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BIOENERGETIC POTENTIAL OF NATURAL POPULATIONS OF MACAÚBA IN THE CENTRAL REGION OF THE STATE OF TOCANTINS

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ABSTRACT
Macaúba (Acrocomia aculeata), due to its high levels of oil in the fruits, has great bioenergetic potential and offers a promising alternative to produce biofuel and other bioproducts. The objective of this study was to carry out an environmental and morphological characterization of the native populations of macaúba in the central region of the State of Tocantins, as well as to analyze their bioenergetic potential. To carry out the present study, two experimental sites were selected from the identification of 28 potential areas with natural occurrence of macaúba. Experimental Site A, located in the municipality of Lajeado, is characterized by a region of dense Cerrado-type natural vegetation, with an altitude of 230 m. Experimental Site B is in Aparecida do Rio Negro, in an area of extensive pasture and an altitude of 390 m. of the soil, morphological and biometric of the macaúba populations, as well as the analyzes to obtain the oil content of the fruits. In each site, 07 palm trees were selected after measuring height, counting the number of bunches and inflorescences and botanical identification of the species. 2 kg of fruits were collected from each of these palm trees, which were measured, pulped and then the oil content of the mesocarp and endosperm was analyzed (Bligh Method; Dyer) expressed % dry basis, and extraction time (30 and 60 min.), for each area. The results showed that there was a significant difference between the two areas regarding the average oil content, indicating that the average of Site A (30.85%) was higher than the average of Site B (20.73%). There was no significant difference between the oil content of the mesocarp (26.08%) and the endosperm (25.50%), nor in relation to the extraction time.

Keywords: Acrocomia. Scrubland. Oil Content. Biofuel.

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INTRODUCTION

The macaúba palm is a plant native to Brazil widely distributed in environments with different edaphoclimatic characteristics. Its fruits have great economic potential due to the presence of oil in the pulp and kernel, which can be used in the biofuel, cosmetics, and food industries (MADEIRA et al., 2023).

Despite this wide geographical distribution, little is known about the adaptability of macaúba to environmental conditions such as soils, climate and plant formations associated with its populations in the Brazilian territory. There are few studies on the association between environmental conditions and the phenotypic characteristics of their populations (PIRES et al., 2013; COELHO et al., 2019).

The great interest in this species as a feedstock for biodiesel is based on its high fruit yield (approximately 62 kg per plant), the high oil content in the pulp (45% and 60%, dry matter) and almond (61% and 68%, dry matter), and its high oil quality (LANES, COSTA, MOTOIKE, 2014).

From the oil extracted from the mesocarp of the fruit, biofuels, biomaterials and cosmetics are produced. The almond provides fine oil for the cosmetics sector, as well as biokerosene and soap. As waste, the endocarp is directed to the generation of energy, charcoal and biomaterials (CARDOSO et al., 2017; SOUSA, 2020).

Brazil, as an agro-producing country, can benefit from the rational use of renewable energy from residual biomass, promoting sustainability and energy security. The adoption of a circular economy, which recycles, reuses and adds value to materials, requires innovation and technological advances to minimize waste and recover energy, closing industrial cycles (STAHEL, 2016; AMPESE et al., 2021). And with that the macaúba palm tree, *Acrocomia aculeata* (Jacq.) Lodd, has significant bioenergetic potential due to its high oil content, which makes it a promising raw material for bioenergy (ORTEGA et al., 2024).

Traditionally, the economic exploitation of macaúba is done in an extractive way, however, there are projects and areas with commercial cultivation of macaúba in order to meet the energy and food market. However, there is little technical information about the crop and ways of using the fruits (EVARISTO et al., 2017). In this scenario, it is essential to promote genetic improvement programs for macaúba, aiming at systematic cultivation and future commercialization on a large scale. In Brazil, several commercial initiatives are already underway, highlighting the Entaban Brasil, Solea, and Inocas programs, which direct their production mainly to the domestic market (SANT' ANA et al., 2023).

Revista ARACÊ
ISSN: 2358-2472

With the advent of the climate crisis, where countries and companies seek to reduce emissions, the energy transition is a challenging and relevant path to mitigate the potential impacts of climate change. In this context, the company Acelen Renováveis was recently created and is in the implementation and formalization phase of partnerships, which should produce state-of-the-art renewable fuels on a global scale from raw materials of high energy value, such as Macaúba and Palm Oil. Acelen has the goal of producing 1 billion liters/year of renewable aviation fuel (SAF) and green diesel (HVO), as well as thermal energy and other high value-added co-products. In this sense, macaúba stands out for its wide adaptability, in addition to being cultivated primarily on degraded land (ACELEN, 2024).

In Tocantins there is also a need to map the occurrence of macaúba massifs, to carry out experiments, especially regarding the performance of the oil for energy purposes. In addition, there is a need for genetic studies of the species in this region and the development of more research with a view to the possibility of commercial macaúba plantations (NUNES, 2015).

Another contribution of macaúba is that it can also contribute to carbon sequestration and recovery of degraded areas. As only the fruits are removed, the carbon fixed by the species remains stored, suggesting that the carbon accumulation by these palm trees is greater than agricultural crops that are harvested annually or other 10 tree species that are harvested more regularly by total removal or of a large part of their total biomass (TOLÊDO, 2010; MOREIRA, 2019).

In this context, the present study aimed to evaluate the bioenergetic potential of natural populations of macaúba in the central region of the state of Tocantins.

