Original Article
Food Science and Technology
ISSN 0101-2061 (Print)
ISSN 1678-457X (Online)
DOI: https://doi.org/10.5327/fst.00396

Chemical, nutritional, anti-nutritional, and technological profile of bacaba fractions (*Oenocarpus bacaba Mart.*): Promising fruit from the Brazilian legal Amazon

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Abstract

Bacaba belongs to the same family as açaí, and its pulp is consumed by the local population of the Brazilian Amazon region. The aim of this study was to characterize the peel+pulp and seed fraction, and the peel+pulp flour and seed flour, seeking to provide the agro-industrial market with an alternative for exotic fruit consumption, collaborating with the whole consumption of foods. The results showed that all fractions contain amounts of total fiber above 20 g/100 g, lipid contents that vary according to the fraction, highlighting the values of some minerals. Bioactive compounds such as epicatechin, procyanidin A2, biochanin A, myricetin, and kaempferol were found in the peel+pulp, seed, and its flour; the flour from the husk+pulp fraction has good solubility in milk; the seed is a source of carbohydrates; and the seed flour has a high antioxidant capacity. We conclude that bacaba fractions can be applied in food products, mainly in the form of flour, adding nutritional value and contributing to the demand for the full use of the fruits.

Keywords: agro-industrial potential; amazonian fruits; antioxidant capacity; co-products; food technology; full use.

Practical Application: Bacaba fractions offer nutritional and functional potential in food products.

1 INTRODUCTION

The vegetation diversity of the Brazilian Amazon region ranges from a variety of native fruits, such as bacaba (*Oenocarpus bacaba* Mart.). Bacaba fruits are purple, round, and measure about 1.5 cm in diameter. These fruits have been consumed in the form of drinks, ice cream, and jellies (Finco et al., 2012).

In fruit processing in general, peels and seeds are the main by-products discarded, despite containing nutrients and bioactive compounds (Chaouch & Benvenuti, 2020; Van der Goot et al., 2016). Given the need to fully utilize food and reduce the amount of waste generated by industries (EFFPA, 2018), the use of these co-products as sources of compounds of interest to human nutrition and health can be seen as a matter of global relevance (Skwarek & Karwowska, 2023).

Little is known about the functional properties of the bacaba fruit; therefore, gathering this information is important to determine whether the fruit, or parts of it, could be used for human nutrition. According to Carvalho et al. (2016), bacaba is a potential source of phenolic acids and flavonoids in the diet, as its levels are found to be comparable, or even higher, to those observed in other fruits of the same family, such as açaí (*Euterpe oleracea*).

Barros et al. (2017) reported that the fruit has an antioxidant activity of 15,285.51 ± 20.38 µmol TE/100 g (ORAC method) and 16,916.37 ± 10.01 µmol TE/100 g (FRAP method), and total phenolic compounds content of 1,537.45 ± 73.35 mg GAE/100 g, with the residue (peel) being the most promising in terms of the presence of bioactive compounds and antioxidant capacity.

Santos et al. (2022) studied consumption alternatives for the fruit and developed bacaba powder using different dehydration methods. Their study indicated that the use of lyophilization could be particularly useful for the conservation of biocompounds and fruit in the off-season, in addition to being used as a raw material by several industrial segments.

In this context, this study aims to characterize the peel+pulp fractions, seeds, and bacaba seed flours to provide nutritional and technological data that allow the full use of this Amazonian fruit, mainly for the regional population.

Received: 8 Sept., 2024.
Accepted: 1 Oct., 2024
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Conflict of interest: nothing to declare.
Funding: National Council for Scientific and Technological Development (CNPq, Brazil) (process number 88882.428495/2019-01 and number 309985/2020-0).

2 MATERIALS AND METHODS

2.1 Materials and reagents

Fresh fruits of bacaba (*Oenocarpus bacaba* Mart.) from the 2018/2019 harvest (November) were purchased at an open-air market in the city of Itacajé, state of Tocantins, Brazil, where they were sold in bulk. The fruits were packed in plastic bags and transported to the plant for processing vegetable products—UFG, Goiânia-Go, for morphological analyses (mass, transversal, and horizontal diameter).

