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EVALUATION OF LIMA BEAN ACCESSIONS AT HIGH TEMPERATURES[1]

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ABSTRACT – Lima bean (*Phaseolus lunatus* L.) develops at an optimal temperature in the range of 20–30°C, temperatures above 30–35°C compromise the photosynthetic efficiency of the crop. Considering the importance of lima bean cultivation, the objective of this study was to carry out a morphoagronomic and phenological characterization of 46 lima bean accessions tolerant to high temperatures from the core collection of lima bean at the Universidade Federal do Piauí. The experiment was conducted from February to July 2021 in a completely randomized block design with four replications, where the plot consisted of a pot with two plants. Genotype characterization was performed based on 20 morphoagronomic and phenological descriptors of lima bean. Based on Pearson's correlation, the number of emitted and aborted flowers had a greater genetic correlation with the total number of seeds and pods produced. Pod length and width were positively correlated with seed thickness, length, and width. Five groups were formed based on UPGMA grouping. It was observed that the UFPI-922 and UFPI-945 accessions had a higher performance under high-temperature conditions in relation to the number of flowers and pods emitted, as well as lower values for the number of aborted pods. The accessions UFPI-1037, UFPI-876, UFPI-1036, UFPI-1028, UFPI-1052, UFPI-1064, UFPI-1038, and UFPI-1062 are promising for precocity, productivity, emission of flowers and pods formed, and can be used in breeding programs.

Keywords: *Phaseolus lunatus*. Abortion of flowers and pods. Thermal stress. Pearson's linear correlation. UPGMA method.

AVALIAÇÃO DE ACESSOS DE FEIJÃO-FAVA EM CONDIÇÕES DE ALTAS TEMPERATURAS

RESUMO – A cultura do feijão-fava (*Phaseolus lunatus* L) desenvolve-se em faixa ótima de temperaturas de 20-30°C, sendo que, as temperaturas superiores a 30-35ºC compromete a eficiência fotossintética e consequentemente desempenho produtivo. Considerando a importância do cultivo de feijão-fava, objetivou-se realizar a caracterização morfoagronômica e fenológicas de 46 acessos de feijão-fava tolerantes ás altas temperaturas da coleção nuclear de feijão-fava da Universidade Federal do Piauí. O experimento foi conduzido entre fevereiro a julho de 2021, em blocos inteiramente casualizados, com quatro repetições, sendo a parcela constituída por um vaso, com duas plantas. A caracterização dos acessos foi realizada com base em 20 descritores morfoagronômicos e fenológicos de feijão-fava. Com base na correlação de Pearson o número de flores emitidas e abortadas tem maior correlação genética com a quantidade total de sementes e vagens produzidas. Comprimento e largura de vagem apresentaram correlação positiva com os caracteres espessura, comprimento e largura da semente. Pelo agrupamento UPGMA houve a formação de cinco grupos. Os acessos UFPI-922 e UFPI-945 possuem maior desempenho nas condições de alta temperatura, para número de flores e de vagens emitidas como também menores valores de número de vagens abortadas. Os acessos UFPI-1037, UFPI-876, UFPI-1036, UFPI-1028, UFPI-1052, UFPI-1064, UFPI-1038 e UFPI-1062 são promissores tanto para precocidade, produtividade, emissão de flores e vagens formadas em programas de melhoramento de feijão-fava.

Palavras-chave: *Phaseolus lunatus*. Abortamento de flores e de vagens. Estresse térmico. Correlação de Pearson. Método UPGMA.

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INTRODUCTION

The Lima bean (*Phaseolus lunatus* L.) is one of the most important cultivated species of the *Phaseolus* genus in the world (MARTÍNEZ-NIETO et al., 2020; ALMEIDA et al., 2021; GARCIA et al., 2021), being cultivated in North and South America, Europe, East and West of Africa, and Southwest Asia (LOPES; ARAÚJO; GOMES, 2015) as an important source of proteins, carbohydrates, fats, fibers, and minerals (SEIDU; OSUNDAHUNSI; OSAMUDIAMEN, 2018).

