GRASAS Y ACEITES 75 (3)
July-September 2024, 2224
ISSN-L: 0017-3495, eISSN: 1988-4214
https://doi.org/10.3989/gya.0870241.2224

Influence of the extraction method on the yield and quality of bacaba palm oil from southwestern Amazonia

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Submitted: 12 August 2024; Accepted: 28 October 2024; Published: 14 January 2025

SUMMARY: This study evaluated the extraction, yield and physicochemical quality of the oil extracted from the fruit mesocarp of the bacaba palm using the artisanal, mechanical pressing and artisanal reheating methods. The oil was stored at 26 °C and 81% RH for 365 days and analyzed for free fatty acids, peroxide value and refractive index. Artisanal extraction resulted in low oil yield and quality. Cold pressing was the most advantageous method, resulting in a higher yield per harvest and an oil with lower acidity. Prolonged storage, even in amber packaging, did not maintain the quality of the oil after 180 days. The acidity of the oil was high from all three extraction methods, indicating its unsuitability for food use. This, however, may have been the result of improper handling of the fruits during the experiment.

KEYWORDS: *Amazon region; Arecaceae; Oil extraction methods; Oil stability; Oil Storage*

RESUMEN: ***Influencia del método de extracción en el rendimiento y la calidad del aceite de bacaba del sudoeste amazónico***. Se evaluaron la extracción, el rendimiento y la calidad fisicoquímica del aceite extraído del mesocarpio del fruto de la palma bacaba por métodos artesanal, prensado mecánico y recalentado artesanal. El aceite se almacenó a 26 °C y 81 % HR durante 365 días y se analizaron los ácidos grasos libres y los índices de peróxido y de refracción. La extracción artesanal dio lugar a un bajo rendimiento y calidad del aceite. El prensado en frío fue el método más ventajoso, con un mayor rendimiento por cosecha y un aceite de menor acidez. El almacenamiento prolongado, incluso en recipientes ámbar, no mantuvo la calidad del aceite después de 180 días. La acidez del aceite fue alta en los tres métodos de extracción, lo que indica su inadecuación para uso alimentario. Sin embargo, esto pudo deberse a una manipulación inadecuada de los frutos durante el experimento.

PALABRAS CLAVE: *Almacenamiento de aceite; Arecaceae; Estabilidad del aceite; Métodos de extracción de aceite; Región Amazónica*

Citation/Cómo citar este artículo: Álvares VS, Souza JML, Ferreira EJL, Maciel VT, Madruga ALS. 2024. Influence of the extraction method on the yield and quality of bacaba palm oil from southwestern Amazonia. *Grasas Aceites* **75** (3), 2224. https://doi.org/10.3989/gya.0870241.2224

1. INTRODUCTION

The Brazilian Amazon region is home to numerous native plants with promising potential for economic exploitation. However, besides the identification of these plants, the main challenge is the development of techniques to enable successful commercial exploitation (Simmons *et al.*, 2018).

The bacaba palm (*Oenocarpus mapora* H. Karsten) is a species with potential for economic exploitation since the oil extracted from its fruit mesocarp exhibits high values of lipids, fibers and proteins (Domingues *et al.*, 2014). The pulp is used in a similar way to that of the açaizeiro (*Euterpe oleracea* Mart.) for juices, ice creams and preparation of sweets (Smith, 2015). Compared to the açaizeiro, bacaba palm heart exhibits good organoleptic characteristics and yield (Oliveira *et al.*, 2000).

Although it has wide distribution from Central America (Costa Rica and Panama) to northern and western South America in Colombia, Ecuador, Peru, Bolivia and Brazil, it is mainly restricted to the western part of the Amazon region (Henderson *et al.*, 1995). It is small to medium in size with a cespitose stem that reaches up to 15 m tall (Henderson *et al.*, 1995). Fruiting bunches produce an average 9.99 kg of fruit, with an average of 752 fruits per bunch, and the ripe fruits, dark purple in color, weigh 2.96 to 5.70 g (average of 4.23 g), while the seeds weigh 1.17 to 3.26 g (average of 2.20 g) (Barbosa *et al.*, 2011; Pinheiro *et al.*, 2017).