METHODOLOGY

FIELD OF STUDY

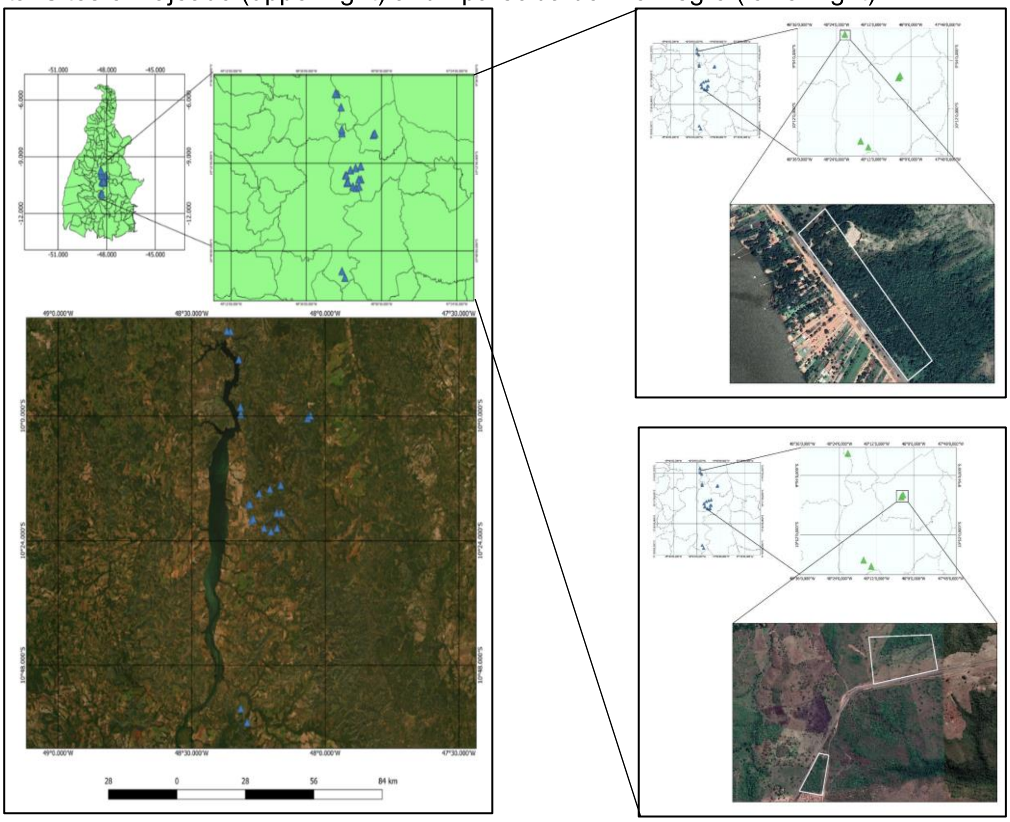
The selected study areas are located in the central region of the state of Tocantins, delimited by the geographic coordinates of 9°40'06''S to 11°20'69''S latitude and 47°41'46''W to 48°50'33''W longitude (Figure 1). Between December 2020 and February 2021, field expeditions were carried out identifying 28 areas containing natural populations of macaúba (*Acrocomia aculeata* (Jacq.) Lodd). Subsequently, in the period from September 2021 to May 2022, based on criteria that included regional representativeness and a minimum density of 50 adult plants per area, four potential experimental areas

Revista ARACÊ
ISSN: 2358-2472

located in the municipalities of Palmas, Lajeado and Aparecida do Rio Negro were selected,

For this study, from the total of 28 areas identified, two experimental sites were chosen from the four pre-selected experimental areas. Based on the criteria of different altitudes and land uses, Experimental Site A, located in Lajeado, has an area of native vegetation of dense Cerrado and an altitude of 230 m. In Experimental Site B, located in the municipality of Aparecida do Rio Negro, macaúbas develop in an area with extensive pasture (Figure 1).

Figure 1. Central region of the state, showing the areas identified with occurrences of macaúba populations and the Experimental Sites of Lajeado (upper right) and Aparecida do Rio Negro (lower right).



Source: Prepared by the authors (2024)

In these Experimental Sites, detailed characterization of the soil and the local environment was carried out, as well as morphological and biometric analyses of the macaúba populations. Measurements of palm height, diameter at breast height (DBH), number of bunches and inflorescences were carried out, as well as botanical evaluations and determination of the oil content of the fruits.

Revista ARACÊ
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ENVIRONMENTAL AND SOIL CHARACTERIZATION

The environmental characterization was based on the distribution of macaúba populations, with four geographic points marked via GPS in each Experimental Site to delimit the study areas in hectares. The coordinates were imported into QGIS using data from IBGE, SEPLAN-TO (2012) and MMA, with the objective of generating reliable thematic maps.

The environmental layers included: pedology, with soil identification based on Embrapa maps (SANTOS et al., 2018); slope, with analysis of altimetric variation in QGIS; and altimetry, with detailed mapping using Digital Elevation Model - MDE Alos Palsar (resolution of 12.5 m). For the analysis of the Cerrado phytophysiognomy, the integration of remote sensing data and field observations was carried out. The *on-site description* included predominant vegetation and land use, differentiating areas of agriculture, pasture, native vegetation and anthropized zones.

For soil characterization, soil samples were collected at each Experimental Site according to the methodology established in the IBGE Technical Manual of Pedology (2015). The chemical and physical analyses of the samples were conducted at the Soil Laboratory of UNITINS-AGRO.

The results of the analyses were submitted to the Shapiro-Wilk normality test, considering a significance level of 5%. Next, the descriptive analysis (mean, minimum, maximum, standard deviation and coefficient of variation) was performed, statistically analyzed using the SISVAR software. The nutrient contents were interpreted based on the limits proposed by Embrapa for different textural classes of soil (SOBRAL et al., 2015), traditionally applied to cultivated areas. However, for the purposes of this study, these same thresholds were adopted to compare native areas and areas under different types of use and management, allowing for a comprehensive and consistent analysis. Table 1 shows the thresholds used to classify phosphorus (P) and other soil chemical parameters.

Table 1. Ranges for interpretation of phosphorus (P) content in the soil as a function of clay content.