In Brazil, most of the production of Lima bean occurs in the Northeast region, accounting for about 99.4% of the national yield, being cultivated in an area of 36.350 thousand hectare in 2019, with an average production of 353 kg/ha^{-1} (IBGE, 2019). This production can oscillate due to climate change, mainly arising from the increase in temperature, which affects crop development and physiology (MACHADO FILHO et al., 2016).

High temperatures can affect the photosynthesis process, causing morpho-physiological modifications in the plant's development in both its vegetative and reproductive stages (RAZA et al., 2019). Critical effects can be observed mainly in the stages of flowering and grain maturation, causing late or premature flowering, flower abortion, pollen infeasibility, and reduction in time for grain filling (BARLOW et al., 2015), caused by inhibition of the biosynthesis of proteins, amino acids, fibers, vitamins, and minerals (FAROOQ et al., 2017).

The common bean (*Phaseolus vulgaris*), with the same genus as the Lima bean, has been shown to be highly sensitive to heat stress during flowering and formation of pods, and high temperatures (above 30°C) during the flowering stage are determining factors in the reduction of flower bud setting and pod formation (MORAES, 2017). According to Battisti et al. (2013), the period of maximum flower emission and the end of the flowering stage are usually associated with higher percentages of floral abortion. For the Lima bean crop, there is no information on the influence of temperature on its phenological traits and plant development.

Considering the socioeconomic importance of the Lima bean and the fact that high temperatures during flowering and pod development stages result in lower yields in corelated species (BRITO et al., 2020; MORAES, 2017), there is a need to select superior genotypes that can be used in crosses to obtain high-yielding and high-temperature tolerant cultivars. Under these conditions, the use of multivariate algorithms is an excellent strategy to quantify dissimilarity between individuals based on morphoagronomic and phenological traits. Multivariate statistics corresponds to a set of statistical methods and techniques that use all the information from the traits simultaneously in a theoretical interpretation of the obtained data, taking into account the correlations between them (CRUZ; CARNEIRO; REGAZZI, 2014).

In the face of climate change predictions regarding an increase in global temperature as a consequence of gas emissions, there is a need to identify high temperature tolerant accessions in the Lima bean. The present study aimed to carry out morphoagronomic and phenological characterization of 46 Lima bean accessions from the core collection of *Phaseolus* from the Universidade Federal do Piauí at high temperatures.

MATERIAL AND METHODS

The experiment was carried out in a covered area (50% shading rate) in the Department of Plant Science of the Center for Agricultural Sciences at Universidade Federal do Piauí (UFPI), in Teresina, PI (74.4 m altitude, 05º05'21'' S, 42º48'07'' W) from February to July 2021. The climate in the region is of the Aw type, according to the Köppen classification, with an annual average temperature of 26.5°C, average relative humidity of 70%, and annual average precipitation of 1.448 mm. The maximum, minimum, and average temperatures are shown in Figure 1.

The 46 Lima bean accessions belong to the core collection of Lima beans of the Germplasm Bank of *Phaseolus* at the Universidade Federal do Piauí (BGP-UFPI) established by Almeida et al. (2021) with different origins (Table 1).

The experiment was set up in a completely randomized block design, with four replications, and consisted of a polyethylene pot (14 L) fertilized with vegetable soil in a 3:1 ratio (vegetal soil and humus), with one seed sown in each pot. Phytosanitary treatments for pest control were carried out throughout the cycle and irrigation was carried out using micro-sprinklers. The plants showed an indeterminate growth rate and were tutored with lathstakes.

Accessions were characterized based on 16 quantitative descriptors, as recommended by Bioversity International (2007), and four phenological descriptors (HOFFMANN JÚNIOR et al., 2007).