The fruits were placed in a container to be macerated in water (for the fruits to be submerged in water) for 30 min, and then taken to a pulper (Bonina/025 DFA8, Brazil) to separate the seeds from the husk and pulp. Both the peel+pulp fraction *in natura* (CPB) and the seeds *in natura* (SB) were divided into three lots. The first lot was used for the analysis of soluble solids, pH, acidity, and color. The second batch was stored in high-density polyethylene bags, which were vacuum-sealed and covered with aluminum foil and then stored at -18°C until the remaining analyses (physical, chemical, nutritional, anti-nutritional, and technological). The third batch was dehydrated in a forced-air circulation oven (TE 394/4, Tecnal, Piracicaba, Brazil) at 60°C for approximately 24 h. The dehydrated CPB was ground to a granulometry of 25.40 mm in a knife mill (Willye START FT 50-Brasil) to obtain the peel+pulp flour (FCPB). The seeds were ground in a knife and hammer mill (Nogueira OPM-JR-Brasil) and then ground again in a knife mill (Willye START FT 50-Brasil) to obtain the seed flour (FSB), with a granulometry of 25.40 mm. FCPB and FSB were stored in high-density polyethylene bags, closed under vacuum, and the bags were covered with aluminum foil and stored at -18°C until the analysis.

2.2 Morphological analyses and physical parameters

The mass of the whole fruit was determined on a semi-analytical balance (Scientch /SA 210). The yield was calculated from the mass of the whole fruit and the mass of the peel+pulp fraction and the seed after separation. Readings were performed on a digital caliper (Vernier Caliper, 0–150 mm) to identify the transversal and horizontal diameter.

Water activity was determined using an Aqualab digital device (model CX-2, DECAGON, Brazil), at room temperature (25 ± 1°C). The instrumental color parameters were identified through a colorimeter (Color Quest, XE, Reston, USA) operating in the CIE L*a*b* system (L*: brightness, 0 to 100; a*: + red a - green; b*: + yellow to - blue). Chroma (C) was calculated according to Equation 1. In total, 30 measurements were made on each study object (CPB, FCPB, SB, and FSB):

$$C = \sqrt{a^2 + b^2} \quad (1)$$

2.3 Chemical analysis

A portion of each sample (CPB, FCPB, SB, and FSB) was diluted in water (1:9, sample: water) and used to determine the following features: soluble solids content, in a digital refractometer (AR200, Reichet Analytical Instruments Depew, New York, US); pH, in a potentiometer (TEC5, Tecnal, Piracicaba, São Paulo, Brazil) calibrated with pH 7.0 and 4.0 solutions; and titratable acidity, by titration with 0.1 M sodium hydroxide (NaOH) solution, expressed in g/100 g of citric acid. The following methods were applied: for moisture content, heating of the ash content in an oven at 105°C by carbonization on electric plates, with subsequent incineration in a muffle furnace at 550°C; crude proteins based on the microKjeldahl method (AOAC, 2016) and a conversion factor of 6.25; total lipids calculated by the Bligh and Dyer method (1959); and total carbohydrates calculated by difference (Brasil, 2003). The caloric value was calculated using Atwater coefficients (carbohydrate and protein = 4.0 Kcal/g; lipid = 9.0 Kcal/g) (Merril & Watt, 1973).

Soluble and insoluble fiber contents were determined based on three repetitions according to the gravimetric–enzymatic method, using α-amylase, protease, and amyloglucosidase enzymes (AOAC, 2016). The levels of reducing, non-reducing, and total sugars were obtained using the 3.5-dinitrosalicylic acid (ADNS) method, following the methodology proposed by Silva et al. (2003), performed in 10 repetitions. Minerals (calcium, magnesium, phosphorus, copper, iron, manganese, zinc, and sulfur) were determined based on Malavolta et al. (1997) using flame spectrometry, all in triplicate.

