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Nutrients content, characterization and oil extraction from *Acrocomia aculeata* (Jacq.) Lodd. fruits

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Proximate composition, physical and chemical analysis of the pulp, kernel and oils of *Acrocomia aculeata* (Jacq.) Lodd. were investigated. The macauba pulp and the kernel represented 49 and 6.25% of the mass of the whole fruit, respectively. The main components present in the pulp and kernel are lipids (23.62 and 46.96%) and fibers (13.89 and 15.81%). Furthermore, the mineral analysis showed that the kernel had more micronutrients than pulp, principally Cu, Mn and Zn. The influence of extraction by pressing and Soxhlet extractor in different solvents regarding the quality and yield of the oils was evaluated. The highest yield in oil extraction was obtained by Soxhlet method, influenced by the type of solvent and part of macauba's fruit. For pulp, the better solvent is ethanol and ethanol 95%, and for kernel is ethanol, ethanol 95%, hexane and ethyl either. The analysis of the composition of fatty acids in the oil from the pulp and kernel showed that the monounsaturated fatty acids were predominant in the pulp oil, specially the oleic acid (C 18:1), and saturated fatty acids in the kernel oil, principally the lauric acid (C 12:0).

Key words: *Acrocomia aculeata* (Jacq.) Lodd., macauba oil, pulp, kernel, proximate composition, nutritional components, fatty acids.

INTRODUCTION

One of the major biomes of Brazilian biodiversity is the Cerrado, which harbors many native fruit trees and immense biological wealth, because of its climatic nuances and varied soils (Klink et al., 2005). In recent years, more than half of the Cerrado has been changed by deforestation (Ratter et al., 1997; Verburg et al., 2014). The exploitation of natural resources of this biome increases each year, therefore researchers have been increasingly seeking to study the potential of native plant species, for the development of new products, in order to foster a greater appreciation of plants with therapeutic effects and of fruits with important nutritional properties (Silva et al., 2009a). The macauba *Acrocomia aculeata* (Jacq.) Lodd., has a potential pharmaceutical, foodstuff and chemical applications among the fruit bearing species. *A. aculeata* (Jacq.) Lodd. is a palm tree belonging to the Arecaceae family (Caldas-Lorenzi et al., 2006), popularly known as macauba, bocaiuva, cocobabão, bacauva, mocajuba and macaiba.

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It is found in tropical regions and is abundant in the Brazilian Cerrado (Hiane et al., 2006). It bears fruit between the months of September and January depending on climatic conditions, planting site and maturation (Dessimoni-Pinto et al., 2010).

Macauba fruit is composed of epicarp, mesocarp, endocarp and endosperm. In the harvest time, the epicarp presents a yellowish color and an orange mesocarp or pulp.

The endocarp is hard and dense to protect the kernel, which is coated with a thin brown integument, and makes up the edible portion together with the pulp (Chuba and Sanjinez-Argandoña, 2011).

Pulp and kernel are consumed *in natura* or in ice creams, pastries, cakes and biscuits (Hiane et al., 2006; Bora and Rocha, 2004; Ramos et al., 2008). In the medicine folk, fruits of the macauba palm are used in the treatment of cardiovascular diseases and vitamin A deficiencies because of its high carotenoid content (Ramos et al., 2007).

Also, macauba contains galactoglucomannan which is a polysaccharide, reported to be a therapeutic agent in the prevention of inflammatory processes (Silva et al., 2009b).

Another interesting aspect of the fruit is the oleaginous potential. It can produce ten times more oil mass per hectare than traditional oilseed crops, such as soybeans (Roscoe et al., 2007). This potential makes its use beneficial in food products, pharmaceuticals, cosmetics, as well as in bioenergy.

Therefore, characterization of the fruit is interesting to improve its applicability. Considering this, the work aimed to characterize the fruit of *A. aculeata* (Jacq.) Lodd. regarding its biometric characteristics, nutritional composition and the physical and chemical properties of the pulp, kernel and oils.