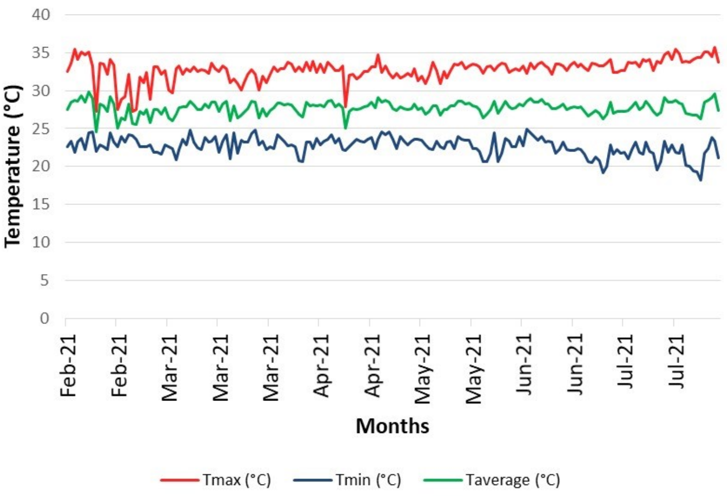

Figure 1. The maximum, minimum, and average temperature values registered in the months of execution of the study according to the Nacional Institute of Meteorology (Instituto Nacional de Meteorologia/INMET), Teresina, PI, Brazil, 2021.

Table 1. Lima bean accessions sourced from the core collection of Lima bean of the Germplasm Bank of *Phaseolus* at the Universidade Federal do Piauí (BGP-UFPI), in Teresina, PI, Brazil.

Accessions	Biological state	Group	Origin
UFPI - 849	Cultivated	Brazil	Brazil
UFPI - 876	Cultivated	Brazil	Brazil
UFPI - 880	Cultivated	Brazil	Brazil
UFPI - 922	Cultivated	Brazil	Brazil
UFPI - 935	Cultivated	Brazil	Brazil
UFPI - 945	Cultivated	Brazil	Brazil
UFPI - 954	Cultivated	Brazil	Brazil
UFPI - 967	Cultivated	Brazil	Brazil
UFPI - 998	Cultivated	Brazil	Brazil
UFPI - 1015	Cultivated	Brazil	Brazil
UFPI - 1026	Cultivated	Unspecific group	United States
UFPI - 1028	Cultivated	Unspecific group	United States
UFPI - 1036	Cultivated	Unspecific group	United States
UFPI - 1037	Cultivated	Unspecific group	United States
UFPI - 1038	Cultivated	Unspecific group	Philippines
UFPI - 1049	Cultivated	Unspecific group	United States
UFPI - 1050	Wild	Mesoamerican	Mexico
UFPI - 1051	Cultivated	Andean	Peru
UFPI - 1052	Cultivated	Not Identified	Not Identified
UFPI - 1054	Wild	Andean	Colombia
UFPI - 1062	Cultivated	Unspecific group	Azerbaijan
UFPI - 1064	Cultivated	Unspecific group	Azerbaijan
UFPI - 1066	Wild	Mesoamerican	El Salvador
UFPI - 1067	Wild	Mesoamerican	Mexico
UFPI - 1068	Cultivated	Unspecific group	Ghana
UFPI - 1075	Cultivated	Unspecific group	Nigeria
UFPI - 1076	Cultivated	Unspecific group	Not Identified
UFPI - 1084	Cultivated	Mesoamerican	El Salvador
UFPI - 1101	Cultivated	Mesoamerican	Costa Rica
UFPI - 1102	Cultivated	Mesoamerican	Argentina
UFPI - 1116	Cultivated	Mesoamerican	Guatemala
UFPI - 1118	Cultivated	Mesoamerican	Guatemala
UFPI - 1141	Cultivated	Unspecific group	United States
UFPI - 1143	Wild	Mesoamerican	Mexico
UFPI - 1152	Cultivated	Unspecific group	China
UFPI - 1178	Cultivated	Brazil	Brazil
UFPI - 1183	Cultivated	Brazil	Brazil
UFPI - 1186	Cultivated	Brazil	Brazil
UFPI - 1188	Cultivated	Brazil	Brazil
UFPI - 1195	Cultivated	Brazil	Brazil
UFPI - 1202	Cultivated	Brazil	Brazil
UFPI - 1206	Cultivated	Brazil	Brazil
UFPI - 1208	Cultivated	Brazil	Brazil
UFPI - 1213	Cultivated	Brazil	Brazil
UFPI - 1218	Cultivated	Brazil	Brazil
UFPI - 1226	Cultivated	Brazil	Brazil

The descriptors evaluated and their respective units were as follows: average number of days to emergence (DE, days); average number of days to the beginning of flowering (NDF, days); average number of days to maturation (NDM, days); average plant height (PH, cm); average first pod height (FPH, cm); average pod length (PL, mm); average pod width (PW, mm); average pod thickness (PT, mm); average seed length (SL, mm); average seed width (SW, mm); average seed thickness (ST, mm); number of locules per pod (NLP, total); average number of seeds per pod (NSP, total); average number of total seeds formed (NTS, total); average number of total pods formed (NTP, total); and the average ratio between the number of total seeds and the number of total pods (RSP).

