FUNCTIONAL PLANT BREEDING JOURNAL
Scientific Journal. ISSN 2595-9433
Volume 4, Number 2, Article n. 5, July/December
D.O.I. http://dx.doi.org/10.35418/2526-4117/v4n2a5
Received: 10/06/2021 - Accepted: 09/08/2022

# ESTIMATES OF GENETIC PARAMETERS AND SELECTION GAINS FOR PHENOLOGICAL AND PRODUCTIVE CHARACTERISTICS IN MACAW PALM: AN IMPORTANT PLANT FOR BIOENERGY

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**Abstract:** This study aimed to estimate genetic traits, determine genetic correlation, and predict breeding values as a way to select macaw palm accessions from the Germplasm Bank of the Universidade Federal de Viçosa, Minas Gerais, Brazil. This trial was carried out via REML/BLUP method, which was applied to following parameters: precocity (PREC), height of the first spathe (HFS), total fruit number (TFN), pulp oil content (POC) and oil production per plant (PROD). Thirty-six accessions - comprised of two to ten plants each - were evaluated. Selegen- Reml/Blup software was used for genetic analysis as well as to identify individuals to compose the population to be exploited in macaw breeding in both short- and long-term programs. The highest correlation coefficients were observed between PREC and HFS, PREC and TFN, and TFN and PROD, which led to indirect gains by the selection. The selection of the top 20 individuals provided a gain of 74.8% over the PROD average for short-term seed production. On the other hand, the selection of the top 52 individuals led to a gain of 40.5% to form a long-term breeding population. Considering the simultaneous selection through an additive selection index coupled to economic weights is possible to obtain direct gains of 67.6%by selecting PROD. Estimates of genetic parameters achieved by the present study demonstrate the excellent selective potential of the accessions, with sufficient genetic variability to establish populations for macaw palm breeding program.

**Keywords:** *Acrocomia aculeata*, biometrics, breeding, genetic parameters, biofuels.

# Introduction

The macaw *Acrocomia aculeata* (Jacq.) Lodd. ex Mart. is a native palm tree widely distributed in the most different of Brazil biomes. This species stands out as a phytogenetic resource to produce biodiesel due to its high potential of oil production (Pires et al., 2013),which is similar to the main species currently explored by the sector of biofuels.

The use of macaw palm as a resource for biodiesel production depends on its adaptation to the field environmental conditions and available technologies applied to boost its intrinsic potential of oil production (Manfio et al., 2012; Pires et al., 2013; Lanes et al., 2016; Lima et al., 2018). One of the technologies that have most contributed to the substantial increase in oil production is crop (plant) breeding (Nugroho et al., 2014). The plant breeding seeks to select the best individuals to constitute the next plant generations – by increasing target values of traits selection – to reduce efforts and spend less time to obtain genetically superior cultivated materials (Farias Neto et al., 2013; Cardoso et al., 2017).

To obtain superior genotype, it is important that it holds the best performance regarding the traits to be selected. In this sense, an efficient estimate of genetic parameters is critical to achieving better results during the process of selection, because it mainly depends on the estimated additive genetic values (Farias Neto et al., 2013). The sensible estimation of genetic parameters and efficient selection can be achievedvia a mixed-model methodology.

Another key factor in plant breeding is the knowledge concerning the association between parameters since the selection of one trait can affect other ones (Cruz et al., 2012). The correlation is also important as the maximum gain with the selection index is obtained in a steady way for related characteristics (Freitas et al., 2013; Karantin et al., 2019). This is because selection may be difficult due to low heritability or problems with measurement and identification (Cruz et al., 2012).

Stated as a hypothetical plant model that presents correlated characteristics with yield, the establishment of crop ideotype is a crucial step for breeding program management (Rocha et al., 2018; Woyann et al., 2019).

Such characteristics are based on market and producers demand, seeking to encompass the technical and financial needs along within the supply chain. Based on the study of the characteristics chosen for the composition of the crop ideotype, the selection of strategies that allow the aggregation of ideal characteristics in a single genotype will be adopted.

