MONTHLY PERFORMANCE OF AÇAIZERO PROGENIES USING DENDROGRAM AND GGE BIPLOT

DESEMPENHO MENSAL DE PROGÊNIES DE AÇAIZEIRO UTILIZANDO DENDROGRAMA E GGE BIPLOT

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Abstract: The consumption of açaí fruit pulp has increased in the national and international markets due to the discovery of its nutraceutical properties, and research is needed to meet this growth demand and overcome the problem of seasonal production. Additionally, the quantity of progenies prevents the correct interpretation of graphical analyses. Therefore, this study aimed to evaluate 76 açaí progenies to identify those with superior performance and seasonal behavior by combining multivariate analysis, dendrogram clustering and GGE biplot analysis. The experimental design adopted was randomized blocks with two replicates and five plants per plot. The characteristics evaluated were as follows: FF - number of bunches with green fruits; FM - number of mature bunches; and TM - bunch size. The conclusions were that the combination of analyses is necessary, important and efficient to allow the interpretation of the results; the best progeny is P50, followed by P68, P12, P30, P29 and P70, in order of performance, adding the progenies P52 and P55 in the dendrogram; there is genetic variability due to the evident distinct individual contributions to the GxA interaction, as well as the months, which should be better known to guide genetic improvement; June represents all the other months and should be adopted when it is impossible to evaluate in more months; and the last four months of the rainy season (March and June) and the first two months of the dry season (July and August) should be prioritized in the evaluations because they allow greater differentiation between the progenies.
Keywords: Euterpe oleracea; genetic improvement; genotype × environment interaction; principal component analysis

Resumo: O mercado nacional e internacional tem aumentado o consumo da polpa do fruto do açaizeiro devido à descoberta de suas propriedades nutracêuticas, demandando pesquisas para atender este crescimento e contornar o problema da produção sazonal, adicionalmente o quantitativo de progênies impede a correta interpretação das análises gráficas, portanto este trabalho teve como objetivo avaliar 76 progênies de açaizeiro visando identificar aos com desempenho superior e o comportamento sazonal, combinando análise multivariada, agrupamento por dendrograma e análise GGE Biplot. O delineamento experimental adotado foi blocos ao acaso com duas repetições e cinco plantas por parcela. As características avaliadas foram: FF - número de cachos com frutos verdes; FM – número cachos maduros e; TM - tamanho do cacho. As conclusões foram de que a combinação das análises mostra-se necessária, importante e eficie par permitir interpretar os resultados; a melhor progênie é P50, seguida por P68, P12, P30, P29 e P70, em ordem de desempenho, somando-se pelo dendrograma as progênies P52 e P55; existe variabilidade genética pelas evidentes contribuições individuais distintas para an interação GxAm ser melhor conhecidos para orientar o melhoramento genético; junho representa todos os demais meses, devendo ser este adotado quando na impossibilidade de avaliações em mais meses; os quatro últimos meses do período chuvoso (março e junho) e os dois primeiros meses de estiagem (julho e agosto), devem ser prioriz
Palavras-chave: Euterpe oleracea; melhoramento genético; interação genótipo x ambiente; análise de componentes principais

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INTRODUCTION

There is a palm tree with outstanding economic importance in the Amazon region, called açaí and belonging to the Arecaceae family, making up an important part of regional fruit production, mainly in Pará, where, in addition to production and consumption, there is a large movement of local commerce (Neves et al., 2015), with the pulp extracted from the fruit of the açaí tree being a symbolic image of this state and corresponding to the main product collected from this palm tree (Silvestre et al., 2016).

Açaí has prominent agronomic, technological, nutritional and economic potential (Yuyama et al., 2011) in the Amazon region. The activity carried out in an extractive manner constitutes an important fraction of the monthly income of a significant portion of the families living on the riverbanks, occurring only in a seasonal period called harvest in four months of the year (June to October), when there is an abundance of açai fruits, whereas in the off-season, the population that lives in the extractive exploitation of this important plant resource has to seek alternatives that are not always available to supplement their monthly income, causing serious social problems due to the presence of a large idle portion of the population (Ximenes et al., 2020).