Nowadays, rural populations in the Brazilian Amazon living in close proximity to forests, where the species occurs naturally, exploit bacaba for domestic consumption and the sale of products derived from this palm is uncommon (Campos and Ehringhaus, 2003).

Currently, small farmers associated with the "Project for Consortium and Dense Reforestation" (RECA Project), in Nova California, Rondônia, are cultivating bacaba (Giugliano *et al.*, 2020). The project is in collaboration with an agro-industry of vegetable oil production which is exploring the feasibility of extracting and marketing its oil for use in the cosmetics industry.

Mesocarp oil from bacaba fruit has a pronounced green color, a higher content of monounsaturated fatty acids (mainly oleic acid), and is suitable for replacing other vegetable oils in the daily diet (Mambrim and Barrera-Arellano, 1997; Santos *et al.*, 2017).

Methods for commercial extraction of mesocarp oil from bacaba fruits have yet to be established, and in the rural areas of the Brazilian Amazon, extraction is usually done manually. Initially the fruits are heated in water to facilitate pulp maceration, followed by cooling and reheating to separate the supernatant oil, a time-consuming and low-yield process. The exposure of pulp to excessive heat also compromises the final quality of the oil. Although a more efficient alternative, chemical extraction may leave behind residues that make the oil unsuitable for use in edible products.

Considering the potential use of the oil extracted from the mesocarp of bacaba palm fruits and the interest in its commercialization by local producers in the southwest of the Brazilian Amazon, this study aimed to evaluate the effect of the extraction method on the yield and physicochemical quality of bacaba oil.

2. MATERIALS AND METHODS

2.1. Fruit harvest and oil extraction methods

In June 2017, 30 kg of ripe bacaba fruits were harvested from a commercial orchard in the RECA Project area, located in Nova California, Extrema district, Rondônia, Brazil. The fruits were transported to the Food Technology Laboratory of Embrapa Acre, located in the city of Rio Branco, Acre. They were sorted and processed through the following steps:

(a) selection of fruits with purple skin and absence of damage or rot.

(b) washing in running water and sanitizing by immersion in a chlorinated water solution (200 $mg \cdot kg^{-1}$) for 5 minutes.

(c) softening and separation of the pulp from the endocarp via immersion in hot water (50 °C) for five minutes.

(d) drainage of excessive water and placement in trays for experimental treatments.

The extraction of oil from the mesocarp was carried out according to three different treatment methods:

a) Artisanal extraction (T1) = after blanching, fruits were manually macerated and heated to 85 °C for 40 minutes. The resulting material (fruit mass and water) was kept at an average room temperature of 28 °C for 72 hours for fermentation and separation of the phases: nonpolar (supernatant) composed of bacaba oil and polar phase (lower) composed of the remaining dilution water. Next, the supernatant was heated until boiling and the appearance of oil for collection.

b) Mechanical extraction by cold pressing (T2) = the water used in the pulp blanching was completed in the proportion 4:2.5 (v/p) water/fruit. The fruit and water mixture were processed for five minutes in a commercial 10 L capacity benchtop pulper (Braesi brand, model DES-1), consisting of a stainless steel cylinder and a rotating internal vertical axis (240 rpm at 380 rpm) fitted with three stainless steel sieves with 0.8 mm, 1.5 mm and 5 mm diameter holes. The pulp obtained was spread into thin layers on trays and placed to dehydrate in an oven with forced air circulation at 45 °C until constant weight (approximately 48 hours). The dehydrated pulp was then subjected to cold pressing in a manual hydraulic press (Bovenau brand, model P15500) at 15 tons for 20 minutes. The press has an overload valve, spring-return piston and height-adjustable worktable with a central shaft fitted with a perforated cylindrical motor and a channel for draining the oil at the base.

c) Artisanal extraction with additional cooking (T3) = in this method the pulp preparation was similar to that used in treatment T1, but the samples were reheated to 85 ºC for 40 minutes three times.