The selection process may present one characteristic or a set of characteristics as a target. To select genotypes considering a combination of desirable traits, the selection indices are used to obtain equilibrated gains for involved traits (Freitas et al., 2013).

Thus, this study aimed to investigate the association between characters, estimate genetic parameters, and predict additive genetic values, seeking to identify and select superior genetic accessions of macaw palm to compose breeding populations, additionally quantifying genetics gain and effective size of breeding population for both short and long term programs.

# Material and methods

## Germplasm bank

Evaluations were performed at the Macaw Germplasm Bank (BGP - Macaw), managed by Universidade Federal de Viçosa- nº 084/2013-SECEX/CGEN -located in the municipality of Araponga, Minas Gerais. 44 accessions were evaluated, which was composed by open pollination progenies collected in the Minas Gerais and São Paulo states (Table 1), which were introduced in February 2009.

The experiment was carried out in a completely randomized design, with the number of plants ranging from two to ten, according to the plant's availability in each BGP - Macaw accession.

**Table 1**. Regions of origin of the BGP - Macaw accessions.

| ACCESSION | REGION |
|---|---|
| **BGP 1** | Campos das Vertentes - MG |
| **BGP 3** | Campos das Vertentes - MG |
| **BGP 5** | Campos das Vertentes - MG |
| **BGP 6** | Campos das Vertentes - MG |
| **BGP 14** | Campos das Vertentes - MG |
| **BGP 15** | Campos das Vertentes - MG |
| **BGP 43** | Campos das Vertentes - MG |
| **BGP 53** | Campos das Vertentes - MG |
| **BGP 16** | Centro – MG |
| **BGP 20** | Centro – MG |
| **BGP 22** | Centro – MG |
| **BGP 27** | Centro – MG |
| **BGP 31** | Centro – MG |
| **BGP 32** | Centro – MG |
| **BGP 37** | Centro – MG |
| **BGP 40** | Centro – MG |
| **BGP 50** | Centro – MG |
| **BGP 2** | Belo Horizonte – MG |
| **BGP 4** | Belo Horizonte – MG |
| **BGP 7** | Belo Horizonte – MG |
| **BGP 8** | Belo Horizonte – MG |
| **BGP 11** | Belo Horizonte – MG |
| **BGP 13** | Belo Horizonte - MG |
| **BGP 17** | Belo Horizonte - MG |
| **BGP 21** | Belo Horizonte - MG |
| **BGP 29** | Belo Horizonte - MG |
| **BGP 33** | Belo Horizonte - MG |
| **BGP 36** | Belo Horizonte - MG |
| **BGP 38** | Belo Horizonte - MG |
| **BGP 48** | Belo Horizonte - MG |
| **BGP 52** | Belo Horizonte - MG |
| **BGP 45** | Noroeste - MG |
| **BGP 25** | Norte - MG |
| **BGP 30** | Norte - MG |
| **BGP 49** | Norte - MG |
| **BGP 26** | Oeste - MG |
| **BGP 23** | No identified |
| **BGP 41** | No identified |
| **BGP 35** | Sudeste - SP |
| **BGP 39** | Sudeste - SP |
| **BGP 42** | Sudeste - SP |
| **BGP 47** | Sudeste - SP |
| **BGP 9** | Zona da Mata - MG |
| **BGP 44** | Zona da Mata - MG |

BGP: Palm Germplasm Bank; MG: Minas Gerais; SP: São Paulo.

## Assessments

The accessions were evaluated for precocity (PREC), by assessing the time comprised between transplant in gand appearance of first spathe in each accession. The height of the first spathe (HFS - m) was measured with a Hagl of EC II digital clinometer. The number of fruits was quantified by counting the total of fruits per bunch. The fruit pulp was dried in an oven at 105ºC during 24 h and then weighed individually on a precision balance to record dry weight (g). The pulp oil content (%) was evaluated using near infrared spectrometry - NIR (Varian ® FT-IR 660), with the spectra assessed through meso carp of each fruit. To estimate oil production per plant (Kg), the number of fruits x pulp dry mass x oil content were multiplied.

