Revista Ciência Agronômica, v. 54, e20228428, 2023
Centro de Ciências Agrárias - Universidade Federal do Ceará, Fortaleza, CE
www.ccarevista.ufc.br

Scientific Article
ISSN 1806-6690

Divergence among mother trees of *Handroanthus serratifolius* (Vahl) S. O. Grose regarding seed quality traits[1]

Divergência entre árvores matrizes de *Handroanthus serratifolius* (Vahl) S. O. Grose quanto a caracteres de qualidade de sementes

Patrícia Cândido da Cruz Silva[2]*, Bruna Zanatto[2], Rinaldo Cesar de Paula[2]

ABSTRACT - Environmental influences and genetic variability can promote, within the same species, variations between plants with intrinsic traits to the seeds. This work aimed at investigating the divergence among *Handroanthus serratifolius* mother trees from traits related to the physiological quality of seeds. Seeds collected from 13 mother trees were submitted to tests germination, electrical conductivity (EC), cold, controlled deterioration, and accelerated aging. Five replications of 50 and 25 seeds each were used for the cold test and other tests, respectively. The average data per mother tree were submitted to cluster analysis by the methods of Ward, k-means, and Principal Component Analysis (PCA). The mother trees were grouped into 4 clusters by the Ward's and K-means methods, and confirmed by the PCA, but with varying cluster compositions. Cluster 2 grouped the mother trees with lower seed quality as demonstrated by the lowest values for most of the evaluated traits, but the highest EC and the second-highest value for the germination uncertainty index. On the other hand, cluster 4 grouped the mother trees with better seed quality. Of the 22 evaluated traits, eight are probably suitable for discarding due to their little contribution to the original variability. The results of the different clustering methods indicate significant differences between the mother trees regarding the physiological quality of seeds, showing that these parameters may be used to guide breeding programs aiming to produce high-quality seeds and seedlings of *H. serratifolius*.

Key words: Cluster analysis. Native species. Vigor.

RESUMO - As influências ambientais e a variabilidade genética podem promover variações entre plantas de uma mesma espécie em características intrínsecas às sementes. Objetivou-se avaliar a divergência entre árvores matrizes de *Handroanthus serratifolius* a partir de caracteres da qualidade fisiológica de sementes. Sementes colhidas de 13 árvores matrizes foram submetidas aos testes de germinação, condutividade elétrica (CE), de frio, deterioração controlada e envelhecimento acelerado. Foram usadas cinco repetições de 50 sementes para o teste de frio e de 25 sementes para os demais testes. Os dados médios por matriz foram submetidos às análises de agrupamento, pelos métodos de Ward, *k-means* e Análise de Componentes Principais (ACP). As árvores matrizes foram divididas em 4 grupos pelos métodos de Ward e *K-means*, e comprovados pela ACP, mas com variações na composição dos grupos entre os métodos. As matrizes do grupo 2 têm qualidade fisiológica inferior, com os menores valores para a maioria dos caracteres avaliados, porém o maior valor de CE e o segundo maior de índice de incerteza da germinação. Por outro lado, o grupo 4 é constituído por matrizes que apresentam sementes de melhor qualidade fisiológica. Oito dos 22 caracteres avaliados são passíveis de descarte, pois contribuem pouco para a variabilidade original dos dados. Os diferentes métodos de agrupamento apontam a existência de divergência entre as árvores matrizes em relação à qualidade fisiológica de sementes, sendo essas informações úteis e que poderão orientar programas de produção de sementes e mudas de *H. serratifolius*.

Palavras-chave: Análise de agrupamento. Espécie nativa. Vigor.

DOI: 10.5935/1806-6690.20230024
Editor-in-Chief: Profa. Charline Zaratin Alves - charline.alves@ufms.br
*Author for correspondence
Received for publication 06/04/2022; approved on 15/08/2022
[1]This research was financed by CAPES and the manuscript is part of the thesis submitted by the first author to the School of Agricultural and Veterinarian Sciences, São Paulo State University (Unesp)
[2]Department of Agricultural Sciences, School of Agricultural and Veterinarian Sciences, São Paulo State University (Unesp), Jaboticabal-SP, Brazil, patriciacandidocs@gmail.com (ORCID ID 0000-0002-3555-5706), brunazanatto@gmail.com (ORCID ID 0000-0002-3301-3073), rinaldo.paula@unesp.br (ORCID ID 0000-0001-9088-3924)

INTRODUCTION

Handroanthus serratifolius (Vahl) S. O. Grose is a tree species of the Bignoniaceae family, popularly known as ipê, ipê-amarelo, ipê-do-cerrado, pau-d'arco, ipê-tabaco, ipê-pardo and yellow pau-d'arco (CARRERO *et al.*, 2014). In Brazil, it is found in the Amazon, in Ceará in the Northeast region, extending to São Paulo in the Southeastern region (ZAPPI *et al.*, 2015). It is recommended for reforestation and recovery of degraded areas, especially in saline soils (LOHMANN, 2018; SILVEIRA *et al.*, 2013).

The species fruits are dehiscent and have wrinkled protuberances (ALVES *et al.*, 2013). The species has epigeal germination and orthodox seeds, and as in other native tree species, its seeds tolerate desiccation (GONÇALVES *et al.*, 2015). The high-density wood (1.08 g.cm^{-3}), having high durability (CAMPOS FILHO; SARTORELLI, 2015) and is commonly used in carpentry, heavy construction, external structures, and the manufacturing of musical instruments (CARRERO *et al.*, 2014; INSTITUTO DE PESQUISAS TECNOLÓGICAS, 2014).

Environmental influence and the high genetic variability of forest species, associated with allogamy, promote variation in the germination process, and the differentiation in the quality of seeds from different mother trees can be determined from germination and vigor tests (ROVERI NETO; PAULA, 2017). Genetic variability is the capacity of a species, population, or progeny to express different phenotypes (RAMALHO; SANTOS; PINTO, 2012). This characteristic can be modified by forest fragmentation resulting from strong anthropic pressure that, consequently, causes a decreasing number of individuals in a population as well as the potential for species dispersal, thus reducing the colonization process in other areas (AGUIAR *et al.*, 2013). Some studies addressing the genetic variability among mother trees regarding the physiological aspects of seeds (LIMA *et al.*, 2014; ROVERI NETO; PAULA, 2017; SILVA *et al.*, 2014; VALDOVINOS; PAULA, 2017) show variation in the germination process and/or physiological quality of seeds for the evaluated traits.