2.4 Anti-nutritional factors

The trypsin inhibitor content was determined as described by Arnon (1970), with extraction at neutral pH, in three repetitions covering four readings per extract. The presence of hydrocyanic acid was evaluated through the Guignard test, a qualitative technique that consists of confirming the presence or absence of cyanides. Plum seed was used as a comparative standard (Araújo, 2011) containing cyanogenic glycoside precursors of hydrocyanic acid. The analyses were performed in three replications.

Phytic acid, condensed tannins, and total tannins were determined upon preparing three extracts, which, in turn, provided 12 readings in the CB, FCPB, SB, and FSB fractions. Phytic acid levels were determined following the method described by Latta and Eskin (1980), using DOEX-Cellulose resin (ion-exchange resin) and a 2.4% HCL extracting solution, according to Vilela et al. (1973). The content of condensed tannins was estimated by spectrophotometry (RAYLEIGH UV-1800), using methanol as an extracting agent, based on the adapted method of Barcia et al. (2012). The method proposed by Swain and Hillis (1959) was applied to determine the total tannin content, using water as an extracting agent.

2.5 Technological analyses of flours

The methodology described by Okezie and Bello (1988) and the equation proposed by Anderson et al. (1969) were applied to determine the water absorption index (WAI), water solubility index (WSI), oil absorption capacity (OAI), and the milk solubility index (MSI) and milk absorption index (MAI).. The analyses were performed in 10 repetitions.

2.6 Extraction and analysis of pigments

Chlorophyll was quantified according to Engel and Poggiani (1991), whereas the total anthocyanin content was determined based on the method adapted from Barcia et al. (2012). Carotenoids were extracted according to Sérino et al. (2009), and both identified and quantified by high-performance liquid chromatography (HPLC), in a chromatograph (Shimadzu, LC-20AT series, Tokyo, Japan) equipped with an isocratic pump system (LC-20AT), automatic injector (SIL 20A), UV-VIS detection system (SPD-20A), and column oven (CTO 6A). A C18 column (LiChroCART 250-4 LiChrospher® 100 RP-18 end-capped 100 x 4.6 mm–5 µm—Merck) was used, reaching an extract injection volume of 20 µL. The mobile phase consisted of acetonitrile:water:ethyl acetate (53:7:40, v/v/v), at a flow rate of 1 mL/min. The temperature was maintained at 30°C throughout the analysis. Absorbance spectra were acquired by scanning (200–600 nm), with monitoring at four wavelengths: 474 nm for lycopene, 454 nm for β-carotene, 286 nm for phytoene, and 448 nm for lutein. Identification was performed by comparing the retention time of the standards and the quantification based on curves built using five different concentrations of the standards.

2.7 α-Tocopherol

Vitamin E (α-, β-, γ-, δ-tocopherol) content was determined by HPLC (Melo & Almeida-Muradian, 2010; Presoto et al., 2000). The extracts were obtained from 5 g of sample, in triplicate. A fluorescence detector (RF-10AXL) set for 295 nm excitation, 330 nm emission, and Shim-pack CLC-Sil (M) silica column (25 × 4.6 mm particle size 5 µm) were used. A mixture of hexane:isopropyl alcohol (99:1, v/v) was used as the mobile phase, after being filtered and degassed, at a flow rate of 1.5 mL/min. Tocopherols were identified by comparing the retention time of synthetic standards and quantified using an external standardization curve, with at least five concentration levels for each standard. The equation described by Holland et al. (1991) was applied to calculate vitamin E in the samples.

2.8 Antioxidant capacity

2.8.1 Preparation of extracts

The bioactive compounds were extracted based on the protocol described by Sousa et al. (2018), in triplicate, using a 1:30 ratio (sample: solution, m/v), with methanol: water solution (60:40, v/v), in an ultrasonic bath (USC2800A, Logen scientific, São Paulo, Brazil; frequency 40 kHz; internal dimension: 293 x 235 x 150 mm) for 11 min. The extracts were centrifuged (3,000 G 15 min at 4°C) in a centrifuge (5403, Eppendorf AG, São Paulo, Brazil), filtered on a synthesized plate filter (G4), stored in amber vials, and kept at -18°C until the timing of spectrophotometric and chromatographic analyses.