Soil P content classes				
Argila g kg^{-1}	Classe textural	Low	Medium	Adequate
---------------------mg $^{DM-3}$---------------------------				
<150	Sandy	0- 10	10,1 – 20	>20
150 - 350	Average	0 - 7	7,1 - 15	>15
350 - 600	Clay	0 - 4	4,1 - 8	>8

Source: Prepared by the author (2024) based on Sobral et al. (2015)

Table 2 presents the pH, Aluminum, Calcium, Magnesium, Potassium and Organic Matter, relating them to the levels of each one.

Table 2. Low, medium and high values that are used to interpret soil analysis results

Elements	Low	Medium	High
Organic Matter Dag $^{kg-1}$	<1,5	1,5 – 3,0	>3,0
pH	<5,0	5,0 – 6,0	> 6,0
Al cmolc dm^{-3}	<0,5	0,5 – 1,0	> 1,0
Ca cmolc dm^{-3}	<1.6	1,6 – 3,0	>3.0
Mg cmolc dm^{-3}	<0.4	0,4 – 1,0	>1.0
K mg dm-3	<30	30 - 60	>60

Source: Prepared by the author (2024) based on Sobral et al. (2015)

MORPHOLOGICAL AND BIOMETRIC CHARACTERIZATION

For characterization, a population census was conducted to count adult and young individuals and the number of fruit bunches, inflorescence, in addition to measuring the diameter at breast height (DBH) and recording the presence of thorns. The height of the palm trees was estimated using the Measure Height application, whose accuracy was validated by previous studies (BRITO NETO; BARRETO; PRADO, 2016; OLIVEIRA, 2018).

Regarding the performance of biometric analyses, the fruits fallen to the ground were collected, which were bagged and identified according to the matrix of origin. The sampling consisted of five fruits of each plant, selected from five palm trees from each Experimental Site.

In the laboratory, the following parameters were evaluated: fruit length and diameter (in mm), in addition to the total mass of the fruit, the peel (epicarp), the pulp (mesocarp), the endocarp and the almond (endosperm), all expressed in grams (g). Length and diameter measurements were performed with a high-precision caliper, and weighing was performed on a properly calibrated semi-analytical balance.

In order to verify the variability between the data obtained, they were analyzed using the SISVAR software, and the position measures (mean, minimum and maximum) and the dispersion measures (standard deviation, coefficient of variation) were calculated.

The botanical identification of the macaúba species was carried out according to the methodology adopted by the HUTO Herbarium of the State University of Tocantins (UNITINS). The collection of botanical samples was carried out in two palm trees per Experimental Site, and the samples were sent to the HUTO Herbarium for herborization and subsequent taxonomic analysis. After the preparation of the material, it was submitted to specialists for confirmation and definitive identification. To ensure taxonomic accuracy, the HUTO Herbarium sent the samples to the Herbarium of the Agronomic Institute of Campinas (IAC), recognized for the presence of palm tree specialists.

OIL EXTRACTION AND ANALYSIS

The methodology involved the collection of fallen fruits from seven palm trees per area, totaling 2 kg per palm tree. The fruits were stored in bags labeled with date, place and identification of the palm tree, and frozen for further processing. The extraction of the oil followed the Bligh method; Dyer at the Lasor Laboratory of UFT, using 2 g of pulp and nuts per dried and ground sample. After the addition of solvents (chloroform, methanol and distilled water), the mixture was stirred and the layers separated, then filtered. The oil was recovered after evaporation of the solvent in an oven at 80 °C and final weighing to calculate the percentage of lipids.

The experiment followed a factorial design with three factors: collection site (Site A and Site B), part of the fruit (mesocarp and endosperm) and extraction time (30 and 60 minutes), totaling eight treatments with seven replications each. The data were statistically analyzed by ANOVA to verify the significance of the factors and their interactions in the percentage of oil extracted. The F-test was applied at 5% significance, and the means were compared using the Scott test; Knott. The analyses were carried out with the AgroEstat software of UNESP, allowing the evaluation of the dispersion and the central tendency of the results obtained.

RESULTS AND DISCUSSION

ENVIRONMENTAL AND SOIL CHARACTERIZATION

In Site A, the vegetation is characterized by the predominance of the tree stratum, while the shrub and herbaceous strata present less expressiveness. The more open canopy allows greater incidence of light in the palm tree crowns, directly influencing their development. Unlike areas of dense forest, where palm trees grow in height to compete for light, in this more exposed environment, their vertical growth is reduced. This lower light competition also contributes to the coexistence of typical plant species from different strata, increasing plant diversity, even if the tree stratum is dominant

Revista ARACÊ
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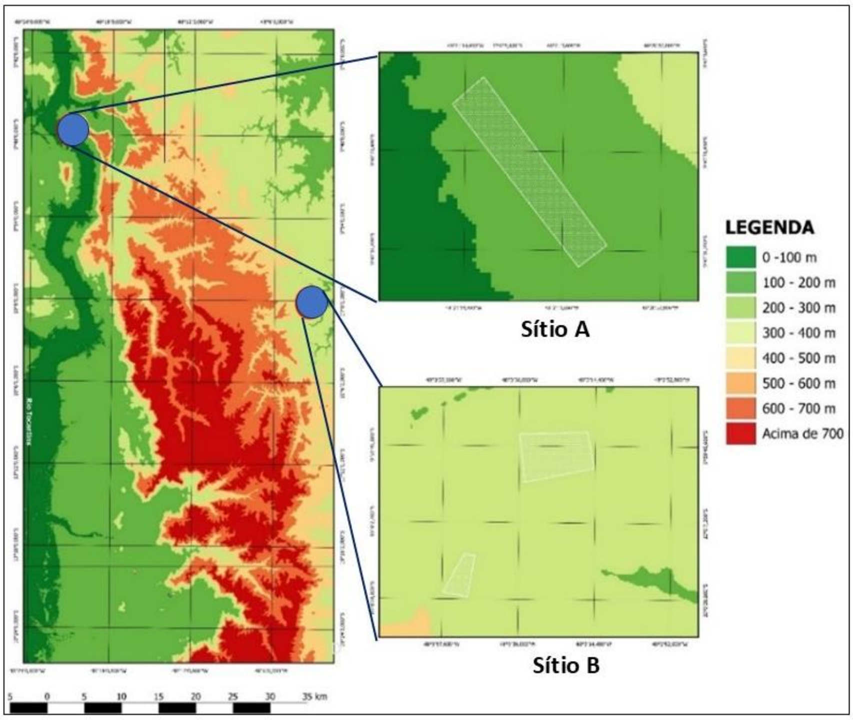
Therefore, Site A represents an example of how variations in canopy density and light input influence the structure and dynamics of plant communities, reflecting the Cerrado's ability to adapt to different environmental conditions. Macaúba was also recorded in this place in the study by Alves; Carvalho (2010), who observed the occurrence of the species in various types of phytophysiognomies, such as Cerrados, Cerrado Fields, Gallery Forests, Slope Forests and Rupestre Fields (Transition between Cerrado and Atlantic Forest).