## Statistical analysis

All analyzes were accomplished using Selegen-Reml/Blup software (Statistical Computerized Genetic Selection System via Mixed Linear Models) - 2014 version (Resende, 2016).

***Correlation between characters:*** genotypic correlations or correlation between genotypic values were assessed by multivariate analysis between pairs of variables;

***Genetic parameters:*** estimates of the components of variance, genetic parameters and genetic values were performed by the mixed-model methodology, REML (Restricted Maximum Likelihood) procedure / BLUP (Best Linear Unbiased Prediction) (Resende, 2007), according to the model: $y = Xb + Zg + e$, where: *y, b, g, e*: data vectors, fixed effects (overall mean), additive genetic effects (random) and random errors, respectively. X and Z: matrices of incidence for b and g, respectively.

***Mixed Model Equations:***

$$\begin{bmatrix} X'X & X'Z \\ Z'X & Z'Z + A^{-1}\left((1-h^2)/h^2\right) \end{bmatrix} \begin{bmatrix} \hat{b} \\ \hat{g} \end{bmatrix} = \begin{bmatrix} X'y \\ Z'y \end{bmatrix}$$

$h^2 = \hat{\sigma}_g^2 / (\hat{\sigma}_g^2 + \hat{\sigma}_e^2)$ : individual heritability in the narrow sense.

***Variance Components Estimates via EM Algorithm***

$$\hat{\sigma}_e^2 = [y'y - \hat{b}'X'y - \hat{g}'Z'y]/[N - r(X)]$$

$$\hat{\sigma}_g^2 = \left[\hat{g}'A^{-1}\hat{g} + \sigma_e^2 \; tr \; C^{22}\right]/N_g,$$

where:

*r(X)*: rank or number of linearly independent columns of X.

$C^{22}$: is the form

$$\begin{bmatrix} C^{11} & C^{12} \\ C^{21} & C^{22} \end{bmatrix} = \begin{bmatrix} X'X & X'Z \\ Z'X & Z'Z + A^{-1}(\sigma_e^2/\sigma_g^2) \end{bmatrix}^{-1}$$

$N_g$: rank or number of linearly independent columns of X.

*A:* additive genetic relationship matrix.

*tr:* matrix trace operator, given by the sum of the matrix diagonal elements

*N*: data total number.

***Selection index:*** The additive index is established by a linear combination, involving genetic values, which are weighted by their respective economic values as shown below:

$$I = (pVG)_{PREC} + (pVG)_{APE} + (pVG)_{NTF} + (pVG)_{TOP} + (pVG)_{PROD}$$

Where: *p* is the economic weight established for character and *VG* is the predicted genotypic value. In a broad context, the most important character in the improvement of macaw palm is the production of oil (PROD). For selection index composition, the determination of economic weights for characters was based on the genetic correlations involving several traits and the PROD, expressed by weight character *pi* = (correlation (i, PROD)) / (sum of the correlations between each character ie a PROD) as proposed by Resende (2007).

The proposed ideotype for selection index targets more productive plants (PROD), with an increased total fruit number (TFN), higher pulp oil content (POC), early-cycle (PREC) and decreased height of the first spathe (HFS). The genetic values predicted by the BLUP methodology were used to calculate the additive selection index with economic weights.

# Results

The values of individual heritability are classified into “low” and “moderate” for values less than 0.15, and 0.50, respectively, and “high” for values above 0.50 (Resende, 2002). Among estimated genetic parameters (Table 2), individual narrow-sense heritability ($h^2a$) presented "moderate" values for PREC, TFN and PROD, whereas the HFS and POC presented values classified as "high", respectively.

The same author also proposes distinct groups for genomic accuracy, where values between 0.40 and 0.70 are considered “moderate”, and “high” when it is higher than 0.70. In this sense, PREC, TFN and PROD presented "moderate" accuracy for selection of accessions; where as HFS and POC presented "high" values.