Given the above, this study aimed to evaluate the divergence between mother trees of *Handroanthus serratifolius* (Vahl) S. O. Grose from traits related to the physiological quality of seeds.

MATERIAL AND METHODS

This trial used seeds from 13 mother trees of *Handroanthus serratifolius* (Vahl) S. O. Grose planted in Jaboticabal, SP, located at 21º15'22" S and 48º18'58" W, and 614 m average altitude. The region climate is classified as Cwa type, tropical altitude, with dry winters and summer rains, according to the Köppen-Geiger classification (ANDRE; GARCIA, 2015). The fruits were harvested at the beginning of the descent with the presence of fine and open cracks, being separated by a matrix, which was georeferenced and registered in the National System of Genetic Resources (SisGen) under the number A2AA3D2.

After harvesting, the fruits were placed in the shade and left to dry naturally in an airy environment, with variable temperature and relative humidity, until completely opened, when the seeds were then manually extracted. The seeds from each mother tree were homogenized, placed in properly identified Kraft paper bags, and stored in an air-conditioned room (20-22 °C and 40-50% relative humidity) for 30 days until further use.

The following tests were performed:

Germination (G): conducted in Biochemical Oxygen Demand (B.O.D.) germinators, at 25 °C with an 8-hour photoperiod for 21 days, using five replicates of 25 seeds per mother tree. A previously sterilized filter paper roll was used as a substrate, moistened with deionized water using an initial volume equivalent to 2.5 times the paper towel mass. The replications of each treatment were packed in transparent plastic bags to prevent water loss through evaporation. The following parameters were evaluated:

Germination percentage (GP): divide the number of healthy seedlings by the total number of seeds in the test multiplied by 100; the germinated seeds presented radicle emission of at least 0.5 cm; **Percentage of normal seedlings (NSP):** the percentage of seedlings presenting perfect essential structures (BRASIL, 2013); **Speed germination index (SGI):** determined by the equation proposed by Maguire (1962), SGI = G1/N1 + G2/N2 + ... + Gn/Nn, where: G1, G2,…, Gn = number of seeds with emission of the primary root, computed in the first count, in the second and last count, N1, N2,…, Nn = number of days from sowing to the first, second and last count; **Germination uncertainty index (GUI):** obtained by the equation proposed by Labouriau (1983), GUI = $-\sum_{i=1}^{k} f_i \log_2(f_i)$, where $f_i = \frac{ni}{\sum_{i=1}^{k} ni}$, where: f_i = relative frequency of germination; k = last day of observation; ni = number of seeds germinated on day i; **Peak value of germination (PV):** obtained by the equation proposed by Czabator (1962), PV = max (G_acum/Ni), that is, PV represents the maximum value of the relationship between accumulated germination and time in days; **Length and dry mass of seedlings (AP and SDM):** at the end of the germination test, the length of the aerial part and main root of normal seedlings was determined, using a graduated ruler, and the results were expressed as cm seedling^{-1}. After these measurements, roots and aerial part of the seedlings of each replicationt were separated using scissors, placed separately in paper bags, and dried in an air circulation oven at 65 °C for 48 hours. After that, the paper bags were placed in desiccators, weighed on an analytical balance (0.001 g), and the results expressed as g seedling^{-1}.

Electrical conductivity (EC): followed the method proposed by Vieira and Krzyzanowski (1999). Initially, the seeds were weighed on an analytical balance (0.001 g) and then left to soak in 75 mL of deionized water in a transparent plastic container (180 mL) at 20 °C, for 48 hours, soon after, the electrical conductivity of the imbibition solution was evaluated with a benchtop conductivity meter with constant 1.0. Five replicates of 25 seeds per mother tree were used.

Cold test (CT): five replicates of 50 seeds were used per mother tree. The substrate was paper rool previously sterilized in an oven at 105 ± 3 °C for 2 hours, weighed and moistened with deionized water using an initial volume equivalent to 2.5 times the paper towel mass. The replications of each treatment were placed in transparent plastic bags inside a chamber set at 10 °C for three days. After that, the replications were placed in a germinator set at 25 °C for the germination test, according to the procedure described above, to evaluate the percentages of germination and normal seedlings, as well as the germination speed index.

Controlled deterioration (CD): initially, seed water content was increased to 20% by the humid atmosphere method, in which 25 seeds arranged in a single layer were placed on an aluminum screen, in transparent plastic boxes with lids (11 x 3.5 x 3, 5 cm), containing 40 mL of deionized water (VIEIRA; KRZYZANOWSKI, 1999) and kept in B.O.D. at 25 °C. The samples were weighed every 30 minutes to monitor the moisture until they reached the target water content (20%). After that, to achieve hygroscopic equilibrium, the seeds were placed in a glass container wrapped with aluminum foil and kept in B.O.D. at 10 °C for one night. Then, these containers were kept in a water bath at 45 °C for 24 hours, and, subsequently, the seeds were submitted to the germination test at 25 °C, according to the procedure described above, to determine the percentages of germination and normal seedlings and the germination speed index.

Accelerated aging (AA): 25 seeds arranged as a single layer were placed on an aluminum screen inside transparent plastic boxes with lids (11 x 3.5 x 3.5 cm), containing 40 mL of deionized water (VIEIRA; KRZYZANOWSKI, 1999). The covered boxes were kept in B.O.D., set at 42 and 45 °C, for 72 hours and, subsequently, the seeds were submitted to the germination test at 25 °C, following the procedure described above, to evaluate the percentage of germination and normal seedlings, and the germination speed index.

Data analysis: initially, the obtained data were submitted to analysis of variance by the F test at $P < 0.05$. All 22 traits evaluated were significantly different for the mother tree effect (data not shown). Subsequently, **cluster analyses** were performed to identify the most similar mother trees and the most important traits for differentiating the mother trees. After calculating the average trait per mother tree, the clustering analyses were performed by the **hierarchical Ward's** and **non-hierarchical k-means methods**, using the Euclidean distance as dissimilarity measure (CRUZ; CARNEIRO; REGAZZI, 2014), based on the standardized mean of each trait.