This açaí fruit market has been experiencing a growing impact on exports because of the positive properties of açaí pulp in terms of vitamin supplementation, antioxidant effects and energy sources, especially in the U.S. market, whose consumption has been experiencing exponential growth. In addition to the US, which imports more than 70% of the production sold, there are Germany, Belgium and the Netherlands, joined more recently by the Netherlands, Japan, and Australia, among others, who are increasingly interested in this fruit obtained in the Amazon estuary. However, one of the obstacles to the consolidation of import contracts, as cited by the National Supply Company - CONAB (2020), is the existence of the fruit's off-season, which is in the first half of the year and harvests concentrated between July and December, as the countries that buy the product require constant availability throughout the year.

One impact on consumers in northern China, as stated by Nogueira et al. (2013) and Nogueira and Santana (2016), due to the increase in exports, is the increase in the price per liter for local consumers, especially when there is little available quantity in the off-season (January--June), when the price of the fruit can quadruple, without maintenance or greater production, aiming to maintain market balance, especially since açaí is a product that is characterized by an inelastic supply in terms of price; that is, the commercial value tends to fluctuate much more than the supply of the product, and this generates problems in food security in the northern region of Brazil, since açaí pulp is an important component of the local diet.

Owing to these aspects of growing exports, food demand for the pulp of the fruit and products derived from açaí, intensive research is being carried out to develop management techniques and forms of production, as cited by Coutinho (2017), so that the harvest period can be extended. One of the possible solutions adopted by Farias Neto et al. (2011) is the use of irrigation and fertilization, associated with planting on dry land to generate a better distribution of the harvest throughout the year and thus reduce the off-season period. In addition, cultivation outside the floodplains facilitates management because better soil conditions and humidity are available to the producer. Despite these advantages, almost all exploration continues in low-lying and extractive areas (Galeão, 2017). The state of Pará is the main national producer, with very large natural populations in the total area and several islands with large production. In the northeast region of this state, gradual changes in production aspects are observed, aiming to reduce low-technology extractive exploration with little production to increase the system with higher productivity rates, reflecting the use of management and irrigation in dry land locations (Homma et al., 2006; Farias Neto et al., 2011).

The adoption of this new model is quite promising when comparing an extractive system in a low-productivity floodplain area (4.2 $t.ha^{-1}$) and systems with management adoption (8.4 $t.ha^{-1}$) with irrigated crops on dry land that can reach 15 $t.ha^{-1}$, which may increase as new technological advances are developed (Santos et al., 2012). Additionally, the adoption of different production methods also affects the açai fruit harvest season, as stated by Sousa and Andrade (2018), where managed açai has lower production in January, with the harvest beginning in March and increasing until reaching its maximum in August, with the off-season between September and October. However, when no management is used, the harvest begins in June, with a maximum in July, and ends in August; that is, different cultivation systems to be developed may generate changes in the harvest period.

One obstacle that exists in genetic improvement research to identify new materials that can increase productivity is the effect that environmental factors have on plant behavior, generating undefined phenotypic expressions. Thus, whenever there is a greater quantity of variation among environmental factors, there will likely also be more differences in the expression of the characteristics of the plants. This effect is called the genotype versus environment interaction (GGATE), which complicates the identification of adapted and stable genotypes (Cruz et al., 2014). Therefore, genetic improvement aims to select materials that have broad adaptability and stability and can be recommended for different locations (Malosetti et al., 2013).

In adaptability and stability studies to support genetic improvement programs, among the various methodologies, the GGE biplot model was developed more recently by Yan et al. (2000), whose theory considers the main effect of genotype together with the genotype and environment interaction, facilitating the visualization of genotypes that are more adapted and stable to certain environments (Yan, 2011).

Owing to the existence of seasonality in the harvest and the importance of selecting progenies that can be planted to increase açaí productivity, there is still little research regarding the monthly behavior of progenies during the year, which refers to the seasonality of production, this work aimed to evaluate the performance of açaí progenies, seeking to identify the existence of superior progenies according to the months, on the basis of the multivariate for the evaluated characteristics, in the preselection of progenies by grouping by the dendrogram and by the GGE biplot graphical analysis.

MATERIAL AND METHODS

This research is part of the açaí tree genetic improvement program for fruit production in the Amazon estuary, with the experiment being planted in a floodplain area at the Mazagão Experimental Field of Embrapa Amapá. The predominant soil is of the low humic gley type and has a medium texture, with medium to high natural fertility from river sediments. It has a flat topography and has secondary vegetation cover. The climate type is Ami according to the Köppen classification, which is characterized as tropical rainy, with total annual precipitation of 2410 mm, concentrated between the months of January and June; the precipitation of the driest month (October) is 32 mm, the rainiest month (March) is 365 mm, the average annual temperature is 27°C, the average of the coldest month (June) is 22.7°C, the hottest month (September) is 32.8°C, and the average relative humidity is 85% (Cimate-Data. Org, 2020). The monthly climate data are presented in Table 1.