2.8.2 Identification and quantification of flavonoids and phenolic acids

The UPLC-DAD-MS method was used for this step, using a Luna C18 (2) HST reversed-phase column (100 × 3.0 mm, 2.5 µm; Phenomenex, Torrance, CA, USA). The mobile phase consisted of water with 0.1% formic acid (A) and acetonitrile (B), eluted at a flow rate of 0.5 mL/min in the following gradient mode: starting with A and B in a 95:5 ratio (v/v); followed by up to 8% B increase in 5 min, and increase to 15% B in 8 min; such a condition was maintained for 2 min, which then increased to 20% of B in 12 min, and to 35% of B in 15 min, which was, in turn, maintained for 3 min. Finally, the proportion of B decreased to 5%, which was maintained for 2 min (Silva et al., 2019). The extracts were filtered through 0.22-µm nylon filters (Millipore) for vials with a volume injected of 5 µL, in triplicate. Flavonoids and phenolic acids were identified based on retention time (0–20 min) and quantified using a curve constructed with commercial standards (Sigma Aldrich, St. Louis, MO, USA).

2.8.3 Determination of antioxidant capacity

DPPH and ABTS assays were performed. The free radical scavenging capacity (DPPH) and the radical reduction capacity test (ABTS) were determined following the methods described by Rufino et al. (2007) and Rufino et al. (2010), respectively.

2.9 Statistical analysis

The experiment was carried out in a completely randomized design (DIC), with a factorial of 2 x 2, *in natura* and dehydrated portions. For comparison, the means were submitted to an analysis of variance, which, upon indicating a significant value, was followed by the t-test (Student), at a confidence level of 95%. Experimental results were presented as mean ± standard deviation. The SISVAR program was used for assistance (Ferreira, 2014).

3 RESULTS AND DISCUSSION

3.1 Morphology and Yield

Table 1 shows the morphological features of fresh bacaba fruit and the yield of the peel+pulp and seed fractions. The fruit reached an average mass of 3.73 g, with transverse and horizontal diameters of 16.97 mm and 21.65 mm, respectively. These values indicate a slight variation compared to those found by Seixas et al. (2016), who reported average transverse/horizontal parameters of 18.00 and 19.00 mm, as well as an average mass of

Table 1. Morphological features and yield of fresh bacaba fruit (*Oenocarpus bacaba* Mart.), 2018/2019 harvest, sold at a street market in Itacajé, Tocantins, Brazil.

Parameters	Fruit[1]
Mass (g)	3.73 ± 0.45
Diameter (mm)	16.97 ± 1.24
Length (mm)	21.65 ± 1.33
Peel+pulp (g)	1.26 ± 0.37
Seed (g)	2.38 ± 0.36
Yield (%)	
Peel+pulp	34.36 ± 8.84
Seed	63.41 ± 3.68

[1]The values correspond to the means ± standard deviation of 30 measurements.

2.20 g for the same fruit. These differences can be attributed to variations in the sampling methodology, climatic conditions during the growth period, or even genetic differences intrinsic to the bacaba populations studied.

In addition, this study highlighted that the bacaba seed represents approximately 63% of the total weight of the fruit, which is a significant finding as it indicates that most of the fruit is made up of seed, which is often discarded in traditional processing. Such a remark meets the growing need to add value to co-products in the food industry, as pointed out by Satari and Karimi (2018). The valuation of the bacaba seed could not only mitigate environmental problems associated with waste disposal but also provide a potential source of bioactive compounds.

3.2 Physicochemical composition and technological properties

Table 2 shows the proximal, chemical, and physical composition, mineral content, technological properties, and nutritional compounds, as well as bioactive compounds of the bacaba fractions. The values of moisture (42.85%), acidity (4.94 g/100 g), and water activity (0.988) found in CPB indicate that this fraction is more prone to developing molds and yeasts, thus representing a challenge in terms of storage and transportation. Concerning SB and FSB, the reduction in moisture (38.84%–7.83%) and water activity (0.938 and 0.546) from the fresh fraction to the flour also suggests that the flour form offers greater chemical and microbiological stability (Canuto et al., 2010).