**Table 2.** Estimates of genetic parameters in 44 analyzed accessions of *Acrocomia aculeata*, regarding to the five phenological and productive characteristics.

| Parameter | PREC | HFS | TFN | POC | PROD |
|---|---|---|---|---|---|
| **Vg** | 3239.29 | 0.39 | 8115.37 | 2.13 | 0.24 |
| **Ve** | 24100.26 | 0.51 | 45428.40 | 4.51 | 1.05 |
| **Vf** | 27339.55 | 0.90 | 53543.77 | 6.65 | 1.30 |
| **CVg** | 3.74 | 32.20 | 31.60 | 2.6 | 44.13 |
| **$h^2$a** | 0.21 ± 0.14 | 0.76 ± 0.28 | 0.27 ± 0.16 | 0.57 ± 0.24 | 0.33 ± 0.18 |
| **$h^2$mp** | 0.26 | 0.63 | 0.31 | 0.52 | 0.36 |
| **Accuracy** | 0.51 | 0.80 | 0.55 | 0.72 | 0.60 |
| **M** | 1520.69 | 1.94 | 285.03 | 56.16 | 1.11 |

Vg = genetic variance between progenies; Ve = residual variance; Vf = individual phenotypic variance; CVg = coefficient of genotypic variation; $h^2a$ = individual narrow-sense heritability; $h^2mp$ = heritability on a progeny mean basis; M = overall average of the experiment; PREC = precocity; HFS = height of the first spat; TFN = total fruit number; POC = pulp oil content; PROD = oil production / kg; Self-fertilization rate = 0.5.

Given the analysis of genetic correlation (Table 3), PROD and TFN, PREC and HFS, and PREC and TFN presented correlations of high magnitude (0.89) and moderate (0.54 and -0.40), respectively, leading to indirect gains by the selection and predictions about directional changes that the selected characteristic may cause on other correlated.

**Table 3.** Matrix of genetic correlation for five phenological and productive characteristics of *Acrocomia aculeata* accessions.

| Traits | PREC | HFS | TFN | POC | PROD |
|---|---|---|---|---|---|
| **PREC** | 1.00 | **0.54** | **-0.40** | 0.02 | -0.30 |
| **HFS** | - | 1.00 | 0.10 | **-0.34** | 0.15 |
| **TFN** | - | - | 1.00 | 0.18 | **0.89** |
| **POC** | - | - | - | 1.00 | 0.18 |
| **PROD** | - | - | - | - | 1.00 |

PREC = precocity; HFS = height of the first spat; TFN = total fruit number; POC = pulp oil content; PROD = oil production / kg.

The predicted genetic gain and generated means of selected accessions concerning PROD are shown in Table 4. The selection of the 20 best individuals encompassed 9 distinct accessions, raising the population average from 1.11 kg to 1.94 kg of oil/plant, which means a genetic gain of 74.8%. The effective size suitable for both short-term and long-term selection is achieved by selecting 20 (Ne = 13.12) and 52 (Ne = 30.09) individuals, respectively.

**Table 4.** Individual additive genetic values, genetic gain, and effective size of the population (Ne) in response to the best individual selection in BGP-Macaw for oil production per plant (Kg), aiming at sexual propagation.