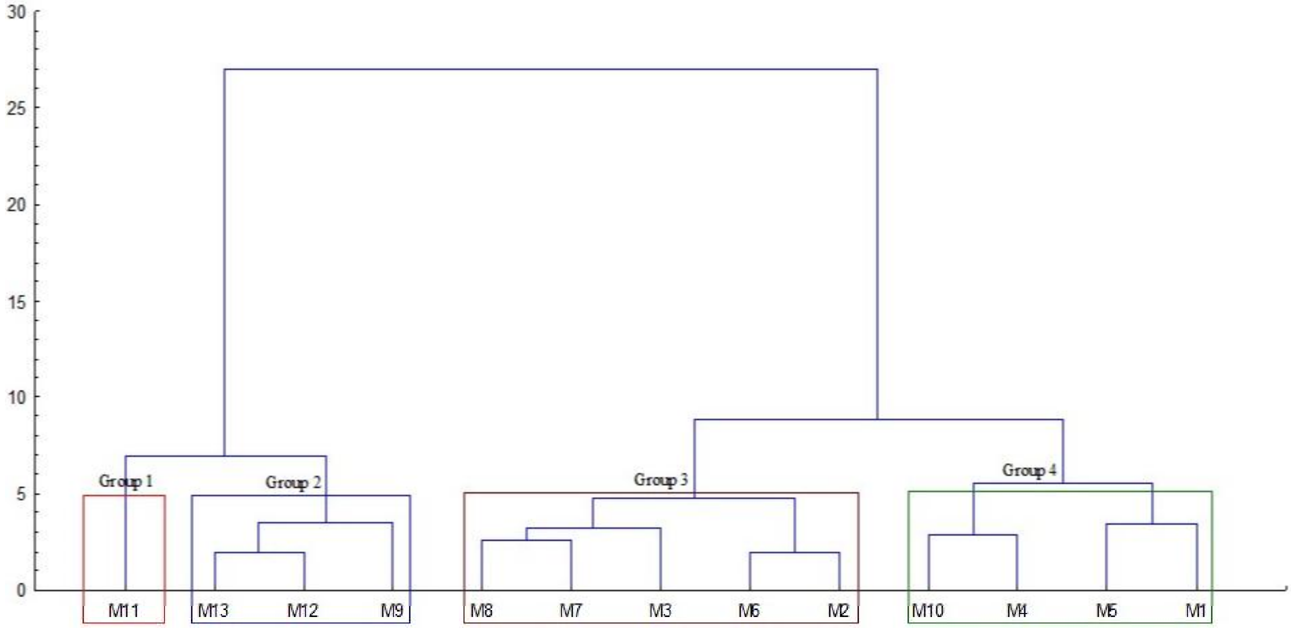
The number of clusters determined by Ward's method was based on the cutoff point of the horizontal axis of the dendrogram corresponding to the average of the Euclidean distances between all pairs of mother trees for the evaluated traits. The number of clusters determined by the k-means method was predefined by the number of clusters identified in Ward's grouping. Additionally, the difference between the mother trees was studied by the graphical dispersion from the Principal Component Analysis (PCA) based on the correlation matrix between the traits.

The importance of the traits in the study of the divergence among the mother trees in PCA was determined from the weighting coefficients associated with each eigenvector. For this, the traits/characteristics with the highest weighting coefficient, in absolute value, from the last principal component to the one whose eigenvalue did not exceed 0.70 (CRUZ; CARNEIRO; REGAZZI, 2014) were considered of less importance. Finally, the Pearson correlation between each pair of evaluated traits was determined. Ward's and k-means clustering methods and Principal Component Analysis were performed using STATISTICA software version 7.0.

RESULTS AND DISCUSSION

The 13 mother trees of *Handroanthus serratifolius* were separated into four clusters by Ward's method, based on the average Euclidean distance between the 22 traits associated with the physiological potential of the seeds evaluated in the different experiments. Cluster 1 has only mother tree 11 (M11) and represents 8% of the evaluated mothers; cluster 2 groups mother trees M9, M12 and M13, that is, 23% of the mother trees; cluster 3 groups mother trees M2, M3, M6, M7 and M8 or 38% of the evaluated mothers, and cluster 4 groups mothers M1, M4, M5 and M10, with 31% of the mother trees (Figure 1).

Figure 1 - Dendrogram defined by hierarchical Ward's clustering method based on the Euclidean Distance obtained from evaluating 22 traits related to the physiological potential of seeds from 13 open-pollinated mother trees of *Handroanthus serratifolius*. (M1, M2, ..., M13 – correspond to the evaluated mother trees)



Assuming the four clusters indicated by Ward's method, the K-means method (Figure 2) suggests a different cluster composition compared to Ward's method. The mothers in cluster 2 (23%) had the lowest values for most of the evaluated traits, but the highest electrical conductivity (EC) value and the second-highest germination uncertainty index (GUI) (Figure 2). Clusters 1 and 2 differed little regarding germination percentage, normal seedlings and speed germination index in the controlled deterioration test, but they differed significantly regarding the other evaluated traits in the other tests.

Cluster 3, with 31% of the mothers, is characterized by medium to high values for most of the evaluated traits, except for the speed index and germination peak value in the standard germination test, speed germination index in the cold and electrical conductivity tests (Figure 2). Therefore, it is concluded that the mother trees in this cluster have seeds of good physiological quality.

Cluster 4, with 23% of the mothers, has seeds of high physiological quality, as shown by the highest values, in general, for most of the evaluated traits, and the lowest electrical conductivity and germination uncertainty index values. The main differences between clusters 3 and 4 (that is, 54% of the mother trees) refer to the most contrasting values observed in the speed germination index (SGI), germination peak value (PV) and germination uncertainty index (GUI) evaluated in the germination standard test (Figure 2).

