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Selection of ideal genotypes in peppers with ornamental potential

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ABSTRACT

Ornamental peppers have a significant economic importance in the national and international markets; however, few cultivars intended for this purpose are grown in Brazil. The objective of this study was to select partially inbred lines (PIL) of peppers with ornamental potential, based on quantitative and qualitative variables with high heritability. The study was conducted over six generations for 4 consecutive years, using the single seed descent method. The last phase (VI) consisted of growing plants of the F_5 generation for selection. Qualitative (LD) and quantitative (QD) descriptors were considered and the ideal genotypes were defined. The statistical analyses consisted of estimating variance components and genetic parameters and predicting genetic values, using REML/BLUP for QD, except for cycle to flowering (CF) and cycle to maturation (CM), which were analysed qualitatively. Therefore, CF and CM were analysed through frequency distribution of continuous variables within class intervals. Descriptive statistics were used to evaluate LD. The results showed that residual values exceeded genetic values, resulting in low heritability for QD, and therefore, they were not considered for PIL selection. Regarding LD, genetic variability was found among the population genotypes for all evaluated descriptors. The selection based on ideal genotypes enabled the selection of 82 PIL with LD of high ornamental value, which differ from the materials already available on the market. The selected genotypes will be used for developing future generations until allele fixation, focussed on subsequent selection of candidate lines for new ornamental pepper cultivars.

Keywords: *Capsicum annuum*, genetic parameters, plant breeding, single seed descent

INTRODUCTION

Peppers are widely grown in tropical and subtropical regions and are marketed worldwide in several forms, including as ornamental plants (Cardoso et al., 2018; Gomes et al., 2019). The genetic diversity of peppers of the genus *Capsicum* results in a wide and versatile marketing of these plants. These plant materials stand out because they have dual purpose: ornamentation and food consumption (Silva et al., 2015; Cortez et al., 2022).

Brazil is one of the 15 largest flower and ornamental plant producing countries (Gomes et al., 2022). The Brazilian market for peppers intended for interior decoration has good growth prospects (Cunha, 2016). Guimarães et al. (2021) reported that ornamental peppers have had increasing acceptance in the consumer market, with demand both in national and international markets. However, despite these demands and the available genetic resources, few pepper cultivars intended for this purpose have been registered in the Brazilian Ministry of Agriculture, Livestock, and Food Supply (MAPA) for growing crops in the country (Costa et al., 2019; BRASIL, 2022).

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The presence and arrangement of aesthetically valuable characteristics determine whether a pepper plant has ornamental potential or not, forming what is known as the ideal genotype. Several characteristics can add ornamental value to a pepper plant, including plant architecture and size; number, shape, position, and colour of fruits; good leaf and fruit durability; contrast between fruit colour and leaf density; and continuous production of fruits with different colour (Neitzke et al., 2010, 2016).

The ideal genotype should have a phenotype of high economic value for the ornamental market, with the ability to raise consumer interest, as well as having suitable structure for its purpose, whether for interior decoration (potted plants) or ornamentation of external areas (landscaping). Despite studies describing ornamental pepper characteristics, the major challenge is to introduce cultivars that meet consumer preferences while providing novelty to the market (Neitzke et al., 2016; Cunha et al., 2020).

The diversity of the genus and the market interest in ornamental varieties are factors that have stimulated and intensified research on pepper plants and the conduction of breeding programs focussed on obtaining new pepper cultivars (Costa et al., 2020; Pimenta et al., 2020). The species *Capsicum annuum* is one of the most used for potted planting for ornamental purposes due to its small size and large variability of fruit shapes and colours (Fingere et al., 2015). Therefore, it is often used in breeding programs for peppers with ornamental potential.

C. annuum is a self-pollinating species and, therefore, the breeding of this species can be conducted using methods traditionally developed for self-pollinating plants, such as single seed descent (SSD). This method consists of advancing generations, after crossing, by collecting one seed per plant, without selection in the initial generations, focussed on increasing homozygosity in the descendants and obtaining lines for subsequent release of new cultivars (Bespalhok et al., 2007).

Estimating genetic parameters and predicting gains are highly important for selecting the best lines based on quantitative traits. The method Restricted Maximum Likelihood/Best Linear Unbiased Predictor (REML/BLUP) is interesting for this purpose because it uses all the effects of statistical model, overcomes imbalance issues, and considers the genetic kinship between the plants evaluated and the coincidence between selection and recombination units (Resende, 2006). According to Nunes et al. (2008), REML/BLUP is a strategy that enhances efficiency in the selection of superior plants in self-pollinating species.

Morphological characterisation of pepper accessions with ornamental potential is widely used in research due to the importance of visual attributes in this type of material (Costa et al., 2020; Cunha et al., 2020; Guimarães, 2020; Morais et al., 2020). However, in general, these qualitative traits are considered individually in breeding programs.

Defining an ideal genotype, i.e., a set of traits that form the desired aspect, can enable a simple and effective selection of plants that meet current market demands. Furthermore, it can avoid traits that already exist in cultivars currently available on the market. Thus, a simple and efficient selection of genotypes with a desired pattern and that differ from those already available on the ornamental market would be possible.

Therefore, the objective of this study was to select partially inbred lines (PIL) of peppers with ornamental potential, based on qualitative and quantitative variables with high heritability.

MATERIALS AND METHODS

Location of the experimental area

The experiments were conducted in a greenhouse, covered with 50% shade screen, at the experimental area of the State University of Montes Claros (Unimontes), Janauba, MG, Brazil (15°48′09″ S, 43°18′32″ W, and altitude of 533 m).