2.2. Physical-chemical quality and yield of bacaba oil

At the end of each treatment, the oil obtained was placed in 30-mL amber vials and stored at an average temperature of 26 °C and relative humidity of 81% for 365 days. Every 90 days all samples were analyzed in duplicate to determine free fatty acids, peroxide index and refractive index, according to AOCS (2009).

Based on the weight of the oil obtained from each extraction method, the following were calculated for each treatment: (a) yield on a wet basis, related to the initial weight of fresh fruits; (b) yield on a dry basis, related to the weight of the dehydrated mass; and (c) estimated amount of oil yield per extraction, per month and per crop, on a wet basis, assuming production of two bunches/crop and 9.99 kg of fruit/bunch (Barbosa *et al.*, 2011).

2.3. Statistical analysis

Data normality was verified by the Shapiro-Wilk test (α = 0.05). To compare extraction methods a completely randomized statistical design was adopted with three treatments and five replications. An ANOVA was performed on the original and/or transformed data (the data of all variables, with the exception of the refractive index, were transformed into square root) to test for differences between the treatments. When the F-test was significant, treatment means were compared with the Tukey test at 5% using the Sisvar statistical program (Ferreira, 2008). The data was transformed into $(X+1)^{-2}$.

To better understand the stability of the oil quality characteristics during the storage period, a linear regression analysis was conducted using data from samples removed from storage after 0, 90, 180, 270 and 365 days of storage.

3. RESULTS

3.1. Oil yield

There was no effect of extraction method on the oil content obtained, reaching an average yield of 0.78% (wet basis) in relation to the initial weight of the fruits and 4.74% (dry basis) in relation to the dehydrated mass (Table 1).

The comparison between artisanal extraction and cold pressing methods shows, over a 30-day horizon, that the estimated amount of oil extracted by cold pressing was significantly higher than artisanal extraction due to the extraction time required for each method. As the cold extraction method lasts for two days, this means that in 30 days it is possible to perform up to 15 extractions, compared to three days and up to 10 extractions in the artisanal method (Table 2).

Table 1. Estimate of the monthly and per crop yield of bacaba mesocarp oil extracted by artisanal and mechanical pressing methods from fruits collected in Nova California, Rondônia, Brazil.

Characteristics	Extraction method		Averages	CV (%)
	Artisanal	Pressing		
Amount of oil in the fruit ($g \cdot 10\ kg^{-1}$)	2642	2642		
Oil yield ($g\ oil \cdot 100\ g^{-1}$ fresh pulp; wet basis)	0.46a	0.73a	0.60	6.38
Method extraction time (days)	3	2		
Estimated amount of oil per extraction ($g\ oil \cdot 10\ kg^{-1}$ fruit; wet basis)	12.22a	19.42a	15.82	16.85
Number of extractions per month	10	15		
Estimated oil per month ($g\ oil \cdot 10\ kg^{-1}$ fruit/month; wet basis)	122.19b	291.28a	206.75	16.91
Estimated oil per crop* (g oil/plant; wet basis)	244.14b	581.98a	413.06	20.97

*As the fruit of *Oenocarpus mapora* has 26.42% pulp and each palm produces two bunches/year (9.99 kg fruit/bunch) (Barbosa et al., 2011), it is possible to extract oil every 3 days using the artisanal method and every 2 days using the pressing method. In each row, means followed by the same letter do not differ statistically, according to the Tukey test at 5% probability. Data transformed into $(X+1)^{-2}$. With 4 repetitions.

