Nascimento MF, Silva VA Filho, Almeida JX Neto, Rêgo MM. Variabilidade em população base de pimenteiras ornamentais (*Capsicum annuum* L.). Rev Ceres. 2014;61(1):84-9.
29. Lima JA, Rêgo ER, Crispim JF, Sales W, Arcelino EC, Rêgo M, et al. Diversidade e seleção em população segregante de pimenteiras ornamentais (*Capsicum annuum* L.). Observ Econ Latinoamericana. 2023;21(12):23486-99.
30. Nascimento NF, Rêgo ER, Nascimento MF, Finger FL, Bruckner CH, Rêgo MM. Heritability and variability for port traits in a segregating generation of ornamental pepper. Acta Hort. 2019;953(1):299-304.
31. Carvalho MG, Rêgo ER, Costa MP, Pessoa AM, Rêgo MM. Genetic diversity among populations F3 ornamental peppers. Rev Caatinga. 2021;34(3):527-536.
32. Bento CS, Sudre CP, Rodrigues R, Riva EM, Pereira MG. Descritores qualitativos e multicategóricos na estimativa da variabilidade fenotípica entre acessos de pimentas. Scientia Agraria. 2007;8(2):149-57.
33. Instituto Brasileiro de Floricultura. O mercado de flores no Brasil [Internet]. Holambra: IBRAFLOR; 2022 [cited 2022 Feb 2]. 4p. Available from: https://www.ibraflor.com.br/_files/ugd/b3d028_2ca7dd85f28f4add9c4eda570adc369f.pdf
34. Nascimento NF, Rêgo ER, Nascimento MF, Bruckner CH, Finger FL, Rêgo MM. Combining ability for yield and fruit quality in the pepper *Capsicum annuum*. Genet Mol Res. 2014;13(2):3237-49.
35. Nascimento NF, Nascimento MF, Rêgo ER, Rêgo MM, Silva JJ Neto. Caracterização morfoagronômica em híbridos interespecíficos de pimenteiras ornamentais. Hort. Bras. 2011;29(1):2932-9.
36. Vasconcelos ES, Cruz CD, Bhering LL, Júnior MF. Método alternativo para análise de agrupamento. Pesq Agropec Bras. 2007;42(10):1421-8.
37. Clarke KR, Warwick RM. Change in marine communities: an approach to statistical analysis and interpretation. 2nd ed. Plymouth: Primer-E; 2001.
38. Sturrock K, Rocha JA. Multidimensional scaling stress evaluation table. Field Methods. 2000;12(1):49-60.