Experimental Site B is in a pasture environment bordering a stony cerrado stricto sensu. The pasture present in this area has brachiaria species, already emitting floral tassels, and the cattle were recently removed, being a more thinned pasture. The macaúba palm trees are more dispersed throughout the territory. There is no report of any other species of palm tree in this site, being macaúba the only palm tree in the region. In the studies conducted by Teles et al. (2011) and Sousa (2020), the occurrence of a macaúba population (*Acrocomia aculeata* (Jacq.) Lodd) in pasture areas. This data is relevant because it demonstrates the ability of this native palm tree to adapt to environments modified by agricultural activity.

The hypsometric analysis carried out in Experimental Sites A and B, as represented in Figure 2, reveals distinct and significant altimetric characteristics for environmental and agricultural studies. The map was prepared based on a Digital Elevation Model (DEM), allowing the identification of eight distinct altimetric classes, with altitude variations between 100 m and 700 m.

Revista ARACÊ
ISSN: 2358-2472

Figure 2 - Hypsometry in the regions of Experimental Sites A (Lajeado) and B (Aparecida do Rio Negro)



Source: Prepared by the authors (2024)

Site A, located near Serra do Lajeado, had the lowest altitude among the sites, with an average elevation of 230 m. This proximity to the base of the mountain directly influences the topography of the area, resulting in a lower slope and a smoother relief.

On the other hand, Site B stood out for having the highest altitude, with an average of 390 m. This higher elevation implies a more rugged topography and a higher slope, which can pose additional challenges for agricultural management and soil conservation. However, the higher altitude can also favor better natural drainage and a milder microclimate.

When studying the natural occurrence of macaúba in Minas Gerais, Teles et al. (2011), found macaúbas at altitudes ranging from 600 m to approximately 800 m. They also reported that in the state of Minas Gerais there is a reference indicating that macaúba can occur at altitudes of up to 950 m. Other studies indicate that the altitude margin that the macaúba can be found varies from 150 to 1000 m (SILVA et al., 1986; COSTA, OLIVEIRA, COSTA, 2018), with the two Experimental Sites of the present work, within the range of occurrence of macaúba.

The soils analyzed in the respective Experimental Sites presented, on average, according to the result of the physical analysis (texture) of the soil and according to

Atterberg's textural triangle, the classification in the textural class loam-clay-sandy (Table 3).

And so, this type of soil present in the Experimental Sites is characterized by the highest occurrence of sand, followed by clay and silt. This gives the soil good drainage, allowing for water infiltration and proper aeration, while also retaining nutrients that are essential for plant growth. The presence of clay offers good water and nutrient retention capacity, while sand promotes permeability. This combination makes the soil conducive to the development of a diversity of plants, including macaúba, which prefers well-drained soils with good nutrient availability (SANTOS et al., 2018).

Table 3. Average values of the physical analysis of the soil in the 0-20 cm layer, in experimental sites with natural occurrence of macaúba.

Experimental Site	Sand	Silt	Clay	Classe textural
	g kg-$^{-1}$			
The	700,90	77,00	222,10	Clay-clay-sandstone loam
B	539,49	115,85	344,65	Clay-clay-sandstone loam

Source: Prepared by the authors (2024)

The results of the chemical characterization of the soils of the sites, considering the two depths, are represented in Tables 4 and 5. To evaluate the soil contents, a comparison was made with the thresholds proposed by Embrapa (SOBRAL et al., 2015) and the results obtained in this work.

In Site A, the phosphorus contents are low, with averages of 1.38 mg.dm³ (0-20 cm) and 1.22 mg.dm³ (20-40 cm), while in Site B, there is a greater variation, with averages of 2.09 mg.dm³ and 1.93 mg.dm³ in the respective layers. Despite the higher levels at Site B, both sites show the need for supplementation to optimize plant growth.

Table 4. Maximum, minimum and average values of the chemical analysis of the soil in the 0-20 cm layer, in the experimental sites with natural occurrence of macaúba.

Elements	Website A			Website B			DP	CV (%)
	Max	Min	Med.	Max	Min	Med.		
P (mg.dm³)	4,76	0,55	1,38	24,28	1,21	2,09	5,87	167
Approx (cmol.dm³)	2,80	1,73	1,68	4,19	0,29	1,38	1,18	59,08
Mg (cmol.dm³)	0,47	0,13	0,89	2,42	0,01	1,17	0,68	106
K (mg.dm³)	144,67	43,01	74,29	136,85	19,55	50,83	34,99	59,18
Al (cmol.dm³)	0,36	0,04	0,18	2,31	0	1,33	0,77	125
M.O (dg.kg-^{1})	1,71	0,80	1,37	5,65	2,06	3,39	1,33	55,56
pH	4,95	4,34	4,65	5,50	3,89	4,31	0,42	9,34

Source: Prepared by the authors (2024)

Revista ARACÊ
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Table 5. Maximum, minimum and average values of soil chemical analysis in the 20-40 cm layer, in experimental sites with natural occurrence of macaúba.