The phenological traits evaluated and their measurement units were as follows: average number of emitted flowers (NEF, total), average number of aborted flowers (NAF, total), average number of formed pods (NFP, total), and average number of aborted pods (NAP, total). To determine the dimensions of the pods and seeds (in mm), and plant and first pod height (in cm), a digital pachymeter and measuring tape were used.

The obtained data were subjected to Pearson's linear correlation coefficient matrix (r) between the morphoagronomic and phenological traits using the Student's t-test at 5% probability, and the significance of r was evaluated using the package *corrplot* in the R program. The relationship between the explanatory variables and answer values was obtained using the following equation:

$$r_{xy} = \frac{\mathrm{Cov}(X,Y)}{\sqrt{V(X).V(Y)}} = \frac{\delta(X,Y)}{\delta(X)\delta(Y)}$$

where r(XY) is the Pearson's correlation coefficient for variables X (answer) and Y (explanatory), σ (X,Y) is the covariance between variables X and Y, and σ(X) and σ(Y) are the standard deviations of variables X and Y, respectively.

In this analysis, the existence, direction, and intensity of the linear relationship between traits were analyzed using Pearson's correlation coefficient (r), ranging between -1 and +1. Values close to 1 indicate a strong linear relationship, whereas values close to 0 indicate a weak linear relationship between traits.

A grouping analysis was performed for all the traits considering the Gower (1971) distance as the dissimilarity measurement using the package *biotools* and *cluster* in the R software. Hierarchical grouping was obtained by the genetic distance matrix using the unweighted pair-group method with an arithmetic average (UPGMA) (SNEATH; SOKAL, 1973). All data were analyzed using R (R CORE TEAM, 2018).

RESULTS AND DISCUSSION

The Pearson's correlation values obtained indicate that there was a significant and positive association between the traits days to the beginning of flowering (NDF) and days to maturation (NDM) (r = 0.72), indicating that plants that have early flowering have early pod maturation and plants with late flowering take longer to mature (Figure 2). Correlations between these two traits are frequently reported in different crops, including Lima bean. According to Assunção Filho et al. (2022), these results are expected, given that both determine the crop cycle in the Lima bean.

Additionally, Sousa et al. (2022, 2015) related that the temperature and relative humidity were the factors that most affected the pod formation rate during the crop development. The average temperatures observed were 29.8 (morning) and 33.2ºC (afternoon) and an average relative air humidity of 64%, which described the ideal temperature and humidity for Lima bean to avoid the heat stress and facilitate the pod formation.

The NEF had a strong and positive association with the NAF (r = 0.86), indicating that most of the abortions occurred in accessions with larger quantities of flowers, suggesting that the flower and pod abortions can be of natural cause when they are in excess. However, stress can also cause abortions such as at high temperatures. Similarly, NFP and NAP were positively correlated (r = 0.54), indicating that accessions with a larger number of pods will have a larger number of aborted pods. According to Hoffmann Júnior et al. (2007), high air temperature may be the most influential environmental factor in the abscission of flowers and pods, inappropriate grain filling, setting, and final retention of pods in beans, and it is also responsible for the reduction in the number of seeds per pod in the seed mass.

The correlation between NEF and NFP (r = 0.44) and NAP (r = 0.42) was also positive. This shows that accessions that emitted a larger quantity of flowers also aborted a larger quantity of flowers and pods, despite presenting a larger number of viable pods and seeds at the end of the cycle, which can be visualized by the positive correlation between the number of emitted flowers and the average number of seeds formed. According to Martins et al. (2017), the number of pods is one of the most important production components for beans and is dependent on the number of emitted flowers and floral setting. Moraes (2017) observed that one response to heat stress during the flowering stage is the abortion of reproductive structures, which can reach up to 70% of the opened flowers.