Breeding program phases

The breeding program was developed over six phases, during 4 consecutive years (Table 1), using the SSD method of growing the segregating populations. Two pepper accessions (UNI01 and UNI05) with qualitatively contrasting traits were selected as parents in the in the Active Germplasm Bank (BAG) of Unimontes (Pimenta et al., 2020). The accession UNI01 (*C. annuum* var. *annuum*) has a white flower corolla with no presence of spots, white-greenish fruits before maturation that turn red when ripe, and fruits in an intermediate position in the plant architecture, with a triangular longitudinal shape and an angular transverse shape. The accession UNI05 (*C. annuum* var. glabriusculum) has a violet flower corolla with no presence of spots, purple fruits before maturation that turn red when ripe, and fruits in an upright position and with an oval longitudinal shape and a rounded transverse shape. The F_1 population presented the following characteristics: a white corolla with violet borders and no presence of spots, violet fruits before maturation that turn red when ripe, and fruits in an upright position with a triangular longitudinal shape and a rounded transverse shape.

Phase I consisted of the crossing between the male (UNI01) and female (UNI05) parents to obtain the F_1 population. Phase II consisted of ensuring the self-pollination of the F_1 population by protecting the flowers during pre-anthesis to obtain seeds of the F_2 generation.

Phase III consisted of growing the genotypes of the F_2 generation in 3-L plastic pots filled with a mixture of clayey soil, coarse sand, and bovine manure (1:1:1 ratio), using two plants per pot. After fruit formation and ripening, seeds were collected from the fruits, air-dried at room temperature, and stored under refrigeration for

Table 1. Breeding program phases, using the SSD method, for peppers with ornamental potential from the BAG of the State University of Montes Claros, Janauba, MG, Brazil, 2023.

Phases	Activities	Periods
I	Crossing of parents and obtaining the F_1 population	2nd half of 2019
II	Growth of the F_1 population and obtaining the F_2 population	1st half of 2020
III	Growth of the F_2 population and obtaining the F_3 population	2nd half of 2020
IV	Growth of the F_3 population and obtaining the F_4 population	1st half of 2021
V	Growth of the F_4 population and obtaining the F_5 population	2nd half of 2021
VI	Growth of the F_5 pop. and selection of PIL for $F_{5:6}$ generation	1st half of 2022

PIL, partially inbred lines; SSD, single seed descent.

sowing the next generation. The same management was used to obtain all subsequent generations (F_3, F_4, and F_5).

Throughout the breeding program, the pepper plants were subjected to cultural practices, according to conventional cultivation recommendations for the crop (Filgueira, 2013), with adaptations for protected and potted growing. The plants were irrigated daily as needed.

Evaluated descriptors

Quantitative descriptors

The PIL were evaluated considering five quantitative descriptors: plant height (ALT), number of fruits per plant (NFP), mean fruit weight (MFW), mean fruit length (MFL), and mean fruit diameter (MFD). NFP was determined by counting the number of fruits produced per genotype throughout the crop cycle. MFW, MFL, and MFD were measured on five fruits per plant, calculating their averages to obtain the final mean.

Qualitative descriptors

The qualitative descriptors evaluated were: anthocyanin pigmentation at node height (APN), anthocyanin pigmentation in leaves (APL), corolla colour (CC), fruit colour before maturation (CBM), fruit colour intensity before maturation (CIBM), fruit position (FP) in the plant architecture, predominant shape of the longitudinal fruit section (PLS), predominant shape of the transversal fruit section (PTS), fruit surface texture (FT), fruit colour at maturation (FCM), fruit colour intensity at maturation (FCIM), cycle to flowering (CF), and cycle to maturation (CM). All observations were taken by a single evaluator.

The descriptors were visually evaluated, assigning a response to each genotype involved in the trial, according to the classes presented by the National Service for Plant Variety Protection (SNPC), which is an agency linked to MAPA (BRASIL, 2022).

CF was determined in an experiment conducted in the summer/autumn season, by counting the number of days elapsed from seed sowing to full opening of the first flower. CM was obtained by counting the number of days elapsed from seed sowing to complete ripening of the first fruit. Subsequently, the variables were categorised into classes proposed by the SNPC for describing species of the genus *Capsicum*.

Statistical analyses

Quantitative descriptors

Genetic parameters for quantitative descriptors were estimated using the REML/BLUP method through the genetic-statistical software SELEGEN-REML/BLUP (Resende, 2006). Analysis of deviance (ANADEV) was used to test the model effect and determine the significance of genotypic effects (Viana and Resende, 2014). Model 60 was the mixed linear model used, as follows:

$$y = Xr + Za + e \tag{1}$$

where y is the vector of phenotypic values; r is the vector of repetition effects, assumed to be fixed and added to the overall mean; a is the vector of individual additive genetic effects, assumed to be random; e is the vector of errors or residuals (random), and X and Z represent the incidence matrices for these effects.

Qualitative descriptors

Considering the proposed selection strategy, the data obtained for the qualitative descriptors were analysed through descriptive statistics, using the final percentage (%) of each category per variable. These analyses and graph plotting were performed using the tidyverse and ggplot2 packages in the statistical software R Development 4.1.3 (R Core Team, 2022).

CF and CM were evaluated quantitatively and analysed qualitatively using the frequency distribution of continuous variables within class intervals (early, medium, and late cycles) pre-established in the SNPC, using the software Genes (Cruz, 2016).

Ideal genotypes

Eight qualitative descriptors predicted by the SNPC (BRASIL, 2022) for peppers of the genus *Capsicum* were selected as the basis for defining the expected traits of ideal genotypes. The responses for these descriptors were chosen considering the traits related to fruits of ornamental pepper cultivars currently available on the Brazilian market to avoid them, focussing on introducing diversified materials into the plant ornamental market (Table 3). Traits with high acceptance and preference among consumers were also considered, based on research results regarding preference for ornamental peppers (Cunha, 2016; Neitzke et al., 2016).

The selection of pepper plants through the strategy of ideal genotypes consisted of two steps. The first step involved a pre-selection based on the base descriptors, selecting the genotypes of the present study that fitted into any of the proposed ideal genotype patterns (Table 3). The second step consisted of a final selection, in which the genotypes from the pre-selection were subjected to a filtering process to determine which genotypes would compose the next generation of the breeding program. The applied filter excluded all genotypes with a medium or late CF and an early or medium CM. Thus, the genotypes selected were those that had the base descriptors of the ideal genotypes: an early CF and a late CM.