As for the ash composition, the CPB fraction showed a content of 1.70 g/100 g, while SB reached 1.46 g/100 g. These values

Table 2. Proximal composition (g/100 g), chemical, physical, mineral content (mg/100 g), and technological properties of the peel+pulp fractions *in natura* (CPB), peel+pulp flour (FCPB), seed *in natura* (SB), and seed flour (FSB), on a dry basis, of bacaba (*Oenocarpus bacaba* Mart.), 2018/2019 harvest, collected in the state of Tocantins, Brazil.

Parameters	CPB	FCPB	SB	FSB
Moisture (%)	42.85 ± 0.36^{a}	1.64 ± 0.11^{b}	38.84 ± 0.22^{A}	7.83 ± 0.23^{B}
Ashes	1.70 ± 0.11^{b}	1.83 ± 0.16^{a}	1.46 ± 0.11^{B}	1.98 ± 0.20^{A}
Proteins	5.74 ± 0.38^{a}	5.13 ± 0.20^{b}	5.14 ± 0.36^{A}	5.41 ±0.10^{A}
Lipids	31.83 ± 1.34^{a}	29.11 ± 0.09^{b}	1.41 ± 0.27^{B}	2.77 ± 0.47^{A}
Total carbohydrates	60.73 ± 1.57^{a}	63.93 ± 0.28^{b}	91.99 ± 0.42^{A}	89.84 ±0.53^{B}
Total caloric value (Kcal.100 g^{-1})	552.28 ± 6.37^{a}	538.23 ± 0.61^{b}	401.15 ± 1.43^{B}	405.90 ± 2.60^{A}
Insoluble fiber	21.26 ± 0.31^{b}	37.18 ± 2.20^{a}	39.03 ± 1.31^{B}	63.75± 2.87^{A}
Soluble fiber	1.09 ± 0.24^{b}	1.34 ± 0.29^{a}	0.91 ± 0.34^{B}	1.49 ± 0.55^{A}
Total dietary fiber	22.35 ± 1.55^{b}	38.52 ± 2.59^{a}	39.94 ± 1.65^{B}	65.23 ± 2.69
Reducing sugars	0.56 ± 0.01^{b}	0.98 ± 0.02^{a}	1.46 ± 0.11^{A}	1.58 ± 0.12^{A}
Non-reducing sugars	0.02 ± 0.01^{a}	0.02 ±0.01^{a}	2.14 ± 0.23^{A}	2.32 ± 0.32^{A}
Total sugars	0.58 ± 0.01^{b}	1.00 ± 0.02^{a}	3.60 ± 0.22^{A}	3.90 ± 0.24^{B}
pH	4.94 ± 0.01 ^{b}	5.35 ±0.00^{a}	5.27 ± 0.00^{A}	5.24 ± 0.10^{B}
ATT[2] (g.100 g^{-1})	5.40 ± 0.99^{a}	0.70 ± 0.03^{b}	0.61 ± 0.02^{A}	0.71 ± 0.04^{A}
SS[3] (°Brix)	6. 30 ± 0.87 ^{a}	2.7 ± 0.38^{b}	5.80 ± 0.46^{A}	5.31 ± 0.43^{B}
Aw	0.988 ± 0.002^{a}	0.326 ± 0.017^{b}	0.938 ± 0.00^{A}	0.546 ± 0.015^{B}
L*	40.42 ± 2.47^{a}	26.53 ± 0.33^{b}	53.20 ± 0.75^{A}	53.06 ± 0.23^{A}
a*	5.93 ± 1.16^{a}	3.49 ± 0.17^{b}	6.81 ± 0.16^{A}	6.67 ± 0.14^{A}
b*	11.23 ± 2.48^{a}	2.24 ± 0.26^{b}	16.00 ± 0.22^{A}	12.46 ±0.20^{B}
Chroma	12.85 ± 2.68^{a}	4.12 ± 0.29^{b}	17.44 ± 0.25^{A}	14.13 ± 0.23^{B}
Potassium	47.72 ± 4.38^{b}	50.45 ± 4.63^{a}	380.00 ± 50.33^{B}	412.28 ± 54.66^{A}
Phosphorus	33.40 ± 0.00^{a}	35.32 ± 0.00^{a}	111.00 ± 0.58^{B}	120.43 ± 0.63^{A}
Calcium	136.34 ± 11.81^{b}	144.14 ± 12.58^{a}	ND	ND
Magnesium	102.26 ± 3.94^{b}	108.11 ± 4.16^{a}	ND	ND
Iron	6.09 ± 0.39^{b}	6.44 ± 0.42^{a}	7.26 ± 0.05^{B}	8.52 ± 0.05^{A}
Copper	0.83 ± 0.00^{a}	0.88 ± 0.00^{b}	0.92 ± 0.07^{B}	1.08 ± 0.08^{A}
Manganese	3.35 ± 0.05^{b}	3.54 ± 0.01^{a}	1.39 ± 0.18^{B}	1.63 ± 0.22^{A}
Zinc	0.98 ± 0.00^{b}	1.03 ± 0.00^{b}	0.86 ± 0.03^{B}	1.01 ± 0.03^{A}
WSI[2] (%)	-	6.88 ± 1.31^{b}	-	10.51 ± 0.95^{a}
WAI[3] (g. gel/g)	-	3.76 ± 0.24^{a}	-	3.38 ± 0.11^{b}
OAI[4] (%)	-	2.64 ± 0.24^{a}	-	2.02 ± 0.05^{b}
MSI[5] (%)	-	33.96 ± 5.11^{a}	-	2.90 ± 0.97^{b}
MAI[6] (g. gel/g)	-	1.59 ± 0.64^{a}	-	1.30 ± 0.36^{a}