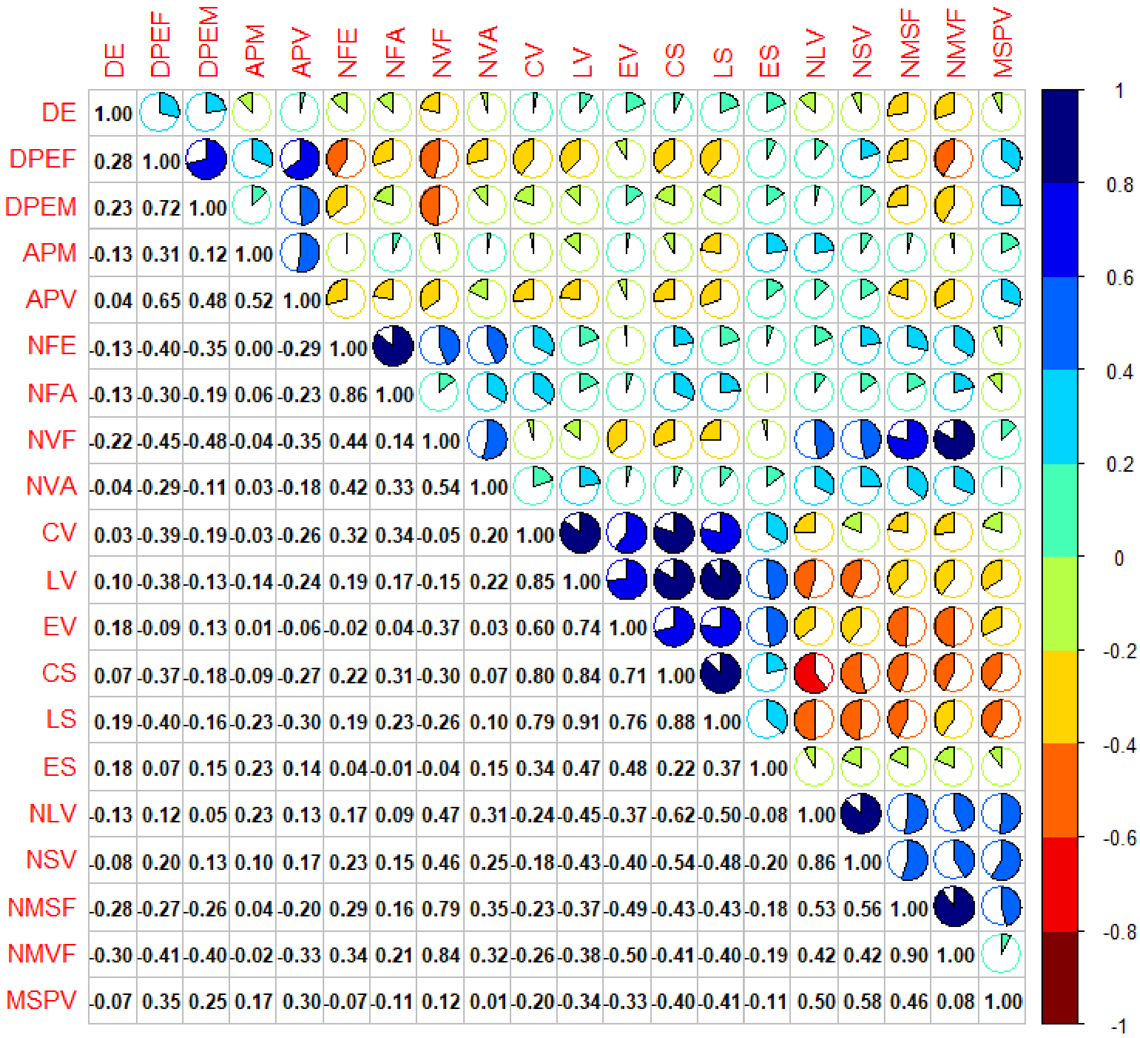

Figure 2. Pearson's correlation coefficient between twenty traits evaluated in 46 Lima bean accessions. average days to emergence (DE); average number of days to the beginning of flowering (NDF); average number of days to maturation (NDM); average plant height (PH); average first pod height (FPH); average number of emitted flowers (NEF); average number of aborted flowers (NAF); average number of formed pods (NFP); average number of aborted pods (NAP); average pod length (PL); average pod width (PW); average pod thickness (PT); average seed length (SL); average seed width (SW); average seed thickness (ST); average number of locules per pod (NLP); average number of seeds per pod (NSP); average number of total seeds formed (NTS); average number of total pods formed (NTP), and the average of the ratio between the number of total seeds and number of total pods (RSP), in Teresina, PI, Brazil.