Table 2. Components of variance, genetic parameters, and ANADEV estimated in PIL for quantitative descriptors in an F_5 population of pepper plants (*Capsicum annuum* L.) State University of Montes Claros, Janauba, MG, Brazil, 2023.

Parameters	PIL (F_5 population)				
	PH	NFP	MFW	MFL	MFD
σ^2a	8.43	5.45	0.17	17.32	1.36
σ^2e	11.65	49.83	0.27	32.77	1.98
σ^2p	20.08	55.29	0.44	50.09	3.34
h^2a	0.41	0.09	0.38	0.34	0.40
Acprog	0.64	0.51	0.62	0.58	0.63
CVgi%	11.17	16.30	18.63	12.62	10.64
CVe%	13.14	49.28	23.48	17.36	12.83
Overall mean	25.97	14.32	2.22	32.97	10.97
LRT	68.7**	13.14**	57.26**	42.44**	64.6**

Tabulated chi-square value = 6.63 for significance level of 1% (**). σ^2a, genetic variance among progenies; σ^2e, residual variance; σ^2p, phenotypic variance; Acprog, accuracy of progeny selection, assuming complete survival; ANADEV, analysis of deviance; CVe, coefficient of residual variation; CVgi, coefficient of individual additive genetic variation; h^2a, individual narrow-sense heritability; LRT, likelihood ratio test; MFD, mean fruit diameter (mm); MFL, mean fruit length (mm); MFW, mean fruit weight (g); NFP, number of fruits per plant (units); PH, plant height (cm); PIL, partially inbred lines.

RESULTS

Quantitative descriptors

The mathematical model used to evaluate the quantitative descriptors proved to be suitable by the ANADEV using the likelihood ratio test (LRT). The random effects (genotypes) were statistically significant for all the evaluated quantitative descriptors (Table 2).

The estimates of genetic parameters and components of variances showed some level of genetic variability that can be explored in all evaluated quantitative descriptors (Table 2). All the evaluated characteristics presented higher residual variance ($\sigma^2 e$) when compared to genetic variance ($\sigma^2 a$), resulting in a low individual narrow-sense heritability ($h^2 a$). The lowest heritability was found for NFP (0.09) and the highest for plant height (0.41) (Table 2).

Regarding estimates of coefficient of individual additive genetic variation (CVgi), the descriptors that had the lowest (10.64%) and highest (18.63%) CVgi were MFD and MFW, respectively. The genetic variability can also be quantified by the coefficient of residual variation (CVe%), which varied from 12.83% (MFD) to 49.28% (NFP) (Table 2).

Qualitative descriptors

Phenotypic variability was found among the F_5 population genotypes for all evaluated qualitative descriptors (Figures 1, 3, and 4). Regarding the descriptor APN, 51.22% of the genotypes presented weak APN, whereas 32.51%, 10.66%, and 3.97% showed medium, strong, and very strong APN, respectively, and 1.64% showed absence of APN (Figure 1A). Regarding APL, most genotypes showed absence of APL (68.58%), whereas 22.68%, 5.73%, and 3.01% showed weak, medium, and strong APL, respectively (Figure 1B).

Three different corolla colours were found for the pepper flowers. Most genotypes (43.03%) had a white corolla, 39.76% had a violet corolla, and 17.21% had a white corolla with violet borders (Figures 1C and 2A).

Regarding the qualitative descriptor FP, five genotypes (0.68%) showed fruits in a pendant position,

Table 3. Description of ideal genotype patterns for the F_5 population of peppers with ornamental potential, considering qualitative descriptors. State University of Montes Claros, Janauba, MG, Brazil, 2023.

Ideal genotype	APN	APL	CC	CBM	FP	PLS	FCM	FCIM
I	Present	Present	Violet or Wvb	Purple	Upright or pendant	Independent	Orange	Independent
II	Present	Present	Violet or Wvb	Purple	Upright or pendant	Narrow-triangular or triangular	Red	Dark
III	Independent	Independent	Violet or Wvb	Purple	Upright	Independent	Wine	Independent

APL, anthocyanin pigmentation in leaves; APN, anthocyanin pigmentation at node height; CBM, fruit colour before maturation; CC, flower corolla colour; FCIM, fruit colour intensity at maturation; FCM, fruit colour at maturation; FP, fruit position in the plant architecture; PLS, predominant shape of the longitudinal fruit section; Wvb, white with violet borders.

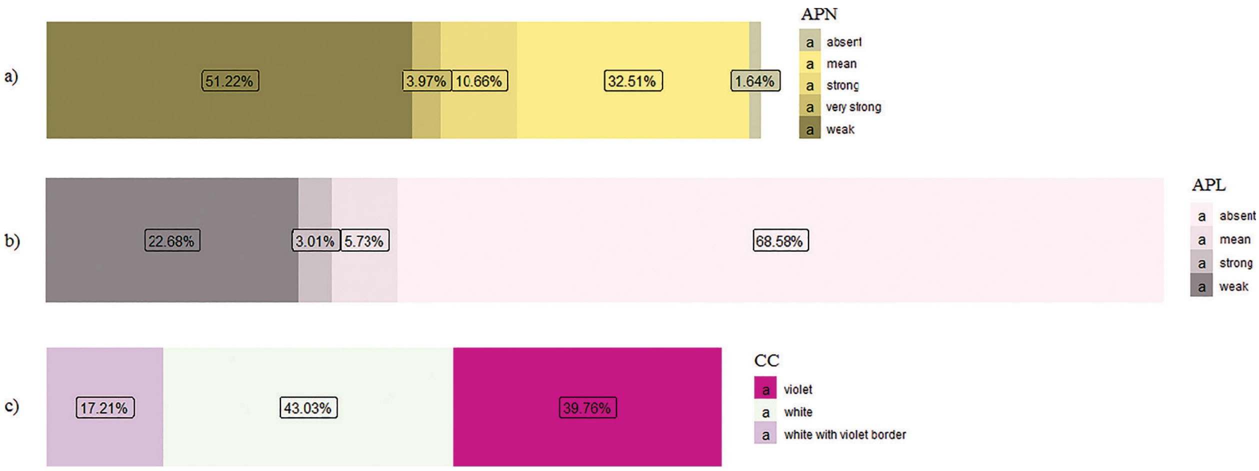

Figure 1. Summary of percentages found for PIL of peppers (*Capsicum annuum* L.) considering the following qualitative descriptors: (A) APN; (B) APL; (C) CC. State University of Montes Claros, Janauba, MG, Brazil, 2023. APL, anthocyanin pigmentation in leaves; APN, Anthocyanin pigmentation at node height; CC, Corolla colour; PIL, Partially inbred lines.