MATERIALS AND METHODS

Harvesting and storage of fruits

Ripe fruits of *Acrocomia aculeata* (Jacq.) Lodd. were collected in the *Fundação MS,* in Maracaju, MS, Brazil latitude 21°36'52" and longitude 55°10'06", at an altitude of 384m, between December 2011 and January 2012, and transported to the Laboratory of Food Technology of the Federal University of Grande Dourados (UFGD). Fruits were selected to obtain a uniform batch regarding size and absence of injuries, and they were washed and sanitized with a solution of 0.66% sodium dichloroisocyanurate dihydrate (content of active chlorine 3%). Afterwards they were peeled, pulped, deseeded, and stored at -5°C until the use.

Physical and chemical characterization of fruits

The longitudinal and transversal diameters of 100 fruits were determined with the aid of a digital caliper (Mitutoyo). The mass of the whole fruit, peel (epicarp), pulp (mesocarp), endocarp and kernel, was determined in an analytical balance (Shimadzu-AUY220). Pulp and kernel were analyzed according to their pH, determined digital potentiometer, total soluble by solids, by refractometry, total titratable acidity, determined by titration with a solution of 0.1 N NaOH, moisture, by gravimetry in an oven at 105°C until constant weight, lipid content, determined by the Soxhlet method, ash, by gravimetry in a muffle furnace at 550°C, and carbohydrates according to the methods described by the Adolfo Lutz Institute (Lutz, 2008). Crude fiber was quantified by acid and alkaline hydrolysis and protein content by quantifying total nitrogen, determined by the microKjedahl method (AOAC, 1984).

Mineral levels were evaluated according to the methodology described by Salinas and Garcia (1985). The samples were crushed and homogenized, followed by organic digestion using a mixture of hydrochloric acid and hydrogen peroxide, both concentrated, at high temperatures, solubilizing macro and microelements. The elements were quantified by spectrometry, using the standard curve for each mineral. Concentration of calcium, iron, magnesium, manganese, zinc and copper were determined with an atomic absorption spectrophotometer (Varian-AA240FS) and acetylene gas.

Extraction and physical and chemical characterization of oils

The pulp and kernel were previously dehydrated at 40°C in a dryer (NG Scientific) with an air flow of 0.5 ms^{-1} for 72 h. The extraction of oil from the pulp and kernel was accomplished by two methods: (a) cold pressing in an "expeller" type press, model MPE-40P (Ecirtec) and the resulting oil centrifuged at 5000 rpm for 15 min; (b) by Soxhlet extraction, using different solvents (ethanol, ethanol (95%), methanol, ethyl ether, petroleum ether, hexane and acetone). The yields of both extraction methods were evaluated to evaluate the yield of extraction (Brumm et al., 2009).

The physical and chemical characterization of oils according to their density, iodine value, refraction index and acidity index, were carried out by official methods (AOAC, 1984) and standards of the Adolfo Lutz Institute (Lutz, 2008). To determine the viscosity of the oils, a Brookfield (Model LVDVIII +) viscometer was used equipped with a cylinder that has a Spindle of reference SC4-18. The viscometer was coupled to a thermostatic bath, which enabled measuring the viscosity of the oils at 40°C, with an accuracy in temperature of 0.5°C (Brock et al., 2008).

Characterization of the fatty acids, present in the oil, was carried out by the transmethylation. The reaction was performed according to the Hartman and Lago method (1973), using an ammonium chloride and sulfuric acid solution in methanol as esterifying agent. The treated samples were analyzed by a gas chromatograph (HP-6890), equipped with automatic sampler (HP-7683); split injector, 75:1 ratio; CP-SIL 88 capillary column (100 m x 0.25 mm i.d., 0.20 mm of film); and flame ionization detector (FID). The chromategraphic conditions were as follows: initial temperature of 120°C/2 min, heating from 120 to 220°C on a scale of 2.2°C/min and from 220 to 235°C; hydrogen carrier gas (flow rate of 1 ml/min); make-up gas, nitrogen at 30 ml/min; injector temperature of 270°C; detector temperature of 310°C; injection volume of 1 ml. The identification of fatty acids was performed by comparing the standard retention time of fatty acids with those of the sample. The quantification was performed by area normalization and the results were expressed in g/100 g of sample.

Statistical analysis

The results of oil extraction yields from the pulp and kernel of the macauba palm were submitted to analysis of variance (ANOVA), and to compare the means, the Tukey test was used ($p< 0.05$).