[1]Values correspond to means ± standard deviation; *Lowercase and uppercase letters on the same line do not differ statistically from each other in the t-test at 5% ($p > 0.05$); [2]Titratable acidity expressed as citric acid; [2]Water solubility index; [3]Water absorption index; [4]Oil absorption capacity; [5]Milk solubility index; [6] Milk absorption index; (-) not carried out; ND: not detected.

are important indicators of the mineral content of the fruit. Such findings are especially important considering the standards set by Brazilian legislation (Brasil, 2005), which established a maximum ash limit of 2% on a dry basis for flours. However, the ash content was slightly lower than that found by Ribeiro et al. (2017) in fresh bacaba seeds (1.65 g ash/100 g). In addition, all fractions showed protein contents higher than 5 g/100 g, suggesting that bacaba can be a good source of protein in the diet, representing more than 10% of an adult's daily requirement, as reported by Ervin (2004).

The CPB fraction had a high lipid content (31.83 g/100 g) and a lower total carbohydrate content (60.73 g/100 g) but had a higher calorific value (552.28 Kcal/100 g) when compared to the FCPB fraction, which had 29.11 g/100 g of lipids and 63.93 g/100 g of total carbohydrates, resulting in 538.23 Kcal/100 g. Concerning these same contents, the SB and FSB fractions had closer values but were statistically different ($p < 0.05$). The biggest difference between the fresh and dehydrated seed fractions was in the lipid content, which was higher in FSB (2.77 g/100 g) compared to fresh (1.41 g/100 g), probably since dehydration has concentrated this compound. The lipid content of CPB and FCPB was higher than that found in the peel and pulp of bacaba (21.02 g/100 g), from Pimenta Bueno, Rondônia, Brazil (Seixas et al., 2016). The higher lipid content in CPB and FCPB, compared to that observed in SB and FSB, suggests the possibility of lipid extraction from CPB and FCPB. In addition, the storage of these fractions should be given more attention since the higher the lipid content, the greater the possibility of rancidity and shorter shelf life of the final product. In addition, the analysis of total carbohydrates showed that the SB and FSB fractions could be interesting alternatives as a source of energy for infant foods.

The results showed that all fractions analyzed contained a high fiber content, especially insoluble fiber. The flour fractions (FCPB and FSB) showed particularly high levels of total dietary fiber, exceeding 38% and 65%, respectively. This finding is particularly relevant in the context of ANVISA (Brasil, 2012) guidelines, which classify food as a source of fiber upon containing at least 6 g/100 g. Therefore, bacaba flour can be considered an excellent source of fiber. This high fiber content aligns with the health benefits described by Dhingra et al. (2012), including preventing conditions such as obesity and cardiovascular diseases.