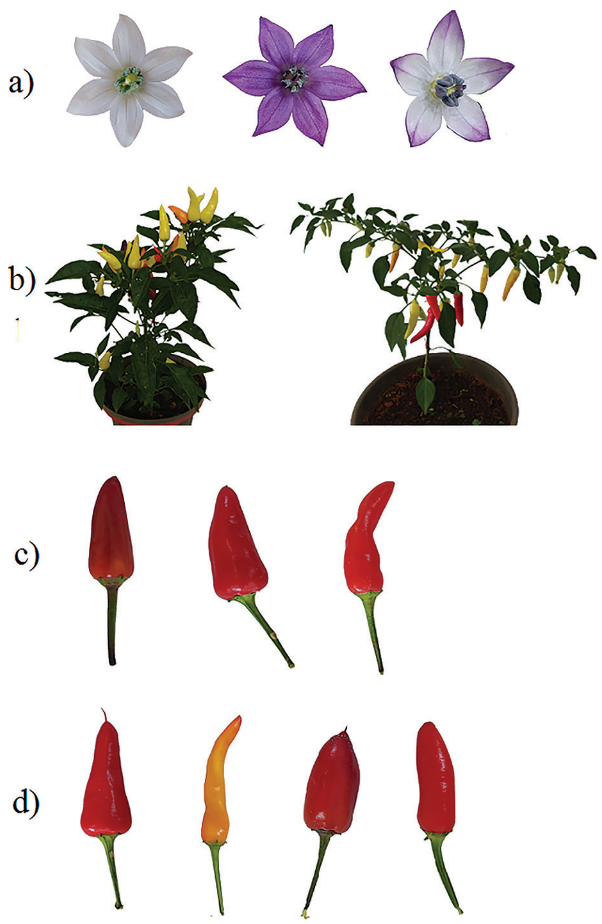

Figure 2. (A) Flower CC: white, violet, and Wvb, respectively; (B) FP in the plant architecture: upright and pendant, respectively; (C) FT: smooth, slightly wrinkled, and strongly wrinkled, respectively; (D) PLS: triangular, narrow-triangular, oval, and elliptical, respectively. State University of Montes Claros, Janauba, MG, Brazil, 2023. CC, corolla colour; FP, fruit position; FT, fruit surface texture; PLS, predominant shape of the longitudinal fruit section; Wvb, white with violet borders.

whereas most genotypes (99.32%) showed upright fruits in the plant architecture (Figures 2B and 3A). Regarding FT, 344 genotypes (47%) presented a smooth FT, 37.29% presented a slightly wrinkled FT, and 15.71% presented a strongly wrinkled FT (Figures 2C and 3B). Four predominant shapes were found for the longitudinal fruit section (PLS): triangular (47.4% of the fruits), narrow-triangular PLS (31.42%), oval (11.07%), and elliptical PLS (10.11%) (Figures 2D and 3C). The predominant shapes found for the transversal fruit section (PTS) were elliptical (55.74%) and rounded PTS (44.26%) (Figure 3D).

The genotypes presented two distinct fruit CBM: purple (57.64%) and white-greenish (42.76%) (Figures 4A and 5A). Most of the genotypes (48.91%) presented dark fruit CIBM, followed by those presenting light (43.85%) and medium CIBM (7.24%) (Figures 4B and 5B).

The fruits at maturation stage presented three distinct colours: red (60.93%), orange (36.06%), and wine (3.01%) (Figures 4C and 5C). The FCIM also varied: most genotypes (52.05%) presented dark FCIM, whereas 35.93% and 12.02% presented medium and light FCIM, respectively, in the last maturation stage (Figures 4D and 5D).

The application of frequency distribution formed three classes for CF and CM: early, medium, and late cycles (Figure 6). Regarding CF, 304 genotypes (41%) presented an early cycle, whose values varied from 40 days to 56.67 days to flowering (Figure 6A). Regarding CM, 118 genotypes (16%) presented a late cycle, varying from 116.33 days to 140 days to maturation (Figure 6B).

Selection of ideal genotypes

The individual selection of genotypes within the population was conducted based on three proposed patterns of ideal genotypes (Table 3). The first selection step considered only the base descriptors considered