Considering that the average oil yield obtained from bacaba using these two methods is very low (average of 0.60 % wet basis), the superiority of the pressing method in terms of time spent becomes highly relevant, especially since a bacaba fruit bunch holds, on average, 9.99 kg of fruit and each palm produces, on average, only two bunches/crop. The data obtained from the present study allow us to estimate that, on average, approximately 413 g of oil/individual bacaba palm can be extracted annually (Table 2).

3.2. Oil quality

Artisanal extraction resulted in higher acidity (Table 1). The fruits were softened before oil extraction in all treatments and when additional cooking took place (T3; Table 1) with reheating of the dough, the oil's acidity was statistically the same as the oil extracted by cold pressing. Although low acidity is desirable, treatment T3 (artisanal extraction plus additional cooking) was highly unstable, with 50% of the samples producing a high oil yield, while the other samples produced no oil, which disqualifies this method for industrial purposes.

Extraction method had no effect on the refractive index of bacaba oil (Table 1). The refractive index is mainly related to the degree of saturation and the ratio between cis/trans double bonds of fatty acids, in addition to being influenced by oxidative processes. Refractive index was not expected to change much with storage, since the raw material remained constant.

Regardless of extraction method, when bacaba oil was stored at room temperature in amber glass, an increase in acidity and peroxide content was observed over time (Figure 1). As mentioned above, the high initial acidity of the oil in this study (Figure 1A) may also be due to inadequate handling of the fruits prior to oil extraction.

Peroxide content also rose with the storage of bacaba oil (Figure 1B). This index only fell within the limits allowed by Brazil's National Health Surveillance Agency (Brasil, 2021) at the beginning of the storage period (maximum limit for vegetable oils = 15 meq $O_2 \cdot kg^{-1}$).

Table 2. Bacaba mesocarp oil content and physicochemical characteristics of the oil extracted under different methods from fruits collected in Nova California, Rondônia, Brazil

Extraction Method*	Oil content (% wet base)	Oil content (% dry base)	Free fatty acids (% oleic acid)	Acidity level (mg KOH/g)	Refractive index	Peroxide index (meq $O_2 \cdot kg^{-1}$ of sample)
1	0.46a	3.27a	20.68a	41.15a	1.4730a	5.52a
2	0.74a	4.15a	3.12b	6.21b	1.4727a	6.33a
3	1.14a	6.79a	4.81b	9.57b	1.4730a	7.27a
Average	0.78	4.74	9.54	18.98	1.4729	6.37
CV (%)	30.91	26.49	15.83	15.83	0.02	8.40

*Extraction method: 1= artisanal; 2= pressing; 3= artisanal with additional cooking. Data for all variables, with the exception of the refractive index, were transformed into Square Root - SQRT (Y). In each column, the means followed by the same letter do not differ statistically from each other according to Tukey's test, at 5% probability, with 4 repetitions.

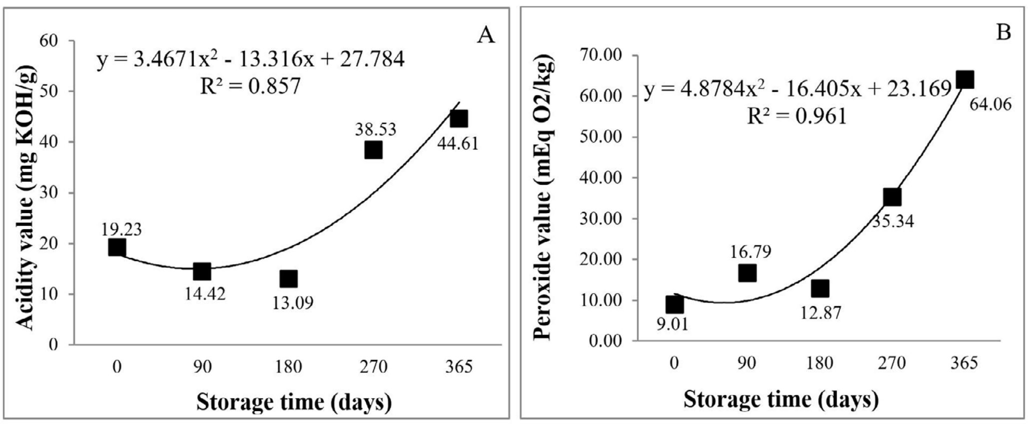

Figure 1. Linear regression of stability of oil quality characteristics during storage period: Acid value (A) and peroxide value (B) of bacaba mesocarp oil stored for 365 days at room temperature of 26 °C, using the mean result of 4 repetitions.