RESULTS AND DISCUSSION

Physical and chemical characterization of fruits

Table 1 shows the biometric characteristics of the fruits. The transversal and longitudinal diameters characterize the macauba as a rounded shape. The pulp represented 49%

Table 1. Biometric characteristics of the *Acrocomia aculeata* (Jacq.) Lodd. fruits.

Biometric characteristic	Present work	Reference Values	
		Hiane et al. (2006)	Chuba et al. (2011)
Transversal diameter (mm)	34.17 ± 2.32	-	33.39 ± 1.26
Longitudinal diameter (mm)	34.68 ± 2.62	-	34.68 ± 1.55
Whole Fruit (g)	22.07 ± 3.69	21.83 ± 2.48	21.83 ± 1.49
Peel (g)	4.22 ± 1.00	4.68 ± 1.07	4.54 ± 0.48
Pulp (g)	11.00 ± 2.19	9.61 ± 1.17	8.98 ± 1.07
Seed (g)	5.36 ± 0.97	6.72 ± 1.23	8.31 ± 0.61
Kernel (g)	1.38 ± 0.44	0.83 ± 0.23	1.35 ± 0.09

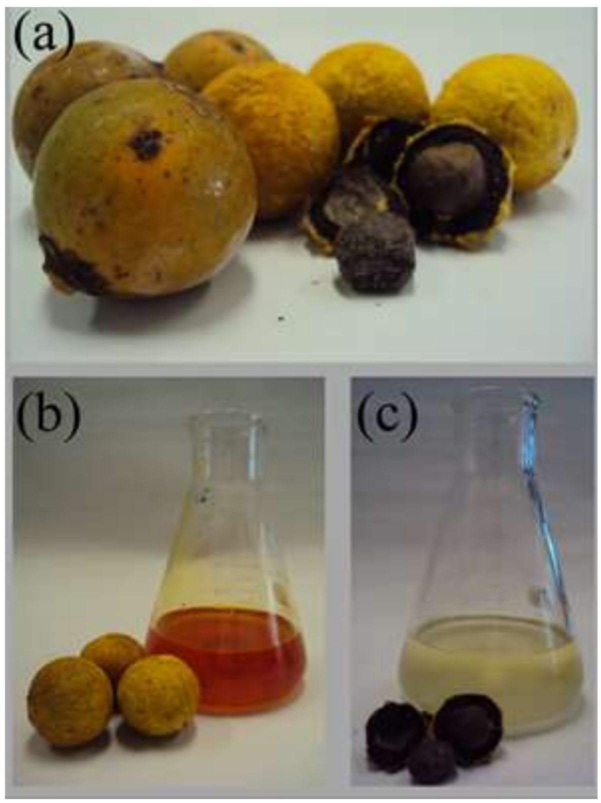

Figure 1. (a) Acrocomia aculeata (Jacq.) Lodd. fruits showing the whole fruit and its parts. **(b)** Macauba pulp oil. **(c)** Macauba kernel oil.

of the mass of the whole fruit (22.07±3.69 g), for this reason, its use in technology and agroindustry is potentialized. The other parts of the fruit were the peel (12%), endocarp (24.28%) and kernel (6.25%) (Figure 1). These values are similar to those obtained by other authors for the same species (Hiane et al., 2006; Chuba and Sanjinez-Argandoña, 2011). Machado et al. (2014) revealed lower values (10. 49 g) for pulp from macauba fruit collected in the Paraná state. This difference in the values of biometric fruits of the same species can be justified by edaphoclimatic difference between the two regions of harvest.

Components of pulp and kernel are shown in Table 2, and the main components observed were lipids and fibers, besides moisture and protein for kernel. Usually, palm tree fruits such as licuri (*Syagrus coronata* (Martius) Beccari), guariroba (*Syagrus oleracea*) and pindo (*Syagrus romanzoffiana*) have high lipid content (Coimbra and Jorge, 2011; Crepaldi et al., 2001). Although, it is less expressive, the protein content of the pulp was similar to the value found by Coimbra and Jorge (2011). On the other hand, the protein content of kernel was lower than that obtained by the same author and by other authors (Hiane et al., 2006;

Table 2. Nutritional components of the *Acrocomia aculeata* (Jacq.) Lodd. fruit.