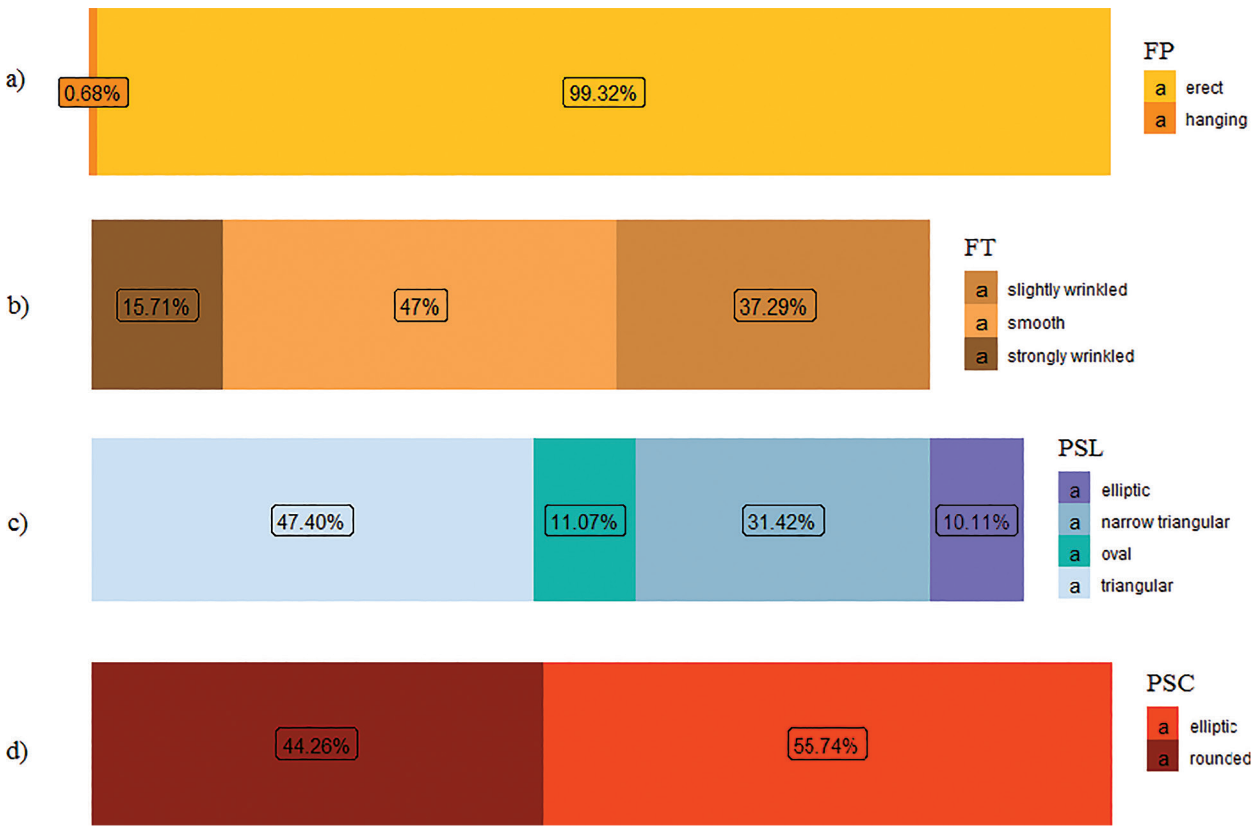

Figure 3. Summary of percentages found for PIL of peppers (*Capsicum annuum* L.) considering the following qualitative descriptors: (A) FP in the plant architecture; (B) FT; (C) PLS; (D) PTS. State University of Montes Claros, Janauba, MG, Brazil, 2023. FP, fruit position; FT, fruit surface texture; PIL, partially inbred lines; PLS, predominant shape of the longitudinal fruit section; PTS, predominant shape of the transversal fruit section.

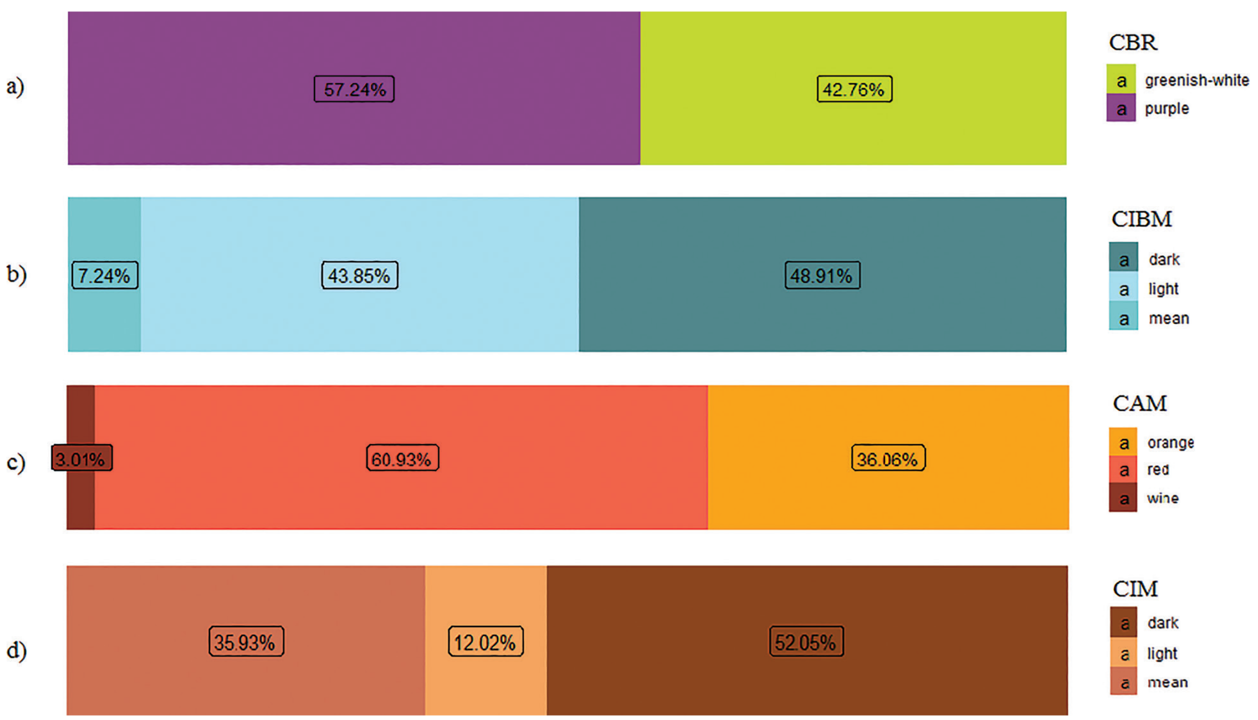

Figure 4. Summary of percentages found for 732 PIL of peppers (*Capsicum annuum* L.) considering the following qualitative descriptors: (A) fruit CBM; (B) fruit CIBM; (C) FCM; (D) FCIM. State University of Montes Claros, Janauba, MG, Brazil, 2023. CBM, colour before maturation; CIBM, colour intensity before maturation; FCIM, fruit colour intensity at maturation; FCM, fruit colour at maturation; PIL, partially inbred lines.

ideal, resulting in the selection of 204 genotypes. The second step used the early CF and late CM classes as filter, resulting in a final selection of 82 genotypes from the 204 genotypes selected in the previous step (Figure 7).