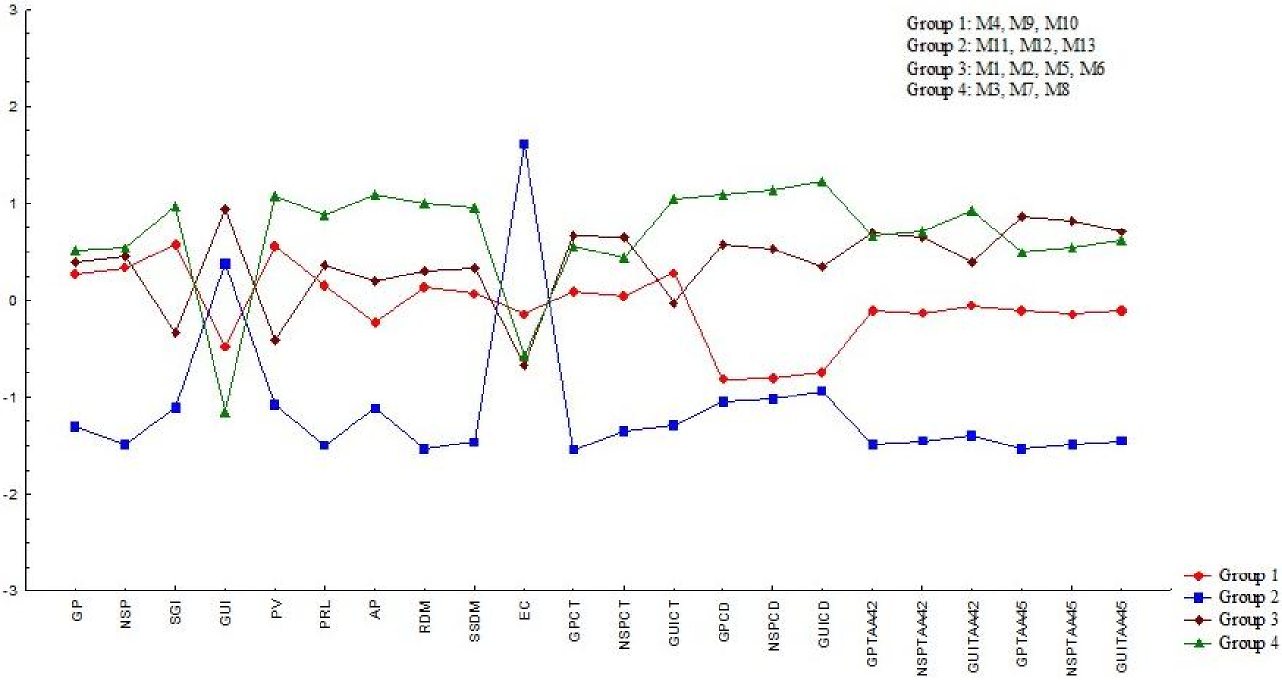
Multivariate techniques, such as clustering analysis, allows forming groups with distinct patterns and compositions (MARANGON *et al*., 2016). Given this, some authors recommend using more than one grouping method/technique to identify the clustering patterns and, consequently, similarity/dissimilarity.

The results of Ward's (Figure 1) and K-means (Figure 2) methods show clearly that the formed clusters had different compositions. However, the K-means method allows evaluating the dispersion of the means of each studied trait for the identified groups so that the identification of mother trees with similar and/or contrasting behaviors is exceptionally reliable.

K-means is a non-hierarchical method that minimizes the sum of residual squares within each formed cluster so that behavior is homogeneous within each cluster, but marked differences are observed between clusters (ALENCAR; BARROSO; ABREU, 2013). Although Ward's is a hierarchical method, the principle for the construction of the dendrogram and the formation of clusters is also to minimize the sum of residual squares, hence the similarity observed between some clusters formed by these two methods.

Through principal component analysis (PCA), new uncorrelated variables (principal components) are obtained, resulting from linear combinations of the originally measured variables (ŠAMEC *et al.*, 2016). Principal component analysis can be used for presenting and interpreting the vigor of results obtained in the various tests conducted to characterize seed performance (COSTA; NOVEMBRE, 2019).

Figure 2 - Clusters defined by the non-hierarchical K-means method according to the evaluated 22 traits associated with the physiological potential of seeds from 13 open-pollinated mother trees of *Handroanthus serratifolius*



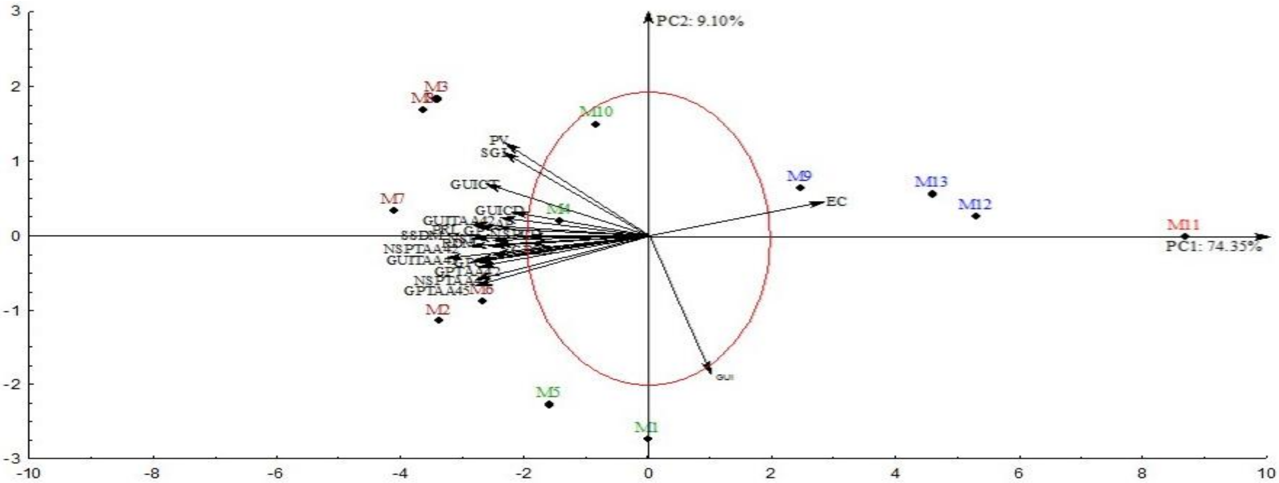
Note: E - eigenvalues; AV - accumulated variance; PC - principal components; GP, NSP, SGI, GUI, PV, PRL, AP, RDM and SSDM - respectively, germination percentage, percentage of normal seedlings, speed germination index, germination uncertainty index, germination peak value, primary root length, aerial part, root dry mass and seedling shoot dry mass, obtained in the standard germination test. EC - electrical conductivity; GPCT, NSPCT, GUICT - germination percentage, percentage of normal seedlings and speed germination index, obtained in the cold test; GPCD NSPCD, GUICD - germination percentage, percentage of normal seedlings and speed germination index obtained in the controlled deterioration test; GPTAA42, NSPTAA42, GUITAA42 - germination percentage, percentage of normal seedlings and speed germination index obtained in the traditional accelerated aging test conducted at 42 °C for 72 hours; GPTAA45, NSPTAA45, GUITAA45 - germination percentage, percentage of normal seedlings and speed germination index obtained in the traditional accelerated aging test conducted at 45 °C for 72 hours