Table 1. Total monthly precipitation (Prec, in mm), average maximum temperature (TMax, in °C), minimum temperature (TMin, in °C), and average annual temperature (TMed, in °C) in Mazagão, AP, historical average between 1980 and 2016.

	JAN	FEB	SEA	APR	MAY	JUN	JUL	AUG	SET	OUT	NOV	TEN
Price	225	275	283	308	250	200	133	67	73	29	46	121
Tmax	31.56	30,31	30,31	30.63	31.56	31.88	32.19	32.81	32.97	33.13	32.81	32.50
Tmin	23.44	23.44	23.75	24.06	24.06	23.85	23.75	24.06	23.97	24.06	24.38	24.31
Tmed	28.26	27.74	27.75	27.94	28.37	28.61	28.54	28.68	28.93	29.03	29.00	28.85

Adapted from Weatherspark (2020)

The experiment included a total of 76 progenies from individuals present in native açai plantations in the western region of Marajó Island, whose predominant harvest occurs in the winter season (December to July). The experimental design used was randomized blocks with two replications, and each plot represented five plants, with a spacing of 4 × 5 m. Notably, the number of replications was due to the large number of progenies and the size of the total area of the experiment.

Monthly assessments were carried out between 2009 and 2013 on the following characteristics: FF - Green Fruit Formation, counting bunches that present green fruit formation per stem; FM - Ripe Bunches Formation, counting bunches that present ripe bunches per stem; and TM - Bunch Size, value attributed to the visual assessment of the bunches: where 1 is attributed to the smallest value and 7 to the largest value.

To discuss the performance of the progenies in relation to the three characteristics simultaneously, a multivariate analysis was carried out because of the need to interpret the behavior in relation to the set of characteristics that would be extremely difficult and inconsistent in a univariate analysis.

After the multivariate analysis, cluster analysis was performed where the generalized distance was assumed.

Mahalanobis (D^{2}) as a dissimilarity parameter, considering the existing correlation between the evaluated characteristics, as presented by Cruz et al. (2014). On the basis of the dissimilarity matrix created, the dendrogram was structured via UPGMA (*unweighted pair group method with arithmetic mean*). This procedure was adopted due to one of the problems of graphical analyses (GGE biplot), where clusters that impede the interpretation of results are presented, due to the high number of progenies constant in the work. This entanglement makes it impossible to distinguish genetic materials.

The biplot method, according to Yan et al. (2000), considers the main effect of progeny and their interaction with the months, which are important and considered concomitantly. The GGE biplot model combines the G values of GxA in the form of two multiplicative terms, which are visualized via the following equation: $Y_{ij} - \bar{y}_j = y_1\varepsilon_{i1}\rho_{j1} + y_2\varepsilon_{i2}\rho_{j2} + \varepsilon_{ij}$, where Y_{ij} represents the average performance of the ith progeny in the jth month; $\bar{y}_j$ represents the general average of the progenies for month j; $y_1\varepsilon_{i1}\rho_{j1}$ represents the first principal component (IPCA1); $y_2\varepsilon_{i2}\rho_{j2}$ represents the second principal component (IPCA2); y_1 and y_2 represent the eigenvalues associated with the IPCA and IPCA2, respectively; ε_{i1} and ε_{i2} represent the scores of the first and second principal components, respectively, of the ith progeny; and ρ_{j1} and ρ_{j2} represent the scores of the first and second principal components, respectively, for the jth month; and ε_{ij} represents the model error associated with the ith progeny in the jth month (Yan and Kang, 2003).

Tinker (2006) was estimated to assess whether the biplot is suitable for displaying the patterns in a double-entry table. This relationship is interpreted on the basis of each PC axis (interaction axis of the principal component analysis), where an RI ≥1 or close to 1 represents patterns (associations between months), and a PC where an RI < 1 represents the absence of any pattern or information. Therefore, a biplot of dimension 2 only has the power to adequately represent the patterns in the data if only the first two PCs present RIs ≥1 or close to 1.

All analyses were performed via procedures from the R program version 3.4.1 (R Core Team, 2020).