Components	Pulp	Kernel
Moisture (%)	48.76 ± 1.92	12.87 ± 1.44
Ash (%)	1.50 ± 0.23	1.86 ± 0.43
Total lipids (%)	23.62 ± 1.10	46.96 ± 0.81
Proteins (%)	5.31 ± 0.77	16.44 ± 0.93
Carbohydrates (%)	6.92 ± 1.26	6.06 ± 0.40
Fibers (%)	13.89 ± 1.00	15.81 ± 0.30
Ascorbic acid (mg/100 g)	15.41 ± 0.34	1.18 ± 0.30
Titratable acidity (%)	0.27 ± 0.03	0.07 ± 0.00
pH	6.00 ± 0.00	6.00 ± 0.00
Water activity	0.988 ± 0.00	0.677 ± 0.00

Values are means ± SD (n = 3).

Table 3. Mineral levels in the pulp and kernel of the *Acrocomia aculeata* (Jacq.) Lodd. fruit.

Minerals	Pulp	Kernel
Macronutrient		
Calcium (mg g^{-1})	1.13 ± 0.03	0.92 ± 0.09
Magnesium (mg g^{-1})	1.23 ± 0.02	1.72 ± 0.07
Micronutrient		
Copper (µg g^{-1})	1.37 ± 0.01	15.80 ± 0.51
Manganese (µg g^{-1})	3.21 ± 0.02	18.78 ± 0.21
Iron (µg g^{-1})	41.34 ± 0.06	26.08 ± 1.49
Zinc (µg g^{-1})	< LQ	45.14 ± 0.84

Values are means ± SD (n = 3). LQ, limit of quantification = 3.33 µg g^{-1} (Zn).

Silva et al., 2008) for the same species. The quantification of carbohydrates content showed that both, pulp and kernel have similar relative values of these compounds, about six percent of its proximate composition. The fruits were characterized as slightly acidic according to its pH, which is 6.0 and its low acidity (0.27%). These results are similar to those found in the literature (Chuba and Sanjinez-Argandoña, 2011). The ascorbic acid content (15.41 mg/100 g) was higher than the licuri (*Syagrus coronata* (Martius) Beccari), which showed traces of vitamin C (Crepaldi et al., 2001), and higher than the buriti (0.7b mg/100 g) and bacuri (0.5 mg/100 g) (Barreto et al., 2009). The variations found in fruits of the same species can be attributed to the soil type, climatic conditions, harvesting period and other edaphoclimatic factors (Kim et al., 2003).

Table 3 presents the results of mineral composition found in the pulp and kernel of macauba fruits. Among the analyzed macronutrient elements, magnesium showed the highest concentration, followed by calcium. In the kernel, the Mg concentration is almost twice the Ca content.

Moreover, the Ca content found in this work (0.62 mg g^{-1}) is higher than the content found by Ramos and collaborators (2008). Although, the mineral concentration is less than the recommended daily intake for adults (Anvisa, 1998), the pulp of macauba can be considered a source of minerals. Whereas, it showed significant levels of some micronutrients, such as copper, iron and manganese, which participate in important protein transport ways, corroborating the importance of the intake of these nutrients. Furthermore, mineral deficiencies have been implicated as causes of several chronic diseases (Ba et al., 2009).

The main cellular electrolytes in the human body are sodium, potassium, magnesium, phosphate and, to a lesser degree, calcium. These nutrients are easily acquired by the ingestion of fruit as well as milk and its derivatives (Clereci and Carvalho-Silva, 2011). In this context, this study provides information that enhance the prospects of consumption of macauba fruits, in addition supports and enable future studies for prevention of malnutrition and degenerative diseases.