The PCA results for the dispersion analysis of the *Handroanthus serratifolius* mother trees show that the first two components (PC1 and PC2, Figure 3) explain 83.45% of the variance contained in the original variables, which, according Cruz, Carneiro and Regazzi (2014), it would be sufficient for studies of this nature. Therefore, these two components can be used to represent the variability contained in the traits associated with the physiological quality of seeds in the studied mother trees. The dispersion pattern (Figure 3) shows that the M11 is the most isolated among the studied mother trees, confirming that this mother tree differs significantly from the others regarding the evaluated traits.

Also, the M9, M12 and M13 (23% of the mothers trees) in the upper right quadrant of the graph, and M1, M4, M5 and M10 (31% of the mothers trees), more centrally distributed in the graph, constitute distinct patterns of dispersion, forming, therefore, clusters that are different from each other (Figure 3). The M1, M4, M5 and M10 are more centrally distributed, indicating a more average behavior pattern, whereas the M9, M12 and M13 mothers trees have seeds with poorer physiological quality, but higher than M11 (8%). These results corroborate those obtained by Ward's and K-means methods. Still, the mother trees located more to the right of the graph have higher values of electrical conductivity (EC) and germination uncertainty index (GUI), to the detriment of lower values determined for the other traits.

The M2, M3, M6, 7 and M8 (38% of the evaluated mother trees) mother trees are highlighted for better physiological quality, as observed in general in cluster 3 of Ward's and in clusters 3 and 4 of K-means, whose main components are located outside the ellipse and to the left of the graph, contrasting with the values of electrical conductivity (EC) and germination uncertainty index – GUI. These mother trees have the highest values of traits seen on the left of the graph. Thus, the analysis of the dispersion pattern of the set of genotypes (mother trees) from a group of evaluated traits is another method that can be used to analyze the similarity/dissimilarity pattern between the mother trees of *Handroanthus serratifolius*.

Figure 3 - Biplot showing the dispersion of the first two main components (PC1 and PC2) obtained from the evaluation of 22 traits regarding the physiological quality of seeds from 13 open-pollinated mother trees of *Handroanthus serratifolius*



Note: E - eigenvalues; AV - accumulated variance; PC - principal components; GP, NSP, SGI, GUI, PV, PRL, AP, RDM and SSDM - respectively, germination percentage, percentage of normal seedlings, speed germination index, germination uncertainty index, germination peak value, primary root length, aerial part, root dry mass and seedling shoot dry mass, obtained in the standard germination test. EC - electrical conductivity; GPCT, NSPCT, GUICT - germination percentage, percentage of normal seedlings and speed germination index, obtained in the cold test; GPCD NSPCD, GUICD - germination percentage, percentage of normal seedlings and speed germination index obtained in the controlled deterioration test; GPTAA42, NSPTAA42, GUITAA42 - germination percentage, percentage of normal seedlings and speed germination index obtained in the traditional accelerated aging test conducted at 42 °C for 72 hours; GPTAA45, NSPTAA45, GUITAA45 - germination percentage, percentage of normal seedlings and speed germination index obtained in the traditional accelerated aging test conducted at 45 °C for 72 hours

Still, in the PCA, the mother trees inside the ellipse (Figure 3), present similar average behavior and do not differ greatly among themselves, being more generalists. On the other hand, the mothers outside the ellipses have some specific traits, as previously mentioned, for example, for M2, M3, M6, M7 and M8 with seeds of better physiological quality, that deserve special attention when developing a genetic breeding program for seeds.

The results show the existence of genetic variability among *Handroanthus serratifolius* mother trees for the germination process and seed quality traits, corroborating results obtained in similar studies with other tree species native to Brazil (LIMA *et al*., 2014; ROVERI NETO; PAULA, 2017; VALDOVINOS; PAULA, 2017). Furthermore, the separation of the mother trees into groups with different properties in relation to the evaluated traits and the agreement of the information provided by the different vigor tests, guarantee greater safety and reliability in the mother trees groupings regarding the physiological potential of the seeds, and reinforce the importance of this kind of study with application in genetic improvement and/or conservation program or even in the recovery of degraded areas through restoration planting and forest recomposition, as it makes it possible to select mother trees with superior traits, but with genetic divergence to adequately represent the variability of the species. The low degree of improvement and the preferentially allogamous crossing system, associated with irregularity flowering and maturation process of fruits and seeds, have been identified as the main causes of the relative variability present in this group of species for the traits evaluated (FREITAS *et al*., 2015; LIMA *et al.*, 2014; PIÑA-RODRIGUES; FIGLIOLIA; GRIMALDI, 2015; ROVERI NETO; PAULA, 2017; VALDOVINOS; PAULA, 2017) and reinforce the need to sample the largest number of mother trees for seed collection, in order to adequately represent the variability of these species.

The multivariate analysis using different methods allowed to compare the obtained results and identify mother trees with similar and divergent behavior. Therefore, considering the marking and selection of *H. serratifolius* mother trees for collecting seeds for forest improvement, genetic conservation and/or area reforestation programs, priority should be given to mother trees from distinct groups, notably from those whose mother trees have good germination performance. It is noted that, regardless of the clustering method, the results indicate that the divergence among the studied mothers trees is generally based on the difference in the physiological quality of the seeds.