Elements	Website A				Website B			DP	CV (%)
	Max	Min	Med.		Max	Min	Med.		
P (mg.dm³)	1,81	0,61	1,22		6,26	1,15	1,93	1,76	79,85
Approx (cmol.dm³)	2,80	1,73	1,59		3,75	0,35	1,16	1,04	67,92
Mg (cmol.dm³)	0,31	0,09	0,85		1,15	0,04	0,99	0,34	91.65
K (mg.dm³)	148,58	31,28	74,29		136,85	19,55	58,65	45,61	67,38
Al (cmol.dm³)	0,41	0,04	0,25		2,42	0	1,16	0,77	109,79
M.O (dg.kg^{-1})	1,51	1,00	1,21		3,39	1,32	2,38	0,74	42,06
pH	4,96	4,24	4,53		4,98	3,86	4,16	0,38	8,74

Source: Prepared by the authors (2024)

Among other functions, phosphorus acts in the processes of preservation and transfer of energy, in the stages of photosynthesis and respiration (DIETRICH, 2022). Low phosphorus availability can be a limiting factor for macaúba growth, especially in acidic soils, where phosphorus tends to become less available to plants (BARROS, 2020). Management practices that include the addition of phosphorus sources, such as natural phosphates, could be exploited to improve soil fertility in areas intended for the recovery or intensification of native macaúba populations.

The calcium contents at Site A are at adequate levels, with averages of 1.68 and 1.59 cmolc.dm³, in the layers of 0-20 cm and 20-40 cm, respectively, while at Site B, the averages were lower (1.38 and 1.16 cmolc.dm³), being considered low. Even so, the growth of the palm trees was satisfactory at Site B, suggesting an adaptation to local conditions. Reasonable amounts of calcium are advantageous for macaúba plants, as they help neutralize soil acidity and stability the cation exchange complex, promoting root growth. In regions where macaúba is native, these levels may be acceptable, but in more acidic soils, it may be necessary to add calcium to improve soil conditions and plant health (VILLAR, 2007).

As for magnesium content, Site A has averages of 0.89 and 0.85 cmolc.dm³ for the layers studied, being considered moderate, while in Site B, the contents are more variable, with averages of 1.17 and 0.99 cmolc.dm³, indicating that some areas may have deficiencies. When macaúbas are deficient in magnesium, it can cause reduced growth, and in this condition, the new leaves do not develop and the presence of generalized chlorosis is observed in the plant, similar to N deficiency (MOTOIKE et al., 2013; PIMENTEL et al., 2022).

The potassium contents at Site A are high, with an average of 74.29 mg.dm³, while at Site B they vary widely, with averages of 50.83 mg.dm³, classified as moderate. This shows that the availability of potassium in the soil is sufficient for the development of macaúba populations, especially in the surface layers. Potassium levels are good, especially in the surface layer, which is a positive indicator, as potassium is vital for several physiological functions of plants (BARROS, 2020). This is explained in the work of Dietrich (2020), where the presence of potassium at moderate to high levels favored the development of macaúba populations, especially in the most superficial layer of the soil, where the roots are more active in nutrient absorption.

Aluminium levels are low at Site A (0.18 and 0.25 cmolc.dm³), but higher at Site B (1.33 cmolc.dm³). Excess aluminum can be toxic to plants, especially in acidic soils, impairing root growth. Although the levels observed at Site B are higher, aluminum is still present in amounts that may pose a risk to plants, especially in conditions of high acidity. This suggests that, despite the adaptation of native populations to soil acidity, measures to mitigate the effects of aluminum, such as liming, could be beneficial, especially in more acidic soils.

The pH at both sites indicates high acidity (strongly acidic): Site A has averages of 4.65 and 4.53, and Site B, 4.31 and 4.16, for the 0-20 cm and 02-40 cm layers, respectively. These values were similar to three areas with macaúba studied by Teles et al. (2011), in the Cerrado, in the central and southern regions of the state of Goiás. This acidity can limit the availability of nutrients and increase the toxicity of aluminum, requiring possible corrections with limestone.

Finally, the organic matter contents at Site A are low to moderate, with averages of 1.37 and 1.21 dag.kg^{-1}, while at Site B they are higher, with 3.39 and 2.38 dag.kg^{-1}. The high organic matter at Site B improves soil structure and fertility, partially compensating for the high acidity.

Site B has higher overall fertility, with emphasis on phosphorus, magnesium and organic matter, but suffers from high levels of aluminum and acidity. Site A, in turn, presents less variation in nutrients, but more stable calcium and potassium contents, with a lower risk of aluminum toxicity. Both require differentiated management to optimize the sustainable use of native areas and maximize the productivity of macaúba populations.

MORPHOLOGICAL CHARACTERIZATION

Experimental Site A, with an area of 8.98 hectares, is home to 117 plants, of which 83 are adults and 34 are young, with a density of 13 plants.ha-1. The average height of the

Revista ARACÊ
ISSN: 2358-2472

plants is 5.76 meters, and only one plant showed inflorescence, resulting in an average of 1 bunch per plant. The diameter at average breast height (DBH) of the plants was 17.75 cm. The significant presence of plants without thorns (72), corresponding to 61.5%, in relation to plants with thorns (45), is remarkable, which can influence the management of the area, especially in harvesting and maintenance (Table 6).

Table 6. General characteristics of macaúba plants in Experimental Sites A and B.