Extraction and physical and chemical characterization of oils

Figure 2 shows the methods evaluated and the values regarding the oil extraction yield from the pulp and kernel from macauba fruits. Among the conventional oil extraction methods, the high temperature extraction method (Soxhlet method), presented the greatest efficiency in yields. The results are compatible with those found in the literature. This is resulted of the immersion of the sample in the solvent and the flow of the solvent through the sample, increasing the effectiveness of the method (Brumm et al., 2009). However, cold pressing has some advantages. For example, no solvents are used, which minimizes the risk of intoxication of the handler and the environment (Pighinelli et al., 2008). In addition, it does not involve high temperatures, which can result in less loss of degradable compounds such as carotenoids and tocopherols (Coimbra and Jorge, 2012), because increased temperatures are associated with the degradation of bioactive compounds (Rodriguez-Amaya et al., 2008). The levels of oil in the pulp, ranged between 19.3 and 47.3%, indicating that the yield of oil depends on the solvent, given that some solvents are able to remove vitamins, steroids, resins and pigments as well as triacylglycerides (Galvão et al., 2008). In the kernel, the values varied from 35.4 to 46.9%. The extraction with hexane by Soxhlet method is commonly applied in research laboratories and it was used in this work to compare with the pressing method. Table 4 presents the physical and chemical characteristics of the oils from the pulp and kernel extracted by pressing and Soxhlet method. The density was kept at the same value (0.919 g cm^{-3}) for all of the analyzed oils; in other words, the extraction method makes no difference for the density of the oil. The values for the iodine value and refraction index observed in

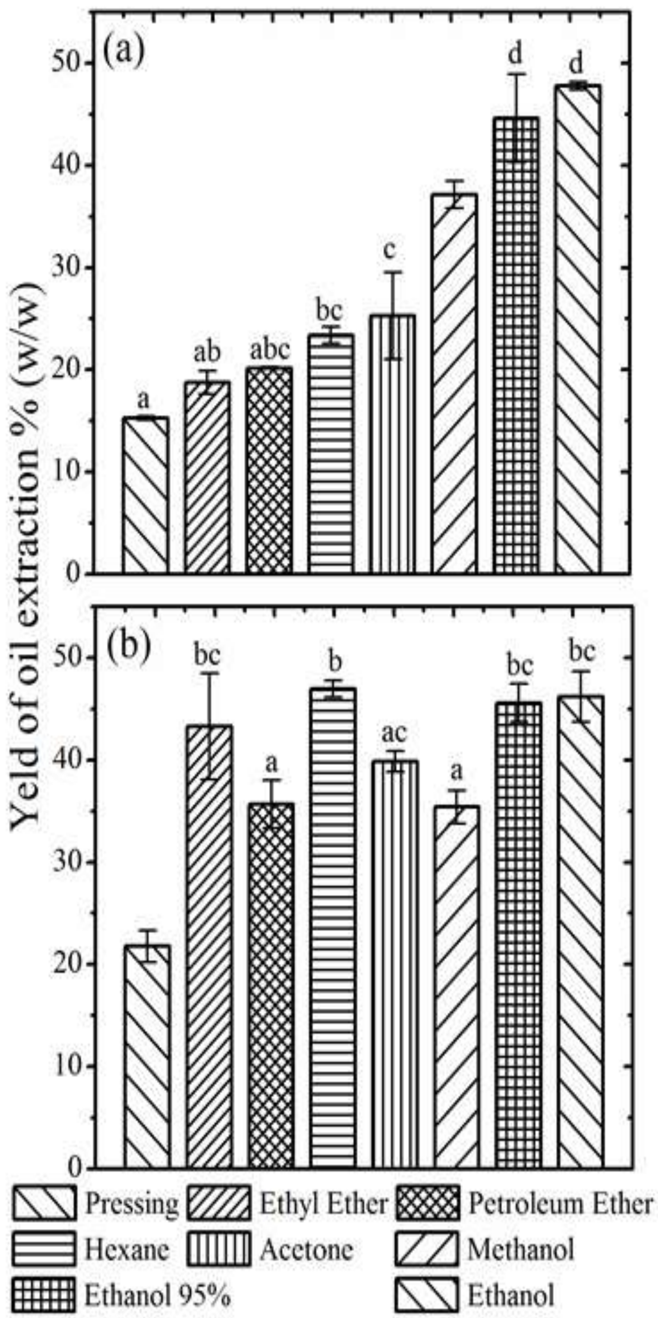

Figure 2. Yield of oil extraction from the pulp (a) and kernel (b) of the *Acrocomia aculeata* (Jacq.) Lodd. fruit. Same letters do not differ significantly among themselves at the level of 5% of Tukey's test. Values are means ± SD (n = 3).