| Order | Accession | f | A | u+a | Gain | New Mean | Ne |
|---|---|---|---|---|---|---|---|
| **1** | 8 | 8.43 | 2.50 | 3.63 | 2.50 | 3.63 | 1.00 |
| **2** | 8 | 4.33 | 1.39 | 2.52 | 1.95 | 3.07 | 1.60 |
| **3** | 8 | 3.34 | 1.13 | 2.25 | 1.67 | 2.80 | 2.00 |
| **4** | 37 | 4.53 | 1.12 | 2.25 | 1.53 | 2.66 | 2.67 |
| **5** | 49 | 3.93 | 0.92 | 2.05 | 1.41 | 2.54 | 3.66 |
| **6** | 43 | 3.68 | 0.89 | 2.01 | 1.33 | 2.45 | 4.65 |
| **7** | 26 | 3.04 | 0.76 | 1.89 | 1.24 | 2.37 | 5.63 |
| **8** | 36 | 3.43 | 0.71 | 1.83 | 1.18 | 2.31 | 6.62 |
| **9** | 26 | 2.73 | 0.67 | 1.80 | 1.12 | 2.25 | 7.25 |
| **10** | 47 | 3.02 | 0.65 | 1.78 | 1.07 | 2.20 | 8.23 |
| **11** | 38 | 3.46 | 0.65 | 1.78 | 1.04 | 2.16 | 9.21 |
| **12** | 43 | 2.75 | 0.64 | 1.76 | 1.00 | 2.13 | 9.83 |
| **13** | 26 | 2.50 | 0.61 | 1.74 | 0.97 | 2.10 | 10.11 |
| **14** | 8 | 1.37 | 0.59 | 1.72 | 0.95 | 2.07 | 10.13 |
| **15** | 8 | 1.22 | 0.55 | 1.68 | 0.92 | 2.05 | 9.99 |
| **16** | 50 | 2.76 | 0.51 | 1.64 | 0.89 | 2.02 | 10.90 |
| **17** | 26 | 2.12 | 0.51 | 1.64 | 0.87 | 2.00 | 11.08 |
| **18** | 36 | 2.66 | 0.50 | 1.63 | 0.85 | 1.98 | 11.76 |
| **19** | 47 | 2.26 | 0.45 | 1.58 | 0.83 | 1.96 | 12.44 |
| ***20*** | ***50*** | ***2.30*** | ***0.39*** | ***1.52*** | ***0.81*** | ***1.94*** | ***13.12*** |
| **21** | 27 | 2.35 | 0.38 | 1.51 | 0.79 | 1.92 | 14.01 |
| **22** | 8 | 0.49 | 0.36 | 1.49 | 0.77 | 1.90 | 13.77 |
| **23** | 26 | 1.55 | 0.36 | 1.48 | 0.75 | 1.88 | 13.82 |
| **24** | 43 | 1.66 | 0.34 | 1.47 | 0.73 | 1.86 | 14.30 |
| **25** | 6 | 2.28 | 0.33 | 1.46 | 0.72 | 1.85 | 15.15 |
| **26** | 29 | 2.39 | 0.31 | 1.44 | 0.70 | 1.83 | 16.01 |
| **27** | 50 | 2.01 | 0.31 | 1.44 | 0.69 | 1.82 | 16.48 |
| **28** | 15 | 2.18 | 0.29 | 1.42 | 0.67 | 1.80 | 17.34 |
| **29** | 36 | 1.88 | 0.29 | 1.42 | 0.66 | 1.79 | 17.81 |
| **30** | 47 | 1.62 | 0.28 | 1.41 | 0.65 | 1.78 | 18.28 |
| **31** | 27 | 1.85 | 0.24 | 1.37 | 0.63 | 1.76 | 18.96 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **32** | 16 | 1.82 | 0.23 | 1.36 | 0.62 | 1.75 | 19.82 |
| **33** | 43 | 1.23 | 0.23 | 1.35 | 0.61 | 1.74 | 20.09 |
| **34** | 41 | 1.85 | 0.22 | 1.35 | 0.60 | 1.73 | 20.94 |
| **35** | 1 | 1.89 | 0.19 | 1.32 | 0.59 | 1.71 | 21.81 |
| **36** | 41 | 1.74 | 0.19 | 1.32 | 0.57 | 1.70 | 22.48 |
| **37** | 47 | 1.24 | 0.17 | 1.30 | 0.56 | 1.69 | 22.74 |
| **38** | 22 | 1.59 | 0.16 | 1.29 | 0.55 | 1.68 | 23.61 |
| **39** | 50 | 1.42 | 0.15 | 1.28 | 0.54 | 1.67 | 23.87 |
| **40** | 27 | 1.50 | 0.15 | 1.28 | 0.53 | 1.66 | 24.35 |
| **41** | 35 | 1.59 | 0.15 | 1.28 | 0.52 | 1.65 | 25.20 |
| **42** | 36 | 1.33 | 0.14 | 1.27 | 0.51 | 1.64 | 25.48 |
| **43** | 53 | 1.95 | 0.14 | 1.27 | 0.51 | 1.63 | 26.33 |
| **44** | 6 | 1.50 | 0.12 | 1.25 | 0.50 | 1.63 | 27.00 |
| **45** | 32 | 1.92 | 0.12 | 1.25 | 0.49 | 1.62 | 27.86 |
| **46** | 50 | 1.30 | 0.12 | 1.25 | 0.48 | 1.61 | 27.94 |
| **47** | 15 | 1.53 | 0.12 | 1.25 | 0.47 | 1.60 | 28.61 |
| **48** | 22 | 1.32 | 0.09 | 1.22 | 0.46 | 1.59 | 29.28 |
| **49** | 43 | 0.69 | 0.08 | 1.21 | 0.46 | 1.59 | 29.37 |
| **50** | 36 | 1.10 | 0.08 | 1.21 | 0.45 | 1.58 | 29.48 |
| **51** | 26 | 0.50 | 0.07 | 1.20 | 0.44 | 1.57 | 29.43 |
| ***52*** | ***38*** | ***1.23*** | ***0.05*** | ***1.18*** | ***0.43*** | ***1.56*** | ***30.09*** |