Place	Plant Numbers			Plants/ha	Average height (m)	N0 plants with inflorescence	Average curls/pl	DAP (cm)	Presence of thorn - stipe	
	Adult	Young	Total						With	Without
A	83	34	117	13	5,76	1	1	17,75	45	72
B	90	5	95	3,5	6,36	0	2	19,86	10	85
Total	173	39	212	-		-	-	-	55	157

Area of Site A = 8.98 ha and Site B = 27 ha
Source: Prepared by the authors (2024)

The amount of young plants (29% of the total) observed at Site A suggests an active regeneration process, possibly due to plant diversity and the native environment and ecological stability, but also requires attention to management practices that minimize competition between plants and promote uniform development.

Site B has a significantly larger extension, with 27 hectares, and a population of 95 plants, 90 of which are adult and only 5 young, representing a density of only 3.51 plants.ha-1. The average height of the plants is 6.36 meters. None of the plants showed inflorescence, but there is the presence of 2 bunches, which suggests a limited reproductive potential at the time of analysis. The average DBH of 19.86 cm reflects more robust plants compared to Site A. Of the total of 95 macaúba palm trees, 85 plants do not have thorns in their stem, representing an occurrence of about 90%, higher than that of Site A, which was 61.5% (Table 6). Figure 3 shows the differences in the existence of thorns in the stems of macaúba palm trees.

Revista ARACÊ
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Figure 3. Stem of macaúba palm tree with thorns (A) and stem without thorns (B)

Source: Authors' Archives (2022)

Nobre et al. (2015) found that the heights of the macaúbas present in the municipality of Coração de Jesus-MG, varied from 5.82 and 17.02 m, this is possibly linked to the age of the palm trees, because in this work it was reported that they are older palm trees, unlike the present study, which reported the predominance of young palm trees. In the book Harri et al. (2006), they describe that the macaúba has an average height of 10 to 15 m. In the Flora and Funga of Brazil, from the Botanical Garden of Rio de Janeiro, Vianna; Campos-Rocha (2020), observed heights in the range of 5 to 15 m.

In the work of Machado (2018) explains that *A. aculeata* presents phenophases, that is, the time taken from the formation of the fruit, from the appearance of the sheath to the formation of the fruits, causes the population and individuals to have at the same time ripe fruits falling and bunches with green fruit that will ripen only in the other cycle.

The low presence of young plants (5% of the total) may indicate conditions less favorable to regeneration, possibly associated with higher altitude and greater slope, or even due to land use, as in the case of palm trees associated with pastures. This scenario implies the need for interventions to ensure population sustainability and the natural renewal of species. In addition, the lower number of plants with thorns (10) compared to those without thorns (85), in the case of palm harvesting, would facilitate management and harvesting practices, which can be advantageous in operational terms.

According to Cardoso's work; Rodrigues; Santos (2016), where they evaluated the life cycle of macaúba oil, reported palm trees that produce 5 bunches of fruits in a population with a density of 351 plants.ha-1, unlike this work that was developed in natural massifs, where a smaller number of bunches was observed, as well as a very low population density. According to the work of Nobre et al. (2015), native macaúba palms in

Revista ARACÊ
ISSN: 2358-2472

the north of the State of Minas Gerais were evaluated, where the number of bunches per plant ranged from 2 to 6, with an average of 4 bunches per plant. These same authors and Silva (2007) explain that the characterization and comparison of results in the species face significant challenges due to the heterogeneity of the material found under natural conditions. This difficulty is amplified by the expressive genetic variability and the unevenness in the age of the palm trees, factors that compromise the accuracy in the morphometric comparison. In the bibliographic study by Nobre et al. (2014), they also report that these factors mentioned above make the native populations have low total productivity, and considerably increase the work of harvesting the fruits, since they have uneven maturation. And in the study by Berton (2013) he complements by reporting that environmental factors such as fires, rainfall or other conditions unfavorable to pollination can also be some of the causes of oscillation in fruit production.

Figure 4. Plants with fruit clusters observed in the two experimental sites, the one on the left located at Site A and the one on the right at Site B

Source: Authors' Archives (2022

Franco (2019), conducted experiments, consortium of macaúba and coffee, to evaluate the frequency of fruit fall at the Teaching, Research and Extension Unit (UEPE), of the Federal University of Viçosa (UFV), in Viçosa – MG, the number of bunches per palm tree observed ranged from 3 to 6, with a single plant having six bunches. In relation to the inflorescence, the result is due to the phenology of the species and dates of the study that took place in different phases.

Montoya et al. (2016), explain that the macaúba fruit has a double sigmoid growth curve and supra-annual development. Resende et al. (2020) also add that, due to the long period required, the growth and development of fruits, in the same location, occurs throughout all seasons of the year, so that the fruit, in its life, will suffer considerable variations from isolated climatic factors, mainly atmospheric temperature, precipitation and water availability.

The differences between the two sites in terms of area, plant density and morphological characteristics, considering a possible extractive exploitation, suggest the need for different management strategies. Site A, with a higher proportion of young plants and a lower average height (5.76 m), may be suitable for growth control and pest management interventions. Site B, on the other hand, with more robust plants and less regeneration, requires special attention to ensure the long-term sustainability of the plant population.

Regarding the botanical identification, the macaúba plants collected for study were confirmed, that is, they are *Acrocomia aculeata* (Jacq.) Lodd, and are distributed in the two experimental sites. And this can be explained by the research by Lima et al. (2020), where the macaúba populations that were studied were mostly those of the *species A. aculeata* than in other species of macaúba. This observation among macaúba species may be the result of the wider geographic distribution of *A. aculeata,* associated with the low diversity of other macaúba palm species.

From then on this identification by the specialists, the information from these materials collected in the Experimental Sites, deposited in the herbariums, generated an improvement in information on the diversity of the regional flora. Medeiros et al. (2022), highlight the importance of Regional Flora, which contribute to the knowledge of the Brazilian Flora, highlighting that monographic works with specific families are fundamental to update global information. The authors also point out that herbaria play an essential role in this context, being indispensable for studies related to flora and constituting a basis of support for research in various areas of knowledge.