RESULTS AND DISCUSSION

Because 76 progenies were evaluated in this study, which would certainly make it extremely difficult to visualize their distribution in graphical analyses and, consequently, prevent correct understanding in the GGE biplot, it was admitted that it was necessary to use the composition of groups via dendrograms as an initial procedure. The groups are formed on the basis of accentuated changes in levels (Cruz et al., 2014); thus, each group is composed only of progenies that are close to each other, so only one from each group was used in the GGE biplot graphical analysis, whose behavior results were extended to the other progenies existing in the same group. The limit adopted to define the groups was 0.250 of dissimilarity, which was used to delimit a number of groups for the initial selection of 37 progenies for the GGE biplot study.

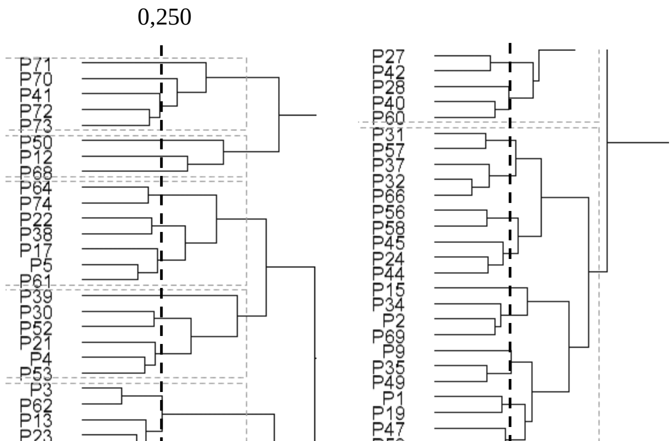

Figure 1. Dendrogram via the between-group average linkage method (UPGMA) involving 76 açaí progenies on the basis of three morphological characteristics.

Using the dendrogram, selection was performed in each group, with the progenies P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11, P12, P13, P15, P16, P17, P18, P21, P24, P30, P33, P35, P38, P39, P40, P41, P45, P50, P53, P58, P59, P70, P71 and P76, to be used in the GGE biplot analysis, and the months were represented by the letter M followed by 1 to 12, from January to December, respectively.

Table 2 shows an accumulated percentage above 80% of the variation explained by the first two axes, considering the multivariate of the three characteristics. The accumulated value provides high reliability regarding the explanation of the total variation in the behavior related to the genetic effect of the progenies, added to the interaction of the effect of months, whose representation is G + GxA. Therefore, the model consisting of two axes is sufficient to correctly visualize and interpret the behavior of the açaí progenies and the contrast between the months of the year. This accumulated percentage for the two axes is above that observed in açaí trees for fruit production characteristics (Yokomizo et al., 2017; Farias Neto et al., 2018), which indicates that the effects resulting from nonestimable environmental factors, which are called noise, which interferes with the accuracy of the GGE biplot graphs and thus compromises the recognition of superior progenies, do not constitute a significant portion of the estimated variability. This is relevant because it shows that the adopted model is reliable and close to reality. The behavior obtained was similar to that of some species previously considered domesticated, such as peppers (Abu et al., 2011) for fresh fruit production; melons for average weight per fruit and number of fruits per plant (Dehghani et al., 2012); cashew trees for the number, productivity and weight of almonds (Aliyu et al., 2014); and cassava for root productivity (Peprah et al., 2016), whose first two axes had an accumulated value above 80%.

Table 2. Singular value, proportion explained in % (PE %), cumulative proportion explained in % (PEA %) and information ratio (RI), considering the first four principal components (PCs), in three joint characteristics of açaí progenies.

	Component Axes				
Parameters	PC1	PC2	PC3	PC4	PC5
Singular Value	1,854	1,289	0.845	0.498	0.392
FOOT %	55,311	26,736	11,480	3,991	2,482
PEA %	55,311	82,047	93,527	97,518	100,000
IR	2,766	1,337	0.574	0.200	0.124

For the estimates of the information relationship (IR) values involving the first five component axes (Table 2), the first two PC axes presented a pattern (IR greater than 1), which means that there are associations between the months. In the other axes, the values are low and therefore do not contain any pattern or information; therefore, on the basis of these values, only the first two axes can be considered in the graphical analysis, which is sufficient for portraying the data patterns.