f: individual phenotypic value or field measurement; a: predicted additive genetic effect; u + a: predicted additive genetic value;

The selection of the 16 best accessions for the weighted additive selection index is shown in Table 5.

**Table 5.** Selection index with economic weights for 16 best accessions from BGP-Macaw.

| Order | Parent | Index |
|---|---|---|
| **1** | 8 | 3.5601 |
| **2** | 26 | 2.4073 |
| **3** | 49 | 2.3705 |
| **4** | 37 | 2.2083 |
| **5** | 47 | 2.0067 |
| **6** | 36 | 1.7728 |
| **7** | 35 | 1.6507 |
| **8** | 43 | 1.5907 |
| **9** | 50 | 1.3363 |
| **10** | 6 | 1.1713 |
| **11** | 14 | 1.1456 |
| **12** | 13 | 1.1317 |
| **13** | 16 | 0.9916 |
| **14** | 38 | 0.9698 |
| **15** | 23 | 0.8504 |
| **16** | 41 | 0.8216 |
| **Mean** | | 0.8115 |

Access 8 was highlighted for simultaneous gains in characteristics related to the proposed ideotype, followed by accessions 26, 49, 37, and 46, which presented index values higher than 2.0.

The selection of such accessions to compose breeding populations will result in cultivars with higher performance and yield, earlier cycles, and low height of emission of the bunch.

Table 6 shows results on the direct gains for selection focused on characteristics of oil production per plant (Kg) and indirect gains for other traits presented in percentage (as compared to the average). The selection was made from the five best individuals within the six best accessions ranked by the weighted additive index. It was possible to achieve gains that resulted in more precocious individuals, with a lower height of cluster emission and a greater number of fruits. The gain obtained for oil content in the pulp (TOP), however, was low in each character, as expected in the simultaneous selection for several characteristics.

**Table 6.** Gains with direct selection for PROD and indirect selection of other characters as a response of the five best individual selection within the six best accessions based on additive selection index with weights**.**

| Gain/Traits | PROD | PREC | HFS | TFW | POC |
|---|---|---|---|---|---|
| **GSD (%)** | 67.6 | - | - | - | - |
| **GSI (%)** | - | -3.23 | -5.31 | 45.35 | 0.37 |

GSD = gain with direct selection; GSI = gain by indirect selection.

# Discussion

The genetic coefficients of variation express the percentage of genetic variation as a percentage of the general average. The traits presented remarkable values for HFS, TFN, and PROD (32.20, 31.60, and 44.13, respectively) and moderate for PREC and POC (3.74 and 2.6, respectively). Altogether, these results suggest that the population studied can be considered a promising group for *A. aculeata* breeding program, being possible achieving significant gains via the selection of traits. Costa et al., 2018 observed in macaw germplasm bank accessions that characteristics of "oil production per plant" presented a genetic coefficient of variation by about 77.16%, and also indicated that the studied population presents elevated potential to be selected and achieve genetic gain.