4. DISCUSSION

4.1. Oil yield

Each individual bacaba palm produces two bunches of fruits per harvest with an average of 9.99 kg of fruits, allowing the extraction of approximately 413 g of oil/individual palm per year. Thus, considering that a successful planting of the species was carried out in the 1980's with a density of 1600 palms/hectare (2.5 m x 2.5 m spacing) in an experimental area of the Parque Zoobotânico, in the municipality of Rio Branco, Acre, Brazil (Deus *et al.*, 1993), it would be possible to extract up to 660.8 kg of oil·ha^{-1}.

Unfortunately, bacaba is plagued by two unfavorable characteristics. First, the fruiting season extends from December to April (Cymerys, 2010), requiring a staggered harvest throughout the season due to the irregular maturation of the fruits in the bunches. Thus, the harvesting of bunches should be done from different palms giving preference to those with a similar degree of maturation. Otherwise, a single harvest would result in fruits at different stages of maturation and, consequently, different oil contents.

In addition, the extraction and marketing of bacaba oil faces a serious market challenge, since the type of oil it produces (oleic-palmitic) has as its main competitor on the international market the oil extracted from the African palm (*Elaeis guineensis*), a cultivated species with a productivity greater than 5 t of oil/hectare and whose market presence is already consolidated. Thus, for the extraction of bacaba oil to be commercially viable, the agronomic aspects of its cultivation need to be improved in order to increase its productivity, including the selection of superior genetic materials with higher oil content.

In the present study, fermented fruit mass was used for oil extraction, resulting in an average yield of 0.78% (wet basis) over initial fruit weight and 4.74% (d.b.) over the dehydrated mass. Santos *et al.* (2013) obtained a yield of 0.66% oil (wet basis) using direct extraction of the concentrated juice from fruits of the fan bacaba (*Oenocarpus distichus*). However, these same authors, when using the fermentation of concentrated juice to extract the oil, obtained a yield of 5.3% (wet basis), which is higher than what was found in this work using fermented fruit mass.

Regarding the methods used for bacaba oil extraction, in the present study it was observed that the estimated amount of oil extracted by cold pressing was significantly higher than artisanal extraction due to the extraction time required for each method. Carvalho *et al.* (2011), analyzing different extraction methods of buriti oil (*Mauritia flexuosa*), registered an oil yield from the pressing method similar to yields obtained from solvent extraction and superior to the artisanal method, emphasizing, however, that the solvent method produced chemical residues, used energy and generated heat in both oil and cake. Using solvent-induced extraction, Ribeiro *et al.* (2012) obtained a higher yield of pequi oil (*Caryocar brasiliense*) than when they used mechanical extraction. Compared to solvent extraction techniques, the main advantage of using mechanical presses is that they are environmentally safer and generate non-toxic by-products that can be used as fertilizer, animal feed or even human food. In addition, it is a simple process, easily installed and maintained on small rural properties.

4.2. Oil quality

Plant oil acidity levels may be related to the quality of the raw material used, the conservation of the product (Pinho and Souza, 2018), or processing techniques (Hiane *et al.*, 2005). Theartisanal extraction of bacaba oil resulted in higher acidity, which may be related to the fruits' excessive exposure to high temperatures, as observed by Hiane *et al.* (2005) after processing the fresh pulp of *Acrocomia aculeate* (Arecaceae) fruits at 40 to 50 °C to obtain flour.