Negative and significant correlations were observed between NDF and NDM with NEF, NAF, NFP, and NAP, with values ranging from 10 to 50%, indicating that accessions with early flowering can have a higher quantity of pod abortions. In addition, there was a positive correlation between NDF and RSP (r = 0.35), indicating that the sooner the accessions bloom, the more seeds may be present in the pod. Sousa et al. (2015) observed that early accessions allowed greater formation of pods.

The accessions with a shorter flowering period have a characteristic of emitting more flowers, possibly to guarantee the production if any stress occurs during the cycle. If this stress does not occur, the plant may be able to eliminate excess flowers and fix more viable pods (MORAES, 2017).

In relation to the seed traits, Pearson's correlation verified a positive correlation between PL and PW (r = 0.85), ST (r = 0.34; 0.70), SL (r = 0.80; 0.84), and SW (r = 0.79; 0.91). This indicates that the higher the values of PL and PW, the higher are the values of SL, SW, and ST. High magnitude and positive correlations were observed between NLP and NSP (r = 0.86), and between NTS and NTP (r = 0.90). These results were expected and are considered important for producers and consumers of Lima bean, because larger seeds are more appealing to the market (ASSUNÇÃO NETO et al., 2022; BRITO et al., 2020). Traits with higher correlation magnitudes can be considered in selection strategies (ASSUNÇÃO FILHO et al., 2022).

No significant correlation was observed between other phenological traits and plant architecture, this result is supported by Ribeiro et al. (2018) and Assunção Filho et al. (2022) who reported that this result can be explained by the fact the selection of phenological traits was not always associated with plant architecture and high grain yield.

Five groups were formed from the UPGMA

grouping, with a cutoff point corresponding to an abrupt change in the graph (Figure 3). This grouping method provides greater accuracy in decision-making because it allows the selection of accessions of interest according to the desirable trait to be improved, in addition to facilitating the choice of superior individuals to obtain crosses that maximize heterosis (CRUZ; CARNEIRO; REGAZZI, 2014; BRITO et al., 2020).

The accession from group 1 (UFPI-1026) had a larger number of days to emergence and a lower number of formed pods in the cycle, and it also presented increased SL (19.57 mm) and SW (12.03 mm) than the other groups. The accessions from group 2 (UFPI-1143) presented larger NDF (111 days) and NDM (131 days), lower values of PL (37.46 mm), PW (8.23 mm), and PT (5.54 mm), and larger RSP with an average of 2.51 seed per pod.

The accessions from group 3 (UFPI-1037, UFPI-876, UFPI-1036, UFPI-1028, UFPI-1052, UFPI-1064, UFPI-1038, and UFPI-1062) presented lower NDF and NDM values, with average values ranging from 37 to 51 d and 62 to 91 d, respectively. In addition, this group presented higher values for NEF and NFP, and lower values for NAF and NAP. The accessions of the group have PL, PW, PT, SL, SW, and ST with averages values ranging from 49.9 to 66.84, 13.4 to 17.17, 6.4 to 8.3, 10.75 to 14.54, 7.78 to 9.8 and 3.84 to 4.69 mm respectively.