At first, it is considered that all the evaluated traits are important to study divergence between the mother trees. However, the least important traits in this type of study can be identified from the scores with the highest weights in the eigenvectors associated with eigenvalues below 0.7 (CRUZ; CARNEIRO; REGAZZI, 2014), that is, the weighting coefficients of the principal components with low explanatory power of the variance contained in the original data. Given this, a careful analysis of the results shows that eight (08) or 36% of the evaluated traits/parameters can be discarded since they contribute little to the original variability of the data and, consequently, to the clustering analysis (Table 1).

Thus, in the present study, the traits/parameters that can be discarded are germination - GPTAA42 (PC12 = -0.44) and speed germination index - GUITAA42 (PC11 = -0.62), evaluated in the accelerated aging test conducted at 42 ºC; electrical conductivity – EC (PC10 = 0.57); normal seedlings evaluated in the accelerated aging test conducted at 42 ºC - NSPTAA42 (PC9 = 0.42); speed germination index evaluated in the cold test - GUICT (PC9 = -0.50); root length - PRL (PC7 = -0.44) and aerial part length - AP (PC6 = 0.44), evaluated in the germination test, and normal seedlings evaluated in the cold test - NSPCT (PC5 = -0.55), given the highest weighting coefficients observed in the components with eigenvalues below 0.70 (Table 1).

Furthermore, the three characteristics evaluated in the accelerated aging test at 42 ºC (GPTAA42, GUITAAE42 and NSPTAA42), two of the three traits evaluated in the cold test (GUICT and NSPCT), electrical conductivity (EC), aerial part length (AP) and root length (PRL) of seedlings in the germination test contributed little to the diversity detected among the *Handroanthus serratifolius* mother trees. In

Table 1 - Eigenvalues (v-variance) associated with the Principal Components (PC) and respective eigenvectors for the 22 traits related to the physiological quality of seeds evaluated in 13 mother trees of *Handroanthus serratifolius*

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12
E	16.35	2.00	1.55	0.95	0.49	0.31	0.12	0.08	0.04	0.03	0.02	0.006
AV	74.34	83.45	90.51	94.86	97.11	98.53	99.11	99.51	99.71	99.86	99.97	100.00
GP	-0.21	-0.01	0.30	-0.24	0.22	0.31	-0.22	0.09	-0.06	0.01	0.24	-0.18
NSP	-0.22	-0.05	0.25	-0.10	0.15	0.28	0.24	-0.22	0.004	0.20	-0.21	0.08
SGI	-0.19	0.37	0.23	-0.12	0.05	0.24	-0.06	0.14	-0.18	0.08	0.03	0.16
GUI	0.08	-0.63	0.10	0.006	0.004	0.41	-0.32	0.18	-0.02	0.05	-0.02	0.22
PV	-0.18	0.42	0.16	-0.09	0.05	0.085	0.06	-0.08	-0.05	0.02	-0.07	0.02
PRL	-0.22	0.03	0.07	0.07	0.31	-0.37	-0.44	0.44	-0.05	0.003	0.27	0.21
AP	-0.19	-0.16	-0.16	0.45	-0.21	0.44	-0.13	-0.20	0.23	-0.29	0.28	-0.11
RDM	-0.21	0.01	0.01	0.42	0.34	-0.10	0.06	0.28	0.30	0.43	-0.07	-0.36
SSDM	-0.20	-0.06	-0.06	0.54	0.20	0.04	0.01	-0.05	-0.23	-0.003	-0.25	0.32
EC	0.23	-0.11	-0.11	-0.08	-0.12	0.15	-0.18	-0.25	0.41	0.57	0.19	0.04
GPCT	-0.23	0.13	0.13	-0.08	-0.05	-0.17	-0.06	0.27	-0.03	0.15	0.11	0.10
NSPCT	-0.21	0.09	0.09	0.05	-0.55	0.25	-0.37	-0.07	-0.26	0.23	-0.15	-0.17
GUICT	-0.21	0.06	0.06	0.12	-0.35	-0.07	0.02	-0.50	0.16	-0.003	0.20	0.28
GPCD	-0.19	-0.44	-0.44	-0.21	0.14	0.02	-0.10	0.10	0.03	0.09	-0.06	0.16
NSPCD	-0.19	-0.45	-0.45	-0.24	0.13	-0.02	-0.05	0.08	0.12	0.08	-0.09	0.13
GUICD	-0.18	-0.49	-0.49	-0.07	-0.005	0.20	-0.08	0.06	-0.40	-0.01	0.08	-0.24
GPTAA42	-0.23	0.05	0.05	-0.13	0.08	-0.08	-0.06	0.01	0.14	-0.17	0.13	-0.44
NSPTAA42	-0.23	0.03	0.03	-0.15	0.003	-0.11	0.04	-0.009	0.42	-0.38	0.005	0.16
GUITAA42	-0.24	0.03	0.03	-0.11	-0.14	0.04	-0.18	-0.011	0.28	-0.12	-0.62	-0.07
GPTAA45	-0.23	-0.01	0.01	-0.04	-0.007	-0.11	0.35	-0.09	-0.13	0.01	0.19	-0.16
NSPTAA45	-0.23	-0.04	-0.04	-0.05	-0.14	-0.03	0.32	-0.17	0.02	0.13	0.25	0.29
GUITAA45	-0.23	-0.02	-0.02	-0.03	-0.27	0.14	0.28	-0.24	-0.03	0.18	-0.05	-0.06

Note: E - eigenvalues; AV - accumulated variance; PC - principal components; GP, NSP, SGI, GUI, PV, PRL, AP, RDM and SSDM - respectively, germination percentage, percentage of normal seedlings, speed germination index, germination uncertainty index, germination peak value, primary root length, aerial part, root dry mass and seedling shoot dry mass, obtained in the standard germination test. EC - electrical conductivity; GPCT, NSPCT, GUICT - germination percentage, percentage of normal seedlings and speed germination index, obtained in the cold test; GPCD NSPCD, GUICD - germination percentage, percentage of normal seedlings and speed germination index obtained in the controlled deterioration test; GPTAA42, NSPTAA42, GUITAA42 - germination percentage, percentage of normal seedlings and speed germination index obtained in the traditional accelerated aging test conducted at 42 °C for 72 hours; GPTAA45, NSPTAA45, GUITAA45 - germination percentage, percentage of normal seedlings and speed germination index obtained in the traditional accelerated aging test conducted at 45 °C for 72 hours