The visualization of where and in which months the açaí progenies are superior and the investigation of the presence of mega-environments, whose definition is the union of those that have similar intrinsic characteristics and can then be grouped in the same quadrant, are presented in Figure 2 ("which-won-where ") of the multienvironment data. The lines that start from the origin of the axes suggest that there is a composition of nine sectors or mega-environments, but curiously, all the months are inserted in the same mega-environment, which means that they were similar in terms of their contributions to the expression of distinctions between the progenies. Notably, the progeny with the best performance were identified as P50, and subsequently, the one that stood out was P12, with a positive association for the averages and for stability. Note the existence of P68, P70, P41, P71 and P72, which also presented a positive contribution to the averages; however, they do not show stability when taking into account the multivariate characteristics for the months.

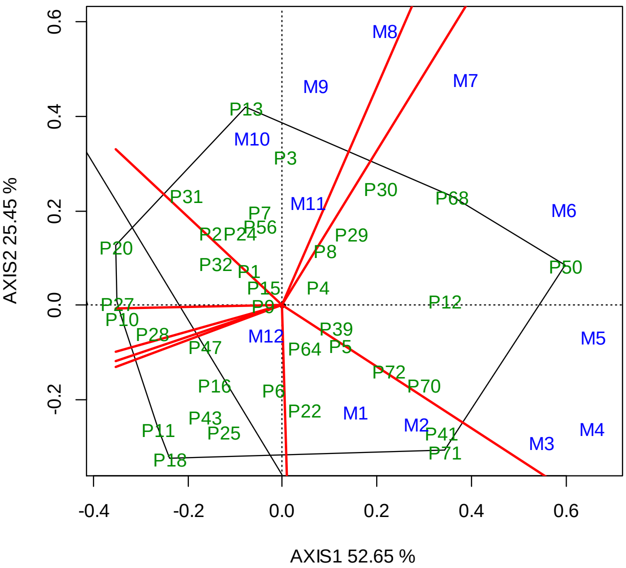

Figure 2. Indicative of which progenies performed best and in which months by GGE biplot (" Which-won-where ") for multivariate analysis among the

characteristics in açaí progenies. The solid red lines delimit sectors that define the mega-environments.

Megaenvironments were composed according to the delimitation by the lines that emerged from the origin of the axes, but only four of them had a distribution of months. The quantity in which there was the presence of months was close to that presented by other species, such as pepper plants for three years by Abu et al. (2011) and peach fruit production for three years (Citadin et al. 2014), whose progenies were located in three vertices of the polygon where there was at least one of the environments. Compared with strawberry plants, the behavior of strawberry plants is different since each location is obligatorily individually composed of a mega-environment (Costa et al., 2016) and cassava (Peprah et al., 2016). Notably, there were progenies that were plotted in sectors without the presence of any month, which is an indication that there was no specificity with respect to environmental control factors in these individuals, a behavior similar to that cited by Aliyu et al. (2014).

The dispersion of months among the three sectors is important because there is dissimilarity between environmental factors with sufficient intensity to generate different conditions. A wide dispersion of progenies is also observed in the GGE biplot, which is extremely interesting for breeding purposes because it allows us to verify that there is differentiation between their performances.

On the basis of the distribution of the progenies, there were those that did not have stability or adaptability in any month. Additionally, those that, owing to location, were divided by their negative and positive contributions. The variations in the graph are common when a set of distinct individuals is involved in the initial stages of genetic improvement and, therefore, still contain many contrasts, similar to what happens in other species, such as pepper (Abu et al., 2011), cashew (Aliyu et al., 2014), peach (Citadin et al., 2014), strawberry (Costa et al., 2016) and cassava (Peprah et al., 2016).

In Figure 3, the straight line containing an arrow is called the "environment-average axis" or "EAM", where the progenies that exceed the tip of the arrow are those that presented superior average performance among the materials evaluated, according to Yan (2002) and Yan (2011). Therefore, on the basis of the average values of the multivariate characteristics, the progenies were classified as follows: P50 > P68 > P12 > P30 > P41 > P71 >... general average >... > P28 > P20 > P 27 > P10 > P11 > P18. Among the materials whose performance was above the general average, P50, P68, P12, P30, P41, and P71 stand out, but it should be noted that because they presented perpendicular distances to the PC1 axis, many did not have stability because, in relation to this EAM in both directions, the greater the distance in relation to the origin, the less stable the materials are (YAN 2002; 2011). Therefore, in terms of a positive contribution to the averages and stability, the superior factors were P50, P68 and P12.