Uceda *et al*. (2006) reported that excessive heating of the raw material for oil extraction can result in undesirable effects, such as loss of aromatic compounds responsible for the flavor and fragrance of the oil and acceleration of the oxidative process. In the artisanal extraction method (T1), the raw material was heated to 85 °C for 40 minutes and then heated to the boiling point.

According to Nde Bup *et al*. (2012), in oil extraction, acidity increases with high cooking time, as it increases the activity of lipases, enzymes responsible for catalyzing the hydrolysis of fats and releasing free fatty acids.

High acidity indicates that the oil or fat has experienced breaks in its triglycerol chain, releasing its main constituents, which are fatty acids. Fatty acids constitute oils and fats in the form of mono, di and triglycerides, and a large amount of free fatty acids signals that the product is in an accelerated degree of deterioration (Rios *et al.*, 2013).

The literature diverges as to the influence of extraction method on the acidity of vegetable oils. Mambrim and Barrera-Arellano (1997) have attributed the high acidity of the fan bacaba (*O. distichus*) oil to deficient storage conditions for fruits prior to oil extraction, which result in strong hydrolytic and oxidative actions. Pinho and Souza (2018) reported that the artisanal extraction method and cold pressing resulted in the same acidity for coconut oil. Souza *et al.* (2015) observed that African palm oil extracted by hydraulic pressing exhibited lower acidity when the fruits were cooked before extraction. Ribeiro *et al.* (2012), when analyzing different methods of pequi oil extraction, observed that mechanical extraction resulted in an oil with higher acidity compared to extraction with solvents. The same authors, however, found low acidity values for the pequi oil obtained from the hot water flotation method, in which the fruit is subjected to repeated artisanal heating processes.

In the current work, the fruits were softened before oil extraction in all treatments. When additional cooking took place (T3 method), with discontinuous heating of the mass, the oil's acidity was statistically the same as the oil extracted by cold pressing. Similar results were reported by Ribeiro *et al.* (2012), who found low acidity values for the pequi oil obtained from the hot water flotation method, in which the fruit is subjected to repeated artisanal heating processes.

The acidity value of cold-pressed bacaba oil (6.21 mg $KOH \cdot g^{-1}$) was higher than the maximum limit of 4.0 mg $KOH \cdot g^{-1}$ allowed by Brazilian legislation (Brasil, 2021) and by the Codex standards for cold-pressed oils (Codex, 2017). The average acidity value found, when expressed in the form of free fatty acids (9.54%), was higher than that obtained for *Oenocarpus bacaba* (2.4%; Santos *et al.*, 2013). However, the values were lower than those recorded for *Oenocarpus distichus* (35.6% free fatty acids; Mambrim and Barrera-Arellano, 1997).

The high acidity recorded in this study may also be due to inadequate handling of the fruits before oil extraction, since multiple harvests were carried out in order to obtain the necessary amount of fruits for the experiment. Between the first and last harvest, these fruits were kept in a cold chamber until final transport to the Embrapa laboratory. The physicochemical properties of vegetable oils depend on the length of time elapsed between the collection and processing of the fruits (Carvalho *et al*., 2011), as well as the storage conditions prior to the extraction, which can lead to a strong hydrolytic and oxidative action of the oil (Mambrim and Barrera-Arellano, 1997).

Therefore, the bacaba oil obtained by the three extraction methods used in this study was not suitable for human consumption, either directly in salads or for use in fried foods. According to the rules of the Brazilian Health Surveillance Agency (ANVISA), the maximum acidity for virgin olive oil is 2% (0.8% for extra virgin) and 0.9% for oils used in frying (Brasil, 2021).

The average refractive index in this study was 1.4729, similar to the 1.4594 of the bacaba fan palm (*Oenocarpus distichus*) oil (Mambrim and Barrera-Arellano, 1997), 1.4565 of the inajá palm (*Maximiliana maripa*) oil (Ataide *et al.*, 2020), and commercial oils such as African palm (*Elaeis guineensis*) (1.454-1.456; Codex, 2017).