According to Resende (2002), most quantitative characters of economic importance present individual heritability around 20%, which is in close agreement with values estimated in the present study. The values of individual heritability for the five traits were classified as moderate to high, representing suitable genetic control of the traits and success to transfer them to future generations.

The values of individual heritability were similar to the values of average heritability of progenies, and this means that is possible to choose both selection strategies, or BLUP, which uses both heritabilities simultaneously, enabling considerable genetic gains in response to the traits selection. Farias Neto et al., (2013) demonstrated heritability values as moderate for total weight of fruits in açaizeiro and peach palm (0.29 and 0.21 respectively), as examples of plants beloging to Arecaceae family.

When plant height, stem diameter, canopy projection, and fruit yield were evaluated in macaw progenies, Domiciano Silva Rosado et al., 2019 observed values classified as moderate to high for heritability in both progenies mean and narrow-sense heritability, suggesting an excellent potential of macaw palm for selection among families, demonstrating close relation with the present work.

Simiqueli et al., 2018 in a study on endogamic depression in macaw, also estimated narrow-sense heritability for some characteristics, evidenced moderate values for: number of inflorescences, height of the first spathe, number of fruits, and high values for: pulp, almond oil, fresh weight and total oil production. For the authors, productive characteristics show strong inbreeding depression, which demonstrates the effects of dominance.

On the other hand, there is a low and varied inbreeding depression for vegetative characteristics, which highlights the effects of additive genetic control. These authors also state that self-fertilization can be an improvement strategy for characteristics that present high heritability. In the present study, these values were observed for "height of the first spathe".

Another genetic parameter that is closely related to character heritability is the selective accuracy, which in turn presents a singular correlation between true and predicted genetic values, in a manner that as the greater it's the value the more complete is the confidence during individuals evaluation (Resende and Duarte, 2007). The values of selective accuracy were classified from moderate to high. Such values reflect the estimated efficiency of the individual's genotypic value, contributing to the efficient selection of accessions (Farias Neto et al., 2013). The association of estimated values of heritability with values of accuracy reveals excellent possibilities of selection in BGP-Macaw.

The estimates of genotypic correlations among the five characters studied reflected associations of inheritable nature. The study of correlations enables identifying characteristics that cause an indirect effect on traits selection. Smiderle et al., (2019) reported that positive correlations demonstrate the occurrence of pleiotropism or imbalance of genetic link between pairs of characters, thus favoring the simultaneous selection of two or more of them, by selecting only one. The genotypic correlation of greatest magnitude displayed to be involved with TFW and PROD (0.89), indicating that it is possible to increase the production of kg of oil per plant via indirect selection for total fruit weight.

The precocity characteristic presented a moderate magnitude of correlation with HFS and TFN(0.54 and -0.40, respectively). The first positive association indicates that the earlier the access the lower is the height of the first spathe, whereas the second negative association indicates that changes in one direction regarding this rait generate changes in the opposite direction in the other, which means that the earlier the access the greater the total number of fruit.

The characteristic height of the first spathe (HFS) also presented a negative and moderate correlation with oil content in the pulp (-0.34).In the other words, the lower the height of spathe emission, the higher the oil content in the pulp. The other characteristics showed low magnitude correlations, with emphasis on the correlation between PREC and PROD (-0.30), which reveals the possibility of selecting productive accessions in kg of oil per plant in an early-cycle plant, an crop ideotype of great interest for macaw palm. When macaw palm accessions were evaluated, Costa et al., (2018) observed positive genotypic correlations between the variables “endocarp dry weight and shell dry weight”, “endocarp dry weight and almond dry weight” and “oil production by plant and pulp dry weight”, however, for oil content, no correlation was observed with other characters. For these authors, non-significant characteristics or with low correlation estimate reflect independence between them, whereas positive correlations provide advantages in the indirect selection, as the selection for dry pulp weight provides positive changes in oil production per plant.