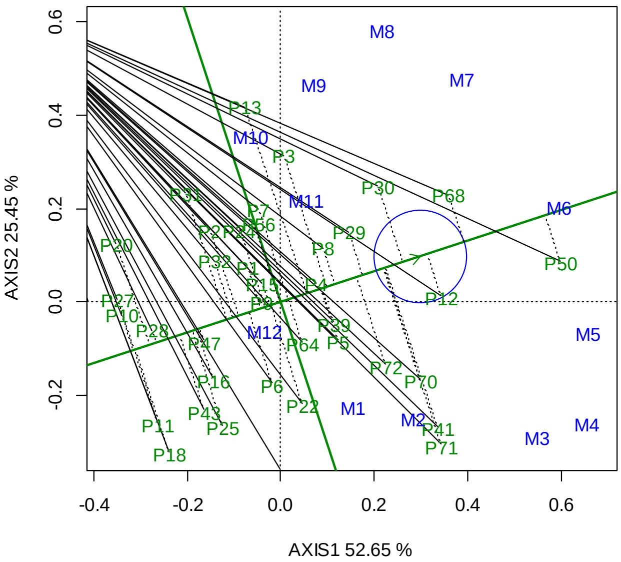

Figure 3. Average performance and stability of progenies according to the GGE biplot ("Average versus Stability") with the environment-average (EAM) axis for multivariate analysis of characteristics of açaí progenies.

A plant that can combine above-average performance and high stability is desirable in genetic improvement programs for any species and is called an ideotype, which is the perfect plant for a given environment. The graphical analysis of the GGE biplot “Average versus Stability” is based on an effective protocol for evaluating genotypes in relation to aspects related to performance and stability (Yan and Tinker, 2006; Yan et al., 2007; Yan, 2011) and for identifying which one is closest to the desired ideotype. The ideotype in the GGE biplot is the central point of the concentric circles, and then all the materials that are closest to this center or in the first circles are those that can be considered those that should be selected.

According to the information in the previous paragraph, it can be noted that there is an extremely promising açaí progeny, in this case P50, close to the location point of the ideotype, followed by P68 and then P12, differentiating it in comparison to other studies involving different species, which obtained results that, in general, had better performance for the average also presented low stability, for example, in cashew trees for the number weight of almond productivity cited by Aliyu et al. (2014). For the dispersed distribution of the progenies, which indicates that there is variability available for selection purposes, there was wide dispersion in this set of progenies, with no concentration near the origin of the lines or at another location on the graph, similar to what was observed in strawberry (Costa et al., 2016) and cassava (Peprah et al., 2016) plants. In the following circumcircles, attention should also be given to the P30, P29 and P70 progenies, which should be considered in future evaluations (Figure 4).

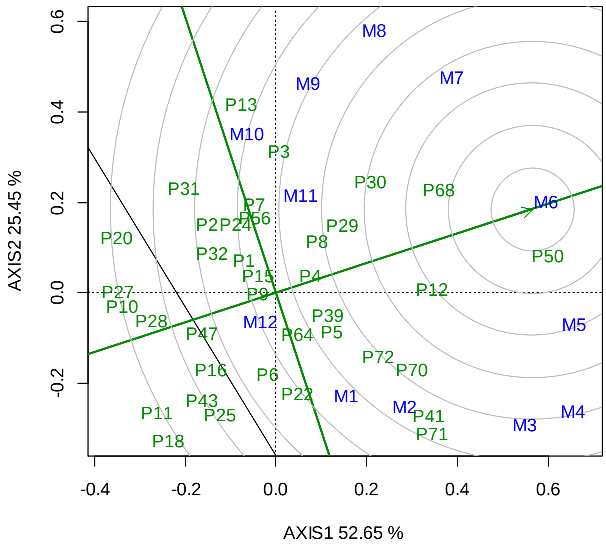

Figure 4. Classification of genotypes in relation to the ideotype (in the center of the concentric circles) via the GGE biplot with the environment-mean axis (EAM) for multivariate characteristics in açaí progenies.

A test environment is one that allows superior genotypes to be identified effectively in mega-environments, or if some environment (month) has the capacity to generate broader differences between genetic materials and then allows subsequent selection of those with better performance. This behavior can be visualized in the GGE biplot in Figure 5, with months that present longer vectors being those that provide environmental factors with greater contributions to the discrimination of progenies in relation to genetic factors. In contrast, months or progenies that present short vectors contribute less to discrimination, meaning that by not generating differentiations, they end up keeping all similar to each other (Hongyu et al., 2015).