Regarding the peroxide index, the mean value obtained, 6.37 meq $O_2 \cdot kg^{-1}$ (Table 1), was lower than that recorded for *Oenocarpus bacaba* (12.0 meq $O_2 \cdot kg^{-1}$; Santos *et al.*, 2017). The peroxide index is used as an indicator of the initial stages of lipid oxidation. High peroxide values indicate that the oil was exposed to an oxidative process, either during the preparation of the raw material, extraction or storage of the oil. For refined and crude oils, the Codex stipulates maximum peroxide index values of 10 and 15 meq $O_2 \cdot kg^{-1}$, respectively.

Acidity and peroxide values are the main parameters which reflect oil quality, and changes in these parameters can be caused not only by extraction method, but also by the high amount of short-chain fatty acids present (Ribeiro *et al.*, 2012).

For certain vegetable oils, authors have reported the effects of extraction method on peroxide value. Comparing different methods of extracting oil from pequi almonds, Torres *et al*. (2016) observed that the peroxide index for cold-pressed oils was 70% lower than artisanal oil, indicating a possible influence of heat and aging time on the degradation of polyunsaturated fatty acids and the formation of peroxides. Ribeiro *et al.* (2012) also reported that mechanical extraction of pequi oil resulted in higher peroxide levels compared to solvent and hot water flotation extraction methods.

Regardless of extraction method, long-term storage of bacaba oil at room temperature in amber packaging was not enough to maintain its quality over time, suggesting a strong effect of temperature on its stability. It is worth mentioning again that the acidity values found for bacaba oil surpassed the maximum parameter allowed by Brazilian legislation (Brasil, 2021) and by the Codex (2017) standards of 4.0 mg $KOH.g^{-1}$. Temperature, light and oxygen concentration are the external factors with the greatest influence on oxidation (Kalua *et al.*, 2007). An increase in pequi oil acidity during storage was also verified by Ribeiro *et al.* (2012), possibly due to the hydrolysis reactions of triacylglycerol which accompany the decomposition of the oil.

Ribeiro *et al.* (2012) also found higher levels of peroxides for pequi oil during storage. High peroxide values indicate the oil was exposed to an oxidative process, whether during the preparation of the raw material, extraction or storage of the oil (Jorge and Luzia, 2012). Therefore, storage conditions at room temperature were not suitable for maintaining the quality of bacaba oil over a long period.

5. CONCLUSIONS

The extraction of oil from the mesocarp of bacaba fruits by cold press is advantageous compared to the artisanal methods, resulting in higher yields per harvest and higher quality oil (i.e., lower acidity). In addition, cold pressing requires no chemical solvents, minimizing the generation of hazardous waste and reducing the cost of the process, making bacaba fruits attractive as a source of raw material for oil extraction. However, when aiming for a higher quality product, care must be taken in the handling of the fruits leading up to extraction, and long periods of storage should be avoided due to probable instability of the oil.

6. ACKNOWLEDGMENTS

We are grateful to the Nacional Research Council (CNPq) for the Scientific Initiation Program Scholarship (PIBIC), to the RECA Project for the supply of bacaba fruits, to Acre Technology Foundation (FUNTAC) for the loan of the oil extraction press and to Embrapa for the physical infrastructure to conduct the experiments.

7. DECLARATION OF COMPETING INTEREST

The authors of this article declare that they have no financial, professional or personal conflicts of interest that could have inappropriately influenced this work.

8. AUTHORSHIP CONTRIBUTION STATEMENT

V. S. Álvares: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Visualization, Writing – original draft;

J. M. L. Souza: Conceptualization, Methodology, Visualization, Writing – original draft;

E. J. L. Ferreira: Visualization, Writing – review & editing

V. T. Maciel: Investigation, Methodology;

A. L. S. Madruga: Investigation.

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