A minimum of effective size by about 13 and 30 was established to compose the population directed to seed production in the short term, and for breeding in the long-term program, respectively. There are high genetic gains using the two selection modalities. The effective population size (Ne) refers to the genetic size of a reproductive population, referring to their genetic representativeness. Thus, the management of Germplasm Banks must take into consideration genetic conservation in order to retain a certain level of genetic variability by considering inbreeding in planting generation, for the composition of the seed production population and the maintenance of compatible effective population size obtaining the selective limit for the composition of the breeding population (Resende & Bertolucci, 1995).

The selection of the 20 best individuals to establish a seed orchard by the BLUP methodology and improve PROD (kg of oil per plant) resulted in gains of 74.8%, raising the average from 1.11 kg to 1.94 kg of oil per plant, with an effective population size of 13.12, which is sufficient to prevent the occurrence of inbreeding depression in the generation of planting (Table 4). Among these 20 selected individuals (Table 3), there are contributions from 9 different accessions (8, 26, 36, 37, 38, 43, 47 and 49), being individuals belonging to accession 8 most to contributed with five individuals, with three at first positions.

On the other hand, the selection of the 52 best individuals corresponding to approximately 37% of the total number of individuals in the experiment for the establishment of a breeding population - simulating a long-term program - consisted of 20 families and provided an estimated gain of 40.5% in relation to the average, raising the population average from 1.11 kg to 1.56 kg and effective size of 30, sufficient to maintain genetic variability and obtain gains in subsequent cycles of selection . It is worth mentioning that the additive genetic values are also useful during planning of crosses for next selective cycle evaluation, in which individuals with the highest additive genetic values can participate in a greater number of crosses (Farias Neto et al., 2013).

To increase the likelihood of success in a breeding program, it is important to consider selecting several traits of interest simultaneously, to bring together in a single genotype allele that is favorable for these traits (Mendes et al., 2009). In this way, it is possible to use the selection indices, which constitute an additional character, being established by the optimal linear combination of several characters (Cruz et al., 2012).

The additive selection index with economic weights was proposed for the selection of accessions intended to compose the final ideotype of early-cycle-macaw plants with higher oil production, since the sooner the cultivar starts production, the greater the incomes (gains) to the producer, besides low height of the bunches in order to facilitate the harvest management. The accession 8 was the highlighted one for this ideotype, which maximized the gains for the characteristics and weights involved, being followed by accessions 26 and 49.

To maximize the gains and the Ne, the equal contribution by the parent is always desirable, thus, the five best individuals were selected within the six best families ranked by the additive index to quantify the direct gains for production of oil per plant (Kg). The direct gain for PROD corresponded to 67.7% in relation to the average, resulting in gains of -3.23 and -5.31%, as compared to the average of PREC and HFS. Since the intention is that both present lower values, the gains are consequently negative. The indirect gain for the total number of fruits (TFN) was 45.3% in relation to the average, which corresponding to a high correlation between PROD and TFN (0.89). Oil content in the pulp (POC) presented the lowest indirect gain, with 0.37% in relation to the average.

This is one of the pioneering studies to evaluate phenological and productive characteristics of macaw palm in a germplasm bank, seeking to select genotypes that can conduct the composition of a breeding population base and achieve macaw palm cultivars as efficient to supply demands of the biofuels sector. As it is a germplasm bank in an initial production stage, future studies are recommended to assess the temporal stability of production accessions and correlation with other characteristics that may provide an early selection.

# Conclusion

The BGP-Macaw accessions showed considerable genetic variability, a fundamental characteristic that provides breeding program continuity for this species, and an excellent prospect to increase oil production via traits selection.

The correlation values allow indirect gains for mainly TFN and PROD, indicating that the selections for oil production per plant (Kg) can be achieved by selecting the easiest variable to be assessed.

The genetic gain for the selection of either both or multiple traits can be obtained.

The selection of the 20 best individuals regarding the character of oil production per plant (Kg) resulted in gains of 74% via BLUP, whereas 67.7% by the selection based on the selection.

The estimates of genetic parameters and effective population size presented reveal an excellent selection potential of the population and genetic variability for genetic macaw breeding programs in both the short and long term.

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