Table 2 - Estimates of correlations between the 22 traits related to the physiological seed quality evaluated in 13 mother trees of *Handroanthus serratifolius*

	NSP	SGI	GUI	PV	PRL	AP	RDM	SSDM	EC	GPCT	NSPCT	GUICT	GPCD	NSPCD	GUICD	GPTAA42	NSPTAA42	GUITAA42	GPTAA45	NSPTAA45	GUITAA45
GP	0.96	0.81	-0.16	0.75	0.80	0.52	0.66	0.57	-0.83	0.88	0.71	0.70	0.53	0.51	0.44	0.89	0.86	0.86	0.78	0.77	0.78
NSP		0.78	-0.16	0.74	0.83	0.63	0.76	0.69	-0.90	0.91	0.76	0.75	0.57	0.55	0.49	0.92	0.90	0.90	0.87	0.86	0.88
SGI			-0.65	0.98	0.72	0.59	0.58	0.53	-0.62	0.67	0.59	0.85	0.45	0.46	0.50	0.66	0.67	0.81	0.52	0.55	0.63
GUI				-0.76	-0.36	-0.34	-0.23	-0.07	0.11	-0.14	-0.17	-0.57	-0.28	-0.32	-0.43	-0.14	-0.18	-0.37	-0.04	-0.09	-0.16
PV					0.73	0.60	0.58	0.54	-0.60	0.64	0.58	0.85	0.48	0.49	0.54	0.64	0.65	0.80	0.51	0.54	0.62
PRL						0.69	0.87	0.81	-0.88	0.88	0.78	0.77	0.68	0.66	0.61	0.89	0.88	0.87	0.83	0.81	0.79
AP							0.80	0.89	-0.69	0.64	0.71	0.81	0.63	0.61	0.73	0.66	0.67	0.76	0.67	0.72	0.78
RDM								0.96	-0.87	0.80	0.69	0.75	0.61	0.59	0.58	0.80	0.78	0.76	0.80	0.78	0.76
SSDM									-0.83	0.72	0.68	0.73	0.59	0.57	0.62	0.72	0.71	0.72	0.76	0.75	0.75
EC										-0.95	-0.84	-0.77	-0.65	-0.62	-0.56	-0.95	-0.93	-0.87	-0.95	-0.92	-0.89
GPCT											0.91	0.81	0.68	0.66	0.58	0.98	0.97	0.93	0.95	0.94	0.93
NSPCT												0.84	0.58	0.56	0.55	0.85	0.86	0.88	0.85	0.88	0.90
GUICT													0.59	0.59	0.65	0.76	0.79	0.89	0.71	0.75	0.81
GPCD														0.99	0.95	0.76	0.77	0.75	0.76	0.78	0.76
NSPCD															0.95	0.74	0.76	0.74	0.74	0.76	0.74
GUICD																0.64	0.66	0.71	0.65	0.69	0.71
GPTAA42																	0.99	0.93	0.96	0.95	0.93
NSPTAA42																		0.95	0.96	0.96	0.94
GUITAA42																			0.87	0.90	0.93
GPTAA45																				0.99	0.95
NSPTAA45																					0.98

Note: E - eigenvalues; AV - accumulated variance; PC - principal components; GP, NSP, SGI, GUI, PV, PRL, AP, RDM and SSDM - respectively, germination percentage, percentage of normal seedlings, speed germination index, germination uncertainty index, germination peak value, primary root length, aerial part, root dry mass and seedling shoot dry mass, obtained in the standard germination test. EC - electrical conductivity; GPCT, NSPCT, GUICT - germination percentage, percentage of normal seedlings and speed germination index, obtained in the cold test; GPCD NSPCD, GUICD - germination percentage, percentage of normal seedlings and speed germination index obtained in the controlled deterioration test; GPTAA42, NSPTAA42, GUITAA42 - germination percentage, percentage of normal seedlings and speed germination index obtained in the traditional accelerated aging test conducted at 42 °C for 72 hours; GPTAA45, NSPTAA45, GUITAA45 - germination percentage, percentage of normal seedlings and speed germination index obtained in the traditional accelerated aging test conducted at 45 °C for 72 hours

general, multivariate studies allow to discarded traits that are redundant, i.e., those highly correlated with other traits, or invariant traits (CRUZ; CARNEIRO; REGAZZI, 2014; ROVERI NETO; PAULA, 2017; VALDOVINOS; PAULA, 2017).

Analyzing the traits considered less important for the divergence study (cited above) with the other traits, and considering a high correlation, greater than or equal to 0.7 ($r \geq 0.7$), it is observed that the traits likely to be discarded have a high correlation estimate with at least one of the traits not recommended for discarding (Table 2) and, therefore, should remain in the study of divergence. Thus, the traits suitable for discarding have high correlation estimates with the traits evaluated in the accelerated aging test at 45 ºC and with other traits evaluated in the other tests and, therefore, provide redundant information for the more important traits.

The identification of the importance and, consequently, of the contribution of the traits to the genetic divergence allows a better planning of future studies, in which traits of low importance can be disregarded for evaluation, leaving only those with an effective contribution, reducing work and costs in conducting the experiments (CRUZ; CARNEIRO; REGAZZI, 2014; ROVERI NETO; PAULA, 2017; VALDOVINOS; PAULA, 2017).

CONCLUSIONS

1. The different methods of multivariate analysis used indicate the existence of divergence between the mother trees while allowing, with greater certainty, to identify the clusters of trees with similar and or divergent traits related to the physiological quality of seeds, and these data may be used to guide seed and seedling production programs for *Handroanthus serratifolius*.
2. The divergence observed between the mother trees indicates that seed collection should occur in trees that belong to distinct groups, especially those in which the mother trees have good germination performance.

ACKNOWLEDGEMENTS

The authors thank the Coordination for the Improvement of Higher Education Personnel - Brazil (CAPES) - Financing Code 001 for supporting this work. To the National Council for Scientific and Technological Development (CNPq) for granting the third author a Research Productivity scholarship (Process 306734/2018-4 and 309275/2021-0).

REFERENCES

AGUIAR, R. V. *et al.* Variabilidade genética de Eugenia uniflora L. em remanescentes florestais em diferentes estádios sucessionais. **Revista Ceres**, v. 60, n. 2, p. 226-233, 2013.