In the multivariate analysis of characteristics, not all months were represented by long vectors, which means that some did not present the intensity or existence of factors that would allow the generation of environmental conditions that would reflect differentiated behavior among the progenies (Figure 5), which is different from that reported by Peprah et al. (2016) with respect to cassava productivity performance, where the environments presented longer vectors than did most genotypes, with only one genetic material with a longer vector in relation to that of the environment, and in cashew trees, where there were genotypes with greater contributions to discrimination according to Aliyu et al. (2014).

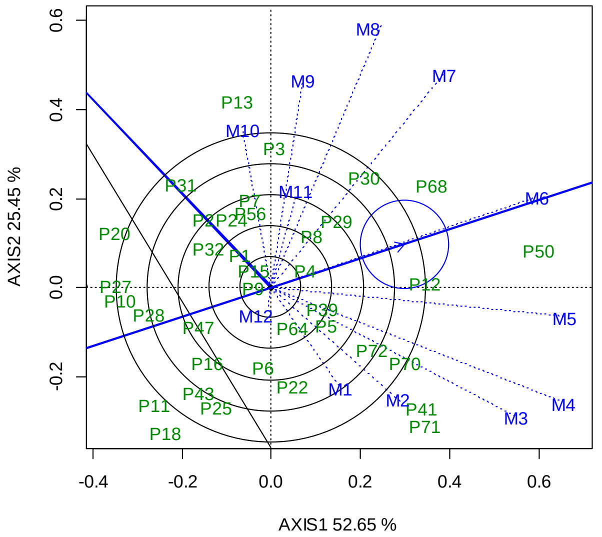

Figure 5. GGE biplot "discrimination and representativeness" to show the discrimination capacity and representativeness of the test environments for multivariate comparisons between FF (green fruits), FM (roue fruits) and TM (bunch size) in açaí progenies.

A second use of Figure 5 is discussed on the basis of the angle formed in relation to the EAM (environment-average axis) to indicate whether one or more environments have the capacity to represent the others. Therefore, an environment that manifests the intensity of controllable and noncontrollable factors on average for all other environments. Here, June contributes within an average in relation to all other months and can therefore represent them (Figure 5), with its smallest angle in relation to the EAM. Between the months of March and August, there is a manifestation of environmental factors with a greater capacity to generate distinct behaviors among genetic materials because of the presence of vectors that are longer than the progenies. This finding shows that the final half of the rainy season and the first two months of the dry season (Figure 5) constitute the period where extragenetic factors related to intrinsic conditions, without the possibility of control, such as precipitation and temperature (Table 1), act with greater intensity, generating an important contribution to the GxE interaction component, with a direct impact on the performance of the progenies; therefore, it is the time when it manifests itself with greater intensity and therefore is more suitable for studying the discrimination of genetic material. These months, with their different environmental factors, are responsible for generating differentiated microclimates, which, as a response, adaptable and diverse specificity of each progeny, exhibit natural behavior, similar to that observed by Aliyu et al. (2014) in cashew trees.

According to the GGE biplot, the progenies P50 are considered superior, followed by P68, P12, P30, P29 and P70. When these progenies are related to the 76 initial progenies of the dendrogram, progenies 52 and 55 can also be added, which can also be assumed to be superior.

CONCLUSIONS

Undoubtedly, the combination of multivariate analysis for characteristics, grouping via dendrograms and graphical analysis via GGE biplots is necessary, important and efficient for interpreting the results in this large number of progenies;

The best progeny is P50, being exceptional among all, followed by P68, P12, P30, P29 and P70, in order of performance, adding the progenies P52 and P55 in the dendrogram.

This group of progenies presents genetic variability due to the evident distinct individual contributions to the GxE interaction, as well as the months with their noncontrollable factors, which should be better studied to guide genetic improvement;

The month of June is the one that represents, in relation to environmental factors, the average of all other months and may be adopted when it is impossible to carry out assessments in more months;

The different behaviors of the progenies between the months show that the last four months of the rainy season (March and June) and the first two months of the dry season (July and August) should be prioritized in the evaluations because they provide conditions that allow greater differentiation between the progenies.

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