the samples is typical for oils, as has been observed in other studies (Ferreira et al., 2008; Jorge et al., 2005). A significant difference can be seen in the determination of acidity value of oils from the pulp when compared with oils from the kernels, which shows that there are more acidic compounds in the pulp oil. However, the kernel oils presented the same determination of acidity values, independently of the extraction process. The same did not occur with the oils from the pulp, which presented higher acidity with the Soxhlet method than with pressing. The viscosity results showed that the extraction methods were similar with regard to this parameter for the kernel oils. However, the oil viscosity of the pulp oil obtained by pressing was 27% higher than the oil obtained by solvent. The explanation is based on the fact that, solvent extraction does not drag the water present in the sample.

Composition of fatty acids

The fatty acids found in the pulp and kernel of macauba´s oils are presented in Table 5. The characterization of fatty acids of the oil obtained by pressing (cold method) and hexane solvent were done. The pulp oil was composed of saturated fatty acids (25.01%) and unsaturated fatty acids (74.99%), of which 68.51% were monounsaturated and 6.48% polyunsaturated. For the kernel oil, the values for saturated fatty acids were 67.15% and for unsaturated fatty acids 32.85%, of which 29.39% were monounsaturated and 3.46% polyunsaturated.

Navarro-Díaz et al. (2014) analyzed the fatty acids from macauba and found similar values of this work, about 70% of the total composition of acids. Unsaturated fatty acids have important functions, such as maintaining the immune system in inflammatory processes and an anti-microbial effect (Menendéz et al., 2006; Weatherill et al., 2005; Debmandal and Mandal, 2011). The fatty acids profile of pulp and kernel evidenced the amount of polyunsaturated acids, thus it is possible to suggest that both oils in the present study are important sources of these bioactive compounds.

In Table 5, the predominance of oleic, palmitic and palmitoleic acids can be observed. The predominant polyunsaturated fatty acids in the pulp were linoleic acids (5.46%) and linolenic acids (1.02%). Santoso et al., (1996) obtained values of 7.18% for linoleic acids and of 1.59% for linolenic acids in the oil from the *Cocos nuciferas* (Arecaceae), which is close to the values found in this study. Medicinal properties, such as antibacterial, antifungal, antiviral, anti-parasite, antioxidant, hypoglycemic, immunostimulant and liver protecting effects have been attributed to the oil of *C. nuciferas*, which is correlated with its fatty acids (Debmandal and Mandal, 2011).

The linoleic fatty acid represents the omega 6 (ω-6) family and it is essential in a diet. Its deficiency results in adverse clinical symptoms, such as scaly skin rashes and reduced growth. It is a precursor of arachidonic acid, a component of the membrane of structural lipids (Hohl and Rosen, 1987). Linolenic acid, of the omega 3 family (ω-3), is a precursor of eicosapentaenoic acid and docosahexaenoic acid. A deficiency in linolenic acid in a diet can result in neurological abnormalities and poor growth. Among other functions, linoleic and linolenic acids are important for the formation of prostaglandins, thromboxanes,

Table 4. Physical and chemical characterization of the pulp and kernel oils of *Acrocomia aculeata* (Jacq.) Lodd.

Parameters	Pulp oil		Kernel oil	
	Solvent*	Pressing	Solvent*	Pressing
Density (g cm^{-3})	0.91 ± 0.00	0.91± 0.00	0.91± 0.00	0.91 ± 0.02
Iodine value (gI_2/100 g)	189.25 ± 3.70	182.37 ± 2.41	193.67 ± 1.84	195.95 ± 3.34
Acidity value (mg KOH/ g)	0.87 ± 0.00	0.97 ± 0.01	0.05 ± 0.01	0.07 ± 0.01
Refraction index (40ºC)	1.45 ± 0.00	1.46 ± 0.00	1.45 ± 0.00	1.45 ± 0.00
Viscosity (mPa.s)	29.00 ± 0.01	36.80 ± 0.08	27.90 ± 0.02	30.46 ± 0.02

Values are means ± SD (*n* = 3). *Hexane was the solvent employed.