The CPB (0.58 g/100 g) showed a lower number of total sugars than the FCPB (1.00 g/100 g), corroborating Santos Filho et al. (2020) for pulps of the same fruit (0.68 g/100 g). The difference between the dehydrated and *in natura* fractions may have resulted from the concentration process that occurs during the drying process. In the SB (3.60 g/100 g) and FSB (3.90 g/100 g) fractions, the contents were significantly the same ($p > 0.05$), showing that the amount of total sugars, whether reductive or non-reductive, in all bacaba fractions are low, thus enabling it to be used, for example, in fermented products, which require a considerable amount of fermentable sugars for the microorganisms in the fermentation process. The soluble solids content confirms such an inference as the values found in the different fractions were lower than 6° Brix.

The pH values in the CPB (4.94) and FCPB (5.25) fractions were similar to those observed by Canuto et al. (2010) in bacaba pulp (5.30). Concerning the SB (5.27) and FSB (5.24) fractions, both were similar to the pH of bacaba seeds *in natura* (5.12) reported by Ribeiro et al. (2017). All bacaba fractions investigated here reached pH values close to 5. According to Franco and Landgraf (2008), foods with a pH above 4.5 are considered to be of low acidity or slightly acidic. The titratable acidity in the CPB (5.40 g citric acid /100 g) and FCPB (0.70 g citric acid /100 g) fractions were lower than those found by Ribeiro et al. (2017) in bacaba pulp (1.48 g citric acid /100 g); in contrast to those found in the SB and FSB fractions, which were much lower than those found by the same authors in the seeds of the fruit *in natura* (3.26 g citric acid /100 g).

In addition, data are congruent when compared with the results from the bibliographical review of Amazonian fruits carried out by Almeida et al. (2023), particularly concerning the variations found in the nutritional content of bacaba. Almeida et al. (2023) reported values for the edible part of bacaba that vary across a wide spectrum. Similarly, Barros et al. (2021) found different values for bacaba peel flour, with a considerably high lipid content, suggesting a variation based on the part of the fruit and the processing method. Some differences in the results might have occurred due to the variation in cultivation, maturation stage, fertilization conditions, climatic factors, and genetic conditions of the plant.

The color components were analyzed for color parameters L*, a*, b*, and chroma. The analysis of the color parameters for the bacaba fractions studied revealed significant changes resulting from the drying process. The drying of the peel+pulp fractions resulted in a darker color, which is consistent with chemical and physical transformations during processing. In comparison, the bacaba peel flour studied by Barros et al. (2021) showed L* values of 19.65, a* of 5.08, b* of 7.87, and chroma of 12.77. Corrêa et al. (2019) also observed a dark hue (L* of 19.03) in bacaba peel. These data indicate that the color of bacaba fractions can vary significantly depending on post-harvest treatment and processing.

As for the mineral profile, the results corroborate the ash analysis, showing a higher amount of minerals in the FCPB and FSB fractions. According to the Institute of Medicine (2006), the average mineral requirement for adults aged between 19 and 70 is 1.8–2.3 mg/day for manganese; 0.9 mg/day for copper; 14 mg/day for iron; 260 mg/day for magnesium; 700 mg/day for phosphorus; 1,000 mg/day for calcium, and 4,700 mg/day for potassium. Therefore, every 100 g of FCPB consumed requires daily 1.01% of potassium, 13.65% of calcium, and 39.33% of magnesium, while for the FSB fraction, every 100 g requires 17.14% of phosphorus and 60.85% of iron.

The technological properties of the fractions studied were measured using the water solubility index (WSI), water absorption index (WAI), oil absorption capacity (OAI), milk solubility index (MSI), and milk absorption index (MAI). Knowing these features is essential to enable these flours to be included in the food industry, hence in the human diet (Barros et al., 2021).