And with this, the registration of species in botanical collections in herbaria becomes one of the tools used in the construction of maps of occurrences and geographical distribution of species (PROCÓPIO; SECCO, 2008). In view of this, in consultation with the *SpeciesLink* website, which is a platform that provides data from herbaria in Brazil and other countries, the samples of *Acrocomia aculeata* (Jacq.) Lodd. are deposited in 54 herbariums, with 290 records of the species in these herbariums. The highest records are in the SinBiota (SP), CEN (Brasília), UnB (Brasília) and IAC (SP) Herbariums.

Revista ARACÊ
ISSN: 2358-2472

Considering the descriptive statistics of the 07 quantitative characteristics analyzed in this study, in the two Experimental Sites, it is observed in Table 7 that the coefficient of variation (CV%) ranged from 8.03% for the leaf width (LAR) to 41.58% for the weight of the fresh mesocarp (MEF). Silva et al. (2020), analyzed 41 quantitative morphoagronomic descriptors used in the characterization of the species *Acrocomia aculeata* in three collection locations located in Minas Gerais and São Paulo, and also found a wide range of records of the coefficient of variation (CV) of the plants, which ranged from 5.1 (fruit length) to 60.0% (number of calyx scar in the female region of the rachilla in the apical portion of the bunch).

Table 7. Maximum (Max), minimum (Min), mean (Average), standard deviation (SD) and coefficient of variation (CV) values for fruit length (COM), fruit width (LAR), fruit weight (WEIGHT), fresh fruit peel (CAF), fresh mesocarp (MEF), fresh endocarp (EDF) and endosperm (ENF)

Biometrics	Site A					Site B				
	Max	My	Med.	CV (%)	DP	Max	My	Med.	CV (%)	DP
COM (mm)	43,00	32,00	38,16	8,43	3,22	40,00	27,00	32,49	9,39	3,50
LAR (mm)	42,00	31,50	37,56	8,03	3,01	37,00	25,00	31,78	8,29	2,63
WEIGHT (g)	38,34	16,20	27,75	22,82	6,33	26,83	9,13	15,21	26,61	4,04
CAF(g)	8,76	2,73	5,16	32,04	1,65	6,33	2,41	3,57	24,87	0,89
MEF (g)	16,39	5,01	10,42	27,45	2,86	10,90	2,20	5,28	41,58	2,19
EDF (g)	13,26	4,20	9,31	27,15	2,53	7,32	3,41	4,89	18,25	0,89
ENF (g)	3,25	1,42	2,20	24,88	0,55	1,30	0,62	0,97	20,73	0,20

Source: Prepared by the authors (2024)

Regarding the biometry of macaúba fruits, it was observed that in Site A, all the averages of the metrics of the fruits analyzed stood out in relation to those of Site B (Table 7). The average fruit length and average fruit width at Site A corresponded to 38.16 mm and 37.56 mm, respectively, with lower coefficients of variation. In addition, the average weight of the fruits was also higher, reaching 27.75 g, ranging from 38.34 g to 16.20g, equivalent to an amplitude of 22.14g and CV = 22.82%, demonstrating high variability for this trait. When compared to the results obtained by Silva et al. (2020), it can be seen that this value is lower than those obtained in Rifaina – SP, Campinas – SP and Luz – MG, which were 37.31g, 38.86g and 57.71g, respectively. However, the maximum weight found

Revista ARACÊ
ISSN: 2358-2472

in the present study (38.34g) is similar to the values observed in São Paulo by Silva et al. (2020).

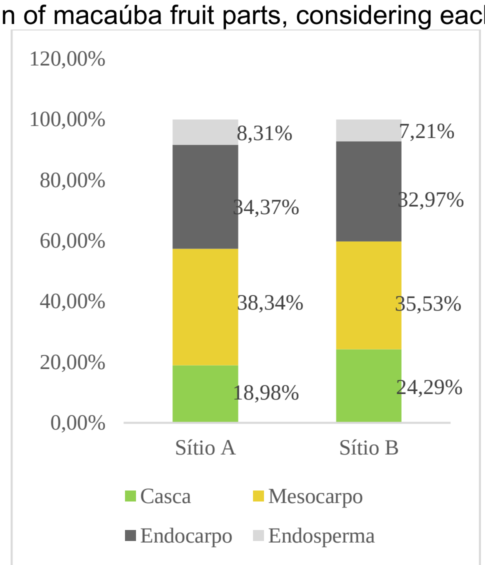
Montoya's study; Motoike; Kuki (2009), who analyzed the development of macaúba fruits in the region of Acaiaca - MG, maximum mean values of 46.0 mm in length and 52.0 g in weight were obtained, also presenting results higher than those observed in this work.

The research by Viroli et al. (2021), carried out in the municipality of Paraíso do Tocantins - TO, recorded fruits with a length of 36.5 mm and a width of 41.8 mm, which are similar to the biometric data obtained in the present study.

The weight of the mesocarp, which is the main source of oil, found at Site A, was 10.42g, being twice the value of Site B, revealing it as a potential for oil removal. The endosperm also showed a higher value, with an average of 2.20g. In addition, the average weight of the bark observed at Site A was 5.16 g, surpassing that of Site B, with a CV = 32.04%, considered high, which demonstrates the variability regarding the uniformity of this characteristic, ranging from 2.73g to 8.76g.

Figure 5, presented under a stacked bar graph, shows the percentage distribution of the parts of the macaúba fruit (peel, pulp, endocarp and seed) in the two distinct sites.