Table 5. Composition of fatty acids in the oil from the pulp and kernel of the *Acrocomia aculeata* (Jacq.) Lodd. fruit.

Fatty Acids (mg/100 g)	Pulp oil		Kernel oil	
	Solvent*	Pressing	Solvent*	Pressing
Caproic acid (C 6:0)	0.24 ± 0.01	0.14 ± 0.01	0.36 ± 0.04	0.48 ± 0.00
Caprylic acid (C 8:0)	0.25 ± 0.01	0.14 ± 0.00	4.49 ± 0.37	5.71 ± 0.09
Capric acid (C 10:0)	0.16 ± 0.01	0.11 ± 0.01	3.85 ± 0.11	4.96 ± 0.13
Lauric acid (C 12:0)	0.85 ± 0.01	0.59 ± 0.00	38.98 ± 0.05	41.88 ± 1.61
Myristic acid (C 14:0)	0.61 ± 0.12	0.39 ± 0.01	8.84 ± 0.08	7.70 ± 0.60
Pentadecanoic acid (C 15:0)	0.04 ± 0.04	0.03 ± 0.00	0.03 ± 0.00	0.02 ± 0.01
Palmitic acid (C 16:0)	17.65 ± 0.15	20.11 ± 0.26	7.22 ± 0.08	6.05 ± 0.19
Palmitoleic acid (C 16:1)	2.44 ± 0.11	2.56 ± 0.01	0.06 ± 0.01	0.04 ± 0.03
Heptadecanoic Acid (C 17:0)	0.08 ± 0.01	0.08 ± 0.01	0.05 ± 0.02	0.04 ± 0.01
Heptadecaenoic acid (C 17:1)	0.13 ± 0.01	0.11 ± 0.01	0.03 ± 0.00	0.03 ± 0.01
Stearic acid (C 18:0)	3.15 ± 0.11	3.09 ± 0.34	3.01 ± 0.02	3.63 ± 0.01
Oleic acid (C 18:1)	70.28 ± 1.33	65.71 ± 1.05	29.13 ± 0.39	25.85 ± 1.82
Linoleic acid (C 18:2)	2.84 ± 0.65	5.46 ± 0.35	3.42 ± 0.03	3.08 ± 0.26
α-Linolenic acid (C 18:3)	0.85 ± 0.04	1.02 ± 0.07	0.04 ± 0.01	0.05 ± 0.03
Eicosanoic acid (C 20:0)	0.18 ± 0.03	0.21 ± 0.00	0.20 ± 0.01	0.25 ± 0.01
Eicosenoic acid (C 20:1)	0.19 ± 0.08	0.16 ± 0.01	0.17 ± 0.00	0.16 ± 0.00
Docosanoic acid (C 22:0)	0.04 ± 0.01	0.06 ± 0.01	0.08 ± 0.01	0.06 ± 0.02
Lignoceric Acid (C 24:0)	0.06 ± 0.01	0.08 ± 0.02	0.10 ± 0.01	0.05 ± 0.01

Values are means ± SD (*n* = 2). *Hexane was the solvent employed.

prostacyclins and leukotrienes, which play an important role in the mediation of immunological and inflammatory reactions (Hohl and Rosen, 1987; Bora and Moreira, 2003). The quantities found in these fatty acids in the pulp and the appropriate consumption of this part of fruit can assist in dietary enrichment and reinforce its importance for human health.

Conclusion

The biometric characterization demonstrates that the pulp is the main component, representing 49% of the fruit's mass. From a nutritional point of view, the pulp and kernel of the macauba have significant lipid, fiber and protein contents, confirming its potential as food. The extraction by the pressing method resulted in the lowest yields. The solvent parameter significantly influenced oil extraction from the pulp by the Sohxlet method.

The physical and chemical analyses of the pulp and kernel oils of the macauba indicated properties that are comparable to good quality vegetable oils, given the predominance of monounsaturated fatty acids, in particular of oleic acid. For the polyunsaturated fatty acids essential to the human diet, the macauba presented a significant percentage for linoleic and linolenic acids.

Conflict of interests

The authors did not declare any conflict of interest.

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