The ISA is crucial to understanding the ability of flours to interact with water. Our study observed that the FCPB fraction had an ISA of 6.88% and the FSB 10.51%, both values

are considerably higher than those of white wheat flour and linseed flour, which have an ISA of 1.15% (Santana et al., 2017). This indicates that bacaba flours, especially FSB, could replace conventional flours in bakery products, offering greater solubility, hence better texture and moisture properties.

Water absorption is desirable in products that require good viscosity, such as soups, sauces, and instant products (Torres et al., 1999), as well as in those whose structure requires hydration and retention of moisture, such as meat and bakery products, and can also improve yield and modify texture (Wang et al., 2006). The WAI values found herein were higher in the FCPB fraction (3.76 g.gel/g), which may be linked to the hydrophilic groups present in these flours, providing them with a greater capacity to absorb water. Trombini et al. (2013) analyzed mixtures of cassava starch, bagasse, and soybean meal and reported WAI variations of 2.35–2.92 g.gel/g, while Santana et al. (2017) found WAI of 14.0 g.gel/g for flaxseed meal.

The amount of oil absorbed per gram of sample is an important characteristic in food formulations, as it improves satiety, taste, and mouthfeel (Odoemelam, 2005; Omosulis et al., 2011). The oil absorption capacity (OAI) was higher in the FCPB (2.64 %) than in the FSB (2.02%), and similar to that found in flaxseed flour (2.39 g.gel/g), as reported by Santana et al. (2017).

The FCPB fraction also showed the best value for ISL (33.69 %), which is an important technological factor for applying flour in breakfast cereals or milk-based cereals, such as instant meals for children, desserts and dairy drinks, creams, cheeses, and sweets (Becker et al., 2014).

3.3 Anti-nutritional compounds, pigments, and antioxidant activity

Table 3 shows the evaluation of the anti-nutritional compounds, pigments, and antioxidant activity of the different bacaba fractions. According to the results (Table 3), cyanogenic acids were absent in all fractions analyzed, which is a positive indication, as these compounds can be toxic.

Phytic acid, known for its ability to bind to minerals and reduce their bioavailability, was not detected in the peel+pulp fractions, both fresh and in flour form. However, in the seeds and their flour, the levels of phytic acid were significantly high, with 115.92 ± 18.06 mg phytic acid/100 g and 125.80 ± 19.73 mg phytic acid/100 g, respectively. This suggests that the bacaba seed may have an impact on mineral absorption, which should be considered in its dietary use. However, this presence can be reduced, as proposed by Vadivel and Biesalski (2012), who found that by applying methods such as immersion in an alkaline $NaHCO_3$ solution (0.2%) and the cooking process, there is a loss of 30–41% of phytic acid in seeds.

In turn, trypsin inhibitors were found in the bacaba fractions in small quantities (0.51–1.09 ITU/mg) compared to flours already on the market, such as soy flour (33.63 ITU/mg) and chickpea flour (23.05 ITU/mg) (Avilés-Gaxiola et al., 2018). The values found in the bacaba fractions after dehydration corroborate those reported by Del-Vechio et al. (2005), who found a reduction in the values of this anti-nutritional after subjecting pumpkin seeds (*Cucurbita* spp.) to the cooking process for 10 min. In fact, it is well-known that trypsin inhibitors have a protein base; therefore, heat denatures this component, thus preventing its action in the human body.

No condensed tannins were found in the CPB and FCPB fractions; however, total tannins appeared in all parts of the fruit (Table 3). Condensed tannin levels of 15.08 and 15.09 mg CAE/100 g were found in the SB and FSB fractions, respectively. Even though the literature has no reports as to the limit of condensed tannins in fresh seeds or bacaba seed flour, these values are lower than those found in fruits native to the Brazilian Cerrado, namely 134 mg CAE/100 g in the pulp of *Anacardium nanum*, and 112 mg CAE/100 g in the pulp of *Anacardium othonianum* (Rocha et al., 2011). Total tannins, like phytates, have been shown to have a beneficial effect on health, as reported by Gibson et al. (2017) and Anunciação et al. (2019).

Concerning pigments, carotenoid levels were only found in the CPB and FCPB fractions, with no significant difference ($p < 0.05$) between the values. These results were similar to those found by