ALENCAR, B. J.; BARROSO, L. C.; ABREU, J. F. Análise multivariada de dados no tratamento da informação espacial: uma abordagem com análise de agrupamentos. **Revista Iberoamericana de Sistemas, Cibernética e Informática**, v. 10, n. 2, p. 6-12, 2013.

ALVES, M. F. *et al*. Self-sterility in the hexaploid *Handroanthus serratifolius* (Bignoniaceae), the national flower of Brazil. **Acta Botanica Brasilica**, v. 27, n. 4, p. 714-722, 2013.

ANDRE, R. G. B.; GARCIA, A. Alguns aspectos climáticos do município de Jaboticabal - SP. **Nucleus**, v. 12, n. 2, p. 263-269, 2015.

BRASIL. Ministério da Agricultura, Pecuária e Abastecimento. **Instruções para análise de sementes de espécies florestais**. Brasília: MAPA, 2013. 98 p.

CAMPOS FILHO, E. M.; SARTORELLI, P. A. R. **Guia de árvores com valor econômico**. São Paulo: Agroicone, 2015. 132 p.

CARRERO, G. C. *et al*. **Árvores do Sul do Amazonas**: guia de espécies de interesse econômico e ecológico. Manaus: Idesam, 2014. 57 p.

COSTA, D. S.; NOVEMBRE, A. D. L. C. Análise multivariada para expressão de resultados de potencial fisiológico de sementes de arroz. **Revista Agrarian**, v. 12, n. 45, p. 418-424, 2019.

CRUZ, C. D.; CARNEIRO, P. C. S.; REGAZZI, A. J. **Modelos biométricos aplicados ao melhoramento genético**. 3. ed. Viçosa, MG: UFV, 2014. 688 p.

CZABATOR, F. J. Germination value: an index combining speed and completeness of pine seed germination. **Forest Science**, v. 8, n. 4, p. 386-396, 1962.

FREITAS, M. L. M. *et al.* Produção de sementes de espécies florestais nativas: estratégias de melhoramento. *In*: PIÑA-RODRIGUES, F. C. M.; FIGLIOLIA, M. B.; SILVA, A. (org.). **Sementes florestais tropicais**: da ecologia à produção. Londrina: ABRATES, 2015. p. 128-152.

GONÇALVES, L. H. N. *et al*. Qualidade fisiológica e expressão de genes em sementes de *Handroanthus serratifolius* submetidas à secagem. **Journal of Seed Science**, v. 37, n. 2, p. 102-110, 2015.

INSTITUTO DE PESQUISAS TECNOLÓGICAS. **Informações sobre madeiras**. Disponível em: http://www.ipt.br/consultas_online/informacoes_sobre_madeira/busca. Acesso em: 5 set. 2014.

LABOURIAU, L. G. **A germinação das sementes**. Washington: OEA, 1983. 174 p.

LIMA, C. R. *et al.* Qualidade fisiológica de sementes de diferentes árvores matrizes de *Poincianella pyramidalis* (Tul.) L. P. Queiroz. **Revista Ciência Agronômica**, v. 45, n. 2, p. 370-378, 2014.

LOHMANN, L. G. **Bignoniaceae in Lista de Espécies da Flora do Brasil, 2018**. Disponível em: http://floradobrasil.jbrj.gov.br/jabot/floradobrasil/FB117466. Acesso em: 1 maio 2018.

MAGUIRE, J. D. Speed of germination aid selection and evaluation for seedling emergence and vigour. **Crop Science**, v. 2, n. 2, p. 176-177, 1962.

MARANGON, G. P. *et al.* Análise de agrupamento de espécies lenhosas da Caatinga no Estado do Pernambuco. **Pesquisa Florestal Brasileira**, v. 36, n. 88, p. 347-353, 2016.

PIÑA-RODRIGUES, F. C. M.; FIGLIOLIA, M. B.; GRIMNALDI, M. C. Ecologia de sementes: revisão de conceitos aplicados à produção e qualidade de sementes florestais. *In*: PIÑA-RODRIGUES, F. C. M.; FIGLIOLIA, M. B.; SILVA, A. (org.) **Sementes florestais tropicais**: da ecologia à produção. Londrina: ABRATES, 2015. p. 102-125.

RAMALHO, M. A. P.; SANTOS, J. B.; PINTO, C. A. B. **Genética na agropecuária**. 5. ed. Lavras: UFLA, 2012. 472 p.

ROVERI NETO, A.; PAULA, R. C. Variabilidade entre árvores matrizes de *Ceiba speciosa* St. Hil para características de frutos e sementes. **Revista Ciência Agronômica**, v. 48, n. 2, p. 318-327, 2017.

ŠAMEC, D. *et al.* Assessment of the diferences in the physical, chemical and phytochemical properties of four strawberry cultivars using principal component analysis. **Food Chemistry**, v. 194, n. 1, p. 828-834, 2016.

SILVA, K. B. *et al*. Variabilidade da germinação e caracteres de frutos e sementes entre matrizes de *Sideroxylon obtusifolium* (Roem. & Schult.) T. D. Penn.. **REB: Revista Eletrônica de Biologia**, v. 7, p. 281-300, 2014.

SILVEIRA, C. E. S. *et al.* Strategies of plant establishment of two Cerrado species: *Byrsonima basiloba* Juss. (Malpighiaceae) and *Eugenia dysenterica* Mart. ex DC (Myrtaceae). **Plant Species Biology**, v. 28, n. 2, p. 130-137, 2013.

VALDOVINOS, T. M.; PAULA, R. C. Diversidad genética de *Handroanthus heptaphyllus* a partir de calidad fisiológica de semillas. **Bosque**, v. 38, n. 2, p. 327-336, 2017.

VIEIRA, R. D.; KRZYZANOWSKI, F. C. Teste de condutividade elétrica. *In:* KRZYZANOWSKI, F. C.; VIEIRA, R. D.; FRANÇA NETO, J. B. (ed.) **Vigor de sementes**: conceitos e testes. Londrina: ABRATES, 1999. cap. 4, p. 4.1-4.26.

ZAPPI, D. C. *et al.* Growing knowledge: an overview of Seed Plant diversity in Brazil. **Rodriguésia**, v. 66, n. 4, p. 1085-1113, 2015.