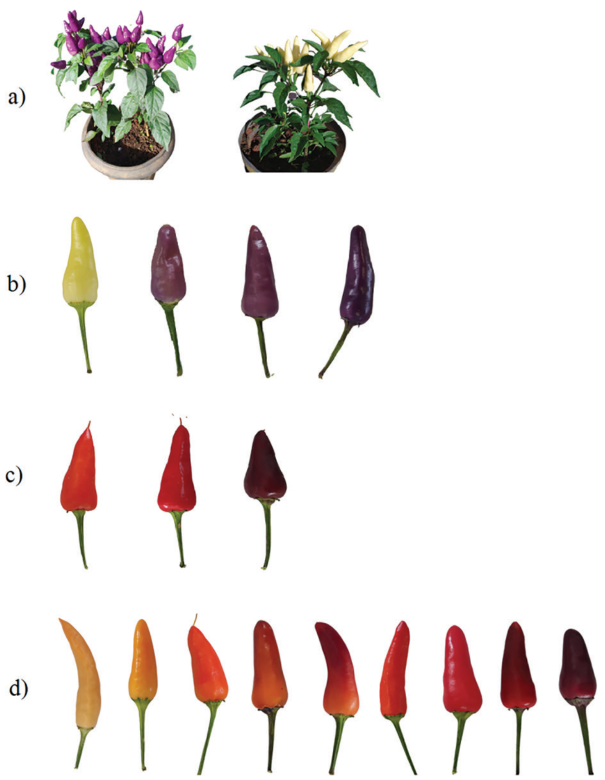

Figure 5. (A) Fruit CBM: purple and white-greenish, respectively; (B) fruit CIBM; (C) FCM: orange, red, and wine, respectively; (D) FCIM. State University of Montes Claros, Janauba, MG, Brazil, 2023. CBM, colour before maturation; CIBM, colour intensity before maturation; FCM, fruit colour at maturation; FCIM, fruit colour intensity at maturation.

Considering the 82 selected ideal genotypes, 41 of them (50%) were classified as ideal genotype pattern I, in which one of the main traits is an orange fruit colour when ripe (CM) (Table 3, Figures 5C and 7). The ideal genotype patterns II and III encompassed 29 (35.37%) and 12 genotypes (14.63%), respectively (Table 3 and Figure 7).

DISCUSSION

Quantitative descriptors

Obtaining variances is highly important for breeding programs because it enables an understanding of the inheritable portion of the phenotypic data found (Cruz, 2005). Genetic variance (σ^2a) is the most commonly used in breeding programs, as it corresponds to the portion of phenotypic variability that will be transmitted to the next generations. On the other hand, residual variance (σ^2e) represents all sources of variation that are considered unknown causes (Bespalhok et al., 2007).

Obtaining satisfactory genetic gains with selection requires at least 80% of heritability (Falconer, 1987), which is a result not found for any quantitative descriptor evaluated in the present study. Traits with low heritability are more susceptible to environmental variations and, therefore, are not entirely reliable for use in plant selection (Sturion et al., 1994). In this sense, a selection based on the quantitative descriptors evaluated in the present study would not be reliable.

Borém et al. (2017) described some factors that affect heritability, such as population diversity, population inbreeding level, and sample size. These factors were observed in the present study, as these are quantitative characteristics, and thus, driven by many genes and highly affected by environmental variations (Ramalho et al., 2012). The plants in the F_5 population may still be undergoing segregation, i.e., they have not yet achieved a high allele fixation, which is related to the inbreeding

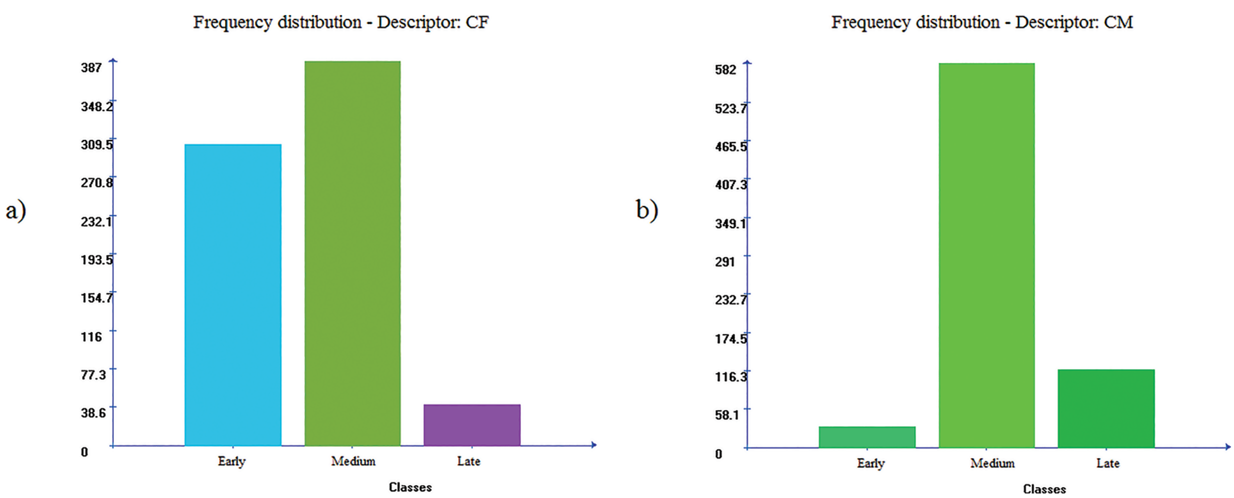

Figure 6. Frequency distribution within class intervals (early, medium, and late cycles) for the following qualitative descriptors: (A) CF; (B) CM. State University of Montes Claros, Janauba, MG, Brazil, 2023. CF, cycle to flowering; CM, cycle to maturation.