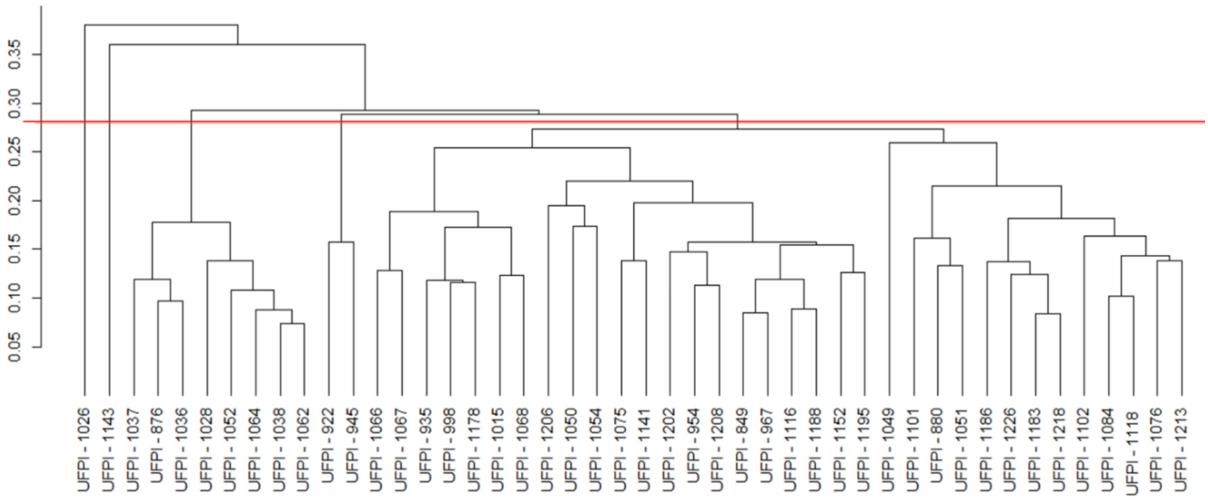

Figure 3. Dendrogram of dissimilarity between 46 Lima bean accessions sourced from the core collection of Lima bean of the Germplasm Bank of *Phaseolus* at the Universidade Federal do Piauí (BGP-UFPI), obtained by the UPGMA method based on the Gower's distance (1971), in Teresina, PI, Brazil.

In group 4 (UFPI-922 and UFPI-945), the accessions had larger NEF, NAF, and NFP values and lower NAP values. In relation to the trait PL they presented the biggest values in comparison to the other groups with averages ranging from 61.76 to 90.55 mm.

Group 5 (UFPI-1206, UFPI-1050, UFPI-1054, UFPI-1075, UFPI-1141, UFPI-1202, UFPI-954, UFPI-1208, UFPI-849, UFPI-967, UFPI-1116, UFPI-1188, UFPI-1152, UFPI-1195, UFPI-1049, UFPI-1101, UFPI-880, UFPI-1051, UFPI-1186, UFPI-1226, UFPI-1183, UFPI-1218, UFPI-1102, UFPI-1084, UFPI-1118, UFPI-1076, and UFPI-1213) presented intermediate NDF values ranging from 37 to 130 days, with NDM values ranging from 62 to 130 days. Groups 1, 2, and 3, it presented the highest values of NEF and the lowest values of NAP.

Based on the grouping made by the UPGMA method based on the Gower distance, it can be inferred that the accessions belong to genetically divergent groups, taking into consideration phenological traits, plant architecture, and grain yield; thus, they can be recommended for hybridization in a plant breeding program.

The accessions UFPI-922 and UFPI-945 performed better under high-temperature conditions for the number of emitted flowers and number of emitted pods, and also showed the highest values for pod length and lowest values for the number of aborted pods. The genotypes from group 3 presented the largest number of emitted flowers and number of formed pods, indicating that they are promising accessions for productivity in Lima bean.

The accessions that presented the largest production of pods and seeds were also responsible for the largest emission of flowers, but also for the largest number of pods aborted. According to Zilio et al. (2011), the quantity of pods formed in beans is influenced by the number of flowers that develop into pods. Such results are of paramount importance for the selection of productive accessions because, based on the NEF by the accessions, it can be inferred that the higher the NEF, the more productive they will be. In this regard, the trait number of flowers needs special attention as it provides early information on the potential for grain yield of the accessions.

CONCLUSION

The accessions UFPI-922 and UFPI-945 had a better performance in high-temperature conditions in relation to the number of emitted flowers and number of emitted pods, as well as higher pod length and lower number of aborted pods. Accessions UFPI -1037, UFPI-876, UFPI-1036, UFPI-1028, UFPI-1052, UFPI-1064, UFPI-1038, and UFPI-1062 are also promising for future plant breeding programs because of their precocity and yield.

The traits number of emitted flowers and number of aborted flowers had a higher genetic correlation with the total quantity of seeds and pods produced, and pod length and pod width had positive correlations with values that were greater than 70% with the traits seed length, seed width, and seed thickness. Thus, the combined selection of these traits must be prioritized in Lima bean.

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