Figure 5. Proportion of macaúba fruit parts, considering each Experimental Site



Source: Prepared by the authors (2024)

Site A stands out for having the highest proportion of mesocarp, with 38.34%, indicating a high potential for oil extraction. On the other hand, it is the place with the lowest proportion of bark, only 18.98%, which can result in less waste generation during processing. This profile makes Site A especially attractive for oil production, given the significant volume of pulp available.

Revista ARACÊ
ISSN: 2358-2472

In contrast, Site B has the highest proportion of bark, with 24.29%, and the lowest proportion of endosperm, only 7.21%. This composition can impact the economic use of the fruit, reducing the amount of oilseed pulp and increasing the production of waste. However, this high proportion of bark can be harnessed for other applications, such as biomass production or composting.

In the work developed by Alves (2022), he obtained the proportion of pulp in the fruits of 4 populations of macaúba, ranging from 35.8 to 52.4%, and of endosperm within the range of 5% to 10.8%, whose values are similar to the results of the present study. Silva et al. (2022) observed in three natural macaúba massifs located in São Paulo and Minas Gerais, higher proportions of mesocarp/fruit, ranging from 46% to 48.2%, and lower endosperm proportions from 4.1% to 4.4%.

Thus, comparing the two experimental sites, the fruits of Site A stand out as more promising for the production of macaúba oil, due to the superiority in almost all biometric parameters, especially in the weight of mesocarp and endosperm. On the other hand, in Site B, the fruits can be used for other purposes, but with less potential for economic exploitation of oil compared to Site A. The management aimed at extractive exploitation in both sites can be optimized to increase efficiency and productivity, especially considering nutritional corrections.

BIOENERGETIC POTENTIAL: OIL CONTENT

Regarding the analysis of the oil content of macaúba fruits, considering the two experimental sites, significant differences were observed between the collection sites, highlighting that it was the only factor with a significant effect (Table 8).

In this case, Site A (Lajeado, with natural vegetation) presented an average oil content of 30.85%, which is higher than the 20.73% of Site B, suggesting that environmental conditions influence the extraction. However, when the fruit parts (mesocarp and endosperm) and the extraction time (30 and 60 minutes) were compared incorporating data from the two sites of a general nature, they did not show significant differences in oil yield.

Revista ARACÊ
ISSN: 2358-2472

Table 8. Average oil contents (%) obtained from macaúba fruits in Sites A and B, considering the collection sites, parts of the fruit and the extraction time.

Local	Medium content Oil (%)	Part of the fruit	Average oil content (%)[1]	Extraction time (min)	Average oil content (%)[2]
Website A	30.85 to	Mesocarp	26.08 to	30	26.40 to
Website B	20.73 b	Endosperm	25.50 to	60	25.18 to

Distinct letters inserted next to the values indicate significant differences ($p < 0.05$).
[1] Overall average oil content of each part of the fruit involving Sites A and B
[2] Overall average oil content of each extraction time involving Sites A and B
Overall average: 25.79% and CV: 16.22%
Source: Prepared by the authors (2024)

The results of the mesocarp oil content, obtained by Silva et al. (2020), carried out in two municipalities in the state of Campinas and Rifaina, were 30.42% and 33.20%, exceeding the value found in this work.

Trentini et al. (2017) analyzed the extraction of oil from macaúba pulp by pressurized liquid extraction (PLE), using ethanol and isopropanol as solvents. The maximum yields achieved were 44.78% with ethanol and 37.12% with isopropanol at 60 °C, equivalent to about 77% of the yield of the Soxhlet method, but in less time and with lower solvent consumption. The process reached maximum yields in just 62 minutes.

In the study by Rosa et al. (2019), developed in the State of Paraná, considering the extraction of *Acrocomia aculeata* oil by the UAE methodology from the endosperm, it resulted in a yield of up to 40.61%, and by the Soxhlet method it obtained 51.17%. Magalhães et al. (2020), in Minas Gerais, obtained an average endosperm oil yield of 30%, and all these studies were higher than those obtained in the present study.

The oil extraction carried out by Rosa et al. (2019), using the UAE methodology from the endosperm, resulted in a yield of up to 40.61%, while Magalhães et al. (2020) obtained 30%. These values are higher than those obtained in this study, where the extraction resulted in an average endosperm oil content of 25.50%.

According to Silva (2023) on the oil contents of macaúba (*Acrocomia aculeata*) revealed that the mesocarp of the fruits presented contents ranging from 52.36% to 66%, while the almond presented values between 37.86% and 49.98%. The author evaluated both ripe and immature fruits, and found that ripe fruits had a higher oil content compared to immature ones.

Soletti (2016) considering the extraction time (3 and 6h), associating the use of two solvents (Hexane - HEX and Isopropanol - ISO) and extraction method (standard Soxhlet -

ISSN: 2358-2472

SP and Continuous extraction - EC) in *Acrocomia intumescens*, it was always higher average oil content, with longer extraction time ranging from 33.40% to 38.51%. The two treatments with superior results were the combination 6h-HEX-SP, with an average oil content of 36.33%, and 6h-ISO-EC, with 38.51%.

Comparing the results regarding the average oil contents, from other authors, with those obtained in the present study, it is highlighted that in general they were more modest, suggesting according to Soletti (2016), that environmental variations, climatic, soil type, the age of the palm tree, the reproduction cycle, the collection period, the handling of the fruits and several other factors, in addition to the methodology that can influence the results.

CONCLUSION

The analysis of natural populations of *Acrocomia aculeata in the* central region of Tocantins showed the wide adaptability of the species in natural areas of the Cerrado and in extensive pasture conditions, which allows it to develop in different environments, soils, climatic conditions and land uses.

The results obtained indicate a bioenergetic potential, with emphasis on Site A, located in Lajeado, which presented a higher average oil content in relation to Site B, in Aparecida do Rio Negro.

There was no significant difference between the average oil content of the mesocarp and the endosperm, nor in relation to the extraction time.

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