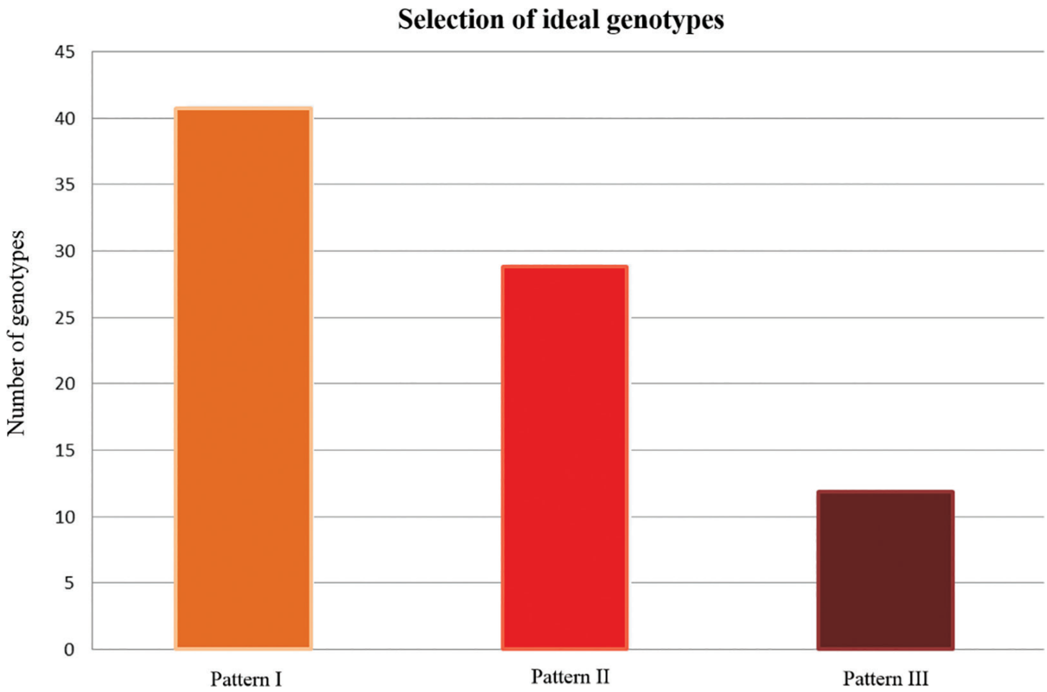

Figure 7. Graph distribution of ideal genotypes selected according to the following patterns: ideal genotype I, ideal genotype II, and ideal genotype III. State University of Montes Claros, Janauba, MG, Brazil, 2023.

level in populations. Additionally, 732 genotypes were evaluated in the present study, which is a significantly large number when compared to other studies evaluating segregating populations of ornamental peppers (Costa et al., 2020; Carvalho et al., 2021). Therefore, the population size and the diversity among genotypes may have affected the results found for the evaluated genetic parameters.

Some solution strategies can be used for cases of low heritability results, such as the use of replications and progenies, which will assist in future selection based on these traits (Sturion et al., 1994; Bernardo, 2010). Therefore, the breeding program conducted in the present study will not select PIL based on quantitative descriptors, but only based on qualitative descriptors. Advancing further generations is recommended for allele fixation of these traits, conducting further trials with replications.

Qualitative descriptors

The anthocyanin pigmentation at node height and in leaves of pepper plants is related to the concentration of anthocyanin in the genotype. In addition to the qualitative variation of this pigment (presence or absence), a quantitative variation in the purple-colour intensity can be found among genotypes (Chaim et al., 2003). Therefore, it is possible to classify different anthocyanin pigmentation contents in pepper plants, varying from absent to very strong.

Pigmentation in vegetative and reproduction organs is essential for breeding programs in ornamental peppers, as it increases the probability of selling (Santos, 2012). Thus, pepper plants with some anthocyanin content in their vegetative organs are more interesting for the ornamental market. Most genotypes evaluated in the present study had some pigmentation content at node height, whereas only a minority showed it in the leaves.

Despite their small size, pepper flowers are interesting in terms of ornamentation, mainly when they have attractive colours and position that enables a better visibility within the plant architecture (Melo et al., 2014). Therefore, violet and white flowers with violet borders tend to attract more attention from consumers due to their unusual and attractive colours.

The purple colour of fruits before maturation, as well as its intensity, is also connected to the anthocyanin contents in the plant (Figure 5B). Some genotypes may exhibit a purple colouration in all organs, whereas others only show it in some organs (Santos, 2012). Therefore, plants with no anthocyanin in nodes, leaves, and flowers but with purplish fruits can be found, although with less probability. The female parent (UNI05) has purple fruits at immature stage, which was a trait inherited by most descendant genotypes.

Epistatic effects do not significantly affect the variation of anthocyanin contents in leaves, flowers, and fruits of pepper plants (Santos, 2012). Probably, no significant interaction is found between genes that make one locus inhibit the pigment expression of the gene at another locus. The purple colour in fruits, as well as in vegetative organs, is more interesting for selection as it confers an ornamental potential trait (Rêgo et al., 2011; Carvalho et al., 2015). Studies on consumer preference for ornamental peppers have reported a greater interest in purple-colour unripe fruits (Neitzke et al., 2016; Cunha et al., 2020).

Ornamental peppers are commonly used for two purposes: ornamentation and food consumption. Therefore, the biochemical compounds in their fruits are also important. Sahid et al. (2022) conducted a study to identify these compounds in ornamental pepper genotypes and found high contents of alpha-glucosidase inhibitors (AGI), reaching up to 83.27%. They attributed the high inhibitory activity of alpha-glucosidase to the purple colour of the fruits, indicating their potential in the prevention and treatment of diabetes. This explains why the purple colour is caused by total anthocyanin and flavonoid contents in pepper plants, mainly when considering that anthocyanin is one of the compounds involved in alpha-glucosidase inhibition activities (Guevara et al., 2019; Papoutsis et al., 2021).

The upright position of fruits in the plant architecture is preferable for the ornamental market, as it makes the fruits more visible and prominent on the foliage (Melo et al., 2014). However, preferences may vary depending on the consumer, who may seek for new options beyond those already available on the market, thus creating opportunities for innovation, targeting new consumers, and even setting new trends. Therefore, genotypes with pendant fruits, depending on the pepper plant architecture, can be interesting for new ornamental cultivars.

Regarding FT, Ribeiro (2012) stated that it is a trait that significantly influences the choice of an ornamental arrangement and that a smooth texture is most appreciated by consumers. However, despite having been reported in studies as the most appreciated, a smooth fruit texture is probably not the only texture trait of interest for a new ornamental pepper cultivar, as similarly mentioned for FP. Plants with eccentric characteristics can be targeted for landscaping and interior decoration, as the unusual is highly valued by some consumers, especially collectors.

The three predominant fruit textures found in the PIL in the present study (smooth, slightly wrinkled, and strongly wrinkled) indicate the potential to reach different consumers. Probably, a smooth fruit texture may satisfy more consumers as it is more discreet. A slightly wrinkled texture can be a middle ground between these tree textures, whereas a strongly wrinkled may satisfy those consumers with preferences for more exotic and extravagant plants, as well as collectors. Most ornamental peppers available on the market have a smoot texture and, according to Neitzke et al. (2016), the release of new cultivars is only justified when it provides innovation to the market, i.e., physiological or morphological characteristics that differentiate these cultivars from those already available. Therefore, all the textures found in the genotypes evaluated in the present study are interesting in terms of the composition of new cultivars.

Most studies on consumer preferences for ornamental peppers have not highlighted the essential aspect of fruit shape (Neitzke et al., 2016; Cunha et al., 2020). This trait has a high ornamental interest; however, the number of available cultivars that highlight this trait is small, denoting the potential of this market niche for breeding programs (Pimenta et al., 2020). The absence of preference for specific pepper shapes denotes the possibility of considering all shapes for developing new cultivars. Therefore, materials with fruit shapes that differentiate them from those already available on market can be interesting, depending on the set of plant characteristics.

Both parents used have red fruits when they reach maturation. Neitzke et al. (2016) stated that fruit colour is the most relevant factor when purchasing ornamental peppers, whether the fruits are ripe or not. Some studies have reported consumer preference for red peppers at maturation (Neitzke et al., 2016; Cunha et al., 2020); however, one of the advantages of ornamental plants is to maximise the phenotypic differences of interest. Thus, the development of new materials with distinct fruit colours can be an attractive alternative for the market. In addition, launching new materials that deviate from the ordinary is a differential strategy that can expand sales, considering that most peppers have a red colour in the final stage.

Colour intensity is not commonly reported in the literature, but it may also have a great ornamental importance. This trait can indicate the contrast level between leaves and fruits, which adds significant aesthetic value to ornamental materials. Colour intensity also has the potential to be used to differentiate genotypes; for example, fruits with orange colour at the maturation stage are not necessarily equal, while the shade of their colours can distinguish them from each other and from other materials already available on the market (Figure 5D). Therefore, colour intensity, whether in unripe or ripe fruits, is a highly interesting trait for ornamental pepper breeding.

An early CF and a late CM were identified as ideal. Earliness in the flowering cycle is directly correlated to earliness in the total cycle of pepper plants, as the plants tend to flower and bear fruit early. The fruiting stage is highly important for these materials, signalling the commercialisation stage of the product. Cultivars with higher earliness ensure to growers a shorter time until the commercialisation stage, and consequently, lower production costs (Silva et al., 2015). The growth of earlier materials contributes to decreased costs with maintenance, managements, inputs, and labour. Additionally, it also decreases the time of exposure of crops to pests and diseases (Carneiro, 2017). The possibility of higher rotation is another significant advantage of using early cultivars. Peppers are usually grown by small and medium-sized farmers; therefore, a higher rotation of the product provides growers with the possibility of higher annual profits, as they can produce more ornamental peppers in less time.

Regarding CM, a late cycle is considered more ideal, as a longer fruit retention on ornamental pepper plants is one of the main attractive factors for consumers

(Melo et al., 2014). The persistence of fruits on pepper plants ensures a longer shelf life for sellers and a better cultivation experience for consumers, satisfying all participants in the process. Rêgo et al. (2012) evaluated pepper plants with ornamental potential and found means of 50 days to flowering and 91 days to fruiting. Silva et al. (2020) evaluated promising materials for ornamental use and found 85 days to flowering and 103 days to fruiting for the earliest genotype. These are similar results to those found in the present study.

Ideal genotypes

The selection of the 82 ideal pepper genotypes in this study was based on high aesthetic value traits, which are important for the ornamental sector and differentiate them from materials available on the market.

These selected genotypes will be used for developing future generations until the achievement of allele fixation. New evaluations then will be performed based on qualitative and quantitative traits of candidate lines for new ornamental pepper cultivars, which is the main objective of this breeding program.

CONCLUSIONS

The definition of three patterns of ideal genotypes enabled the selection of 82 lines for the development of future generations using the SSD method, focussed on obtaining new ornamental pepper cultivars.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

G.C.A.B. – conducting and evaluating the experiment, and manuscript writing. S.P. – experiment planning and statistical analysis. F.S.G. – evaluation of the experiment and statistical analysis. N.S.S. – conducting and evaluating the experiment. B.R.A.R. – assistance in reducing the manuscript. F.C.O. – conducting and evaluating the experiment. N.A.D.J. – experiment planning and manuscript writing. M.C.T.P. – experiment planning and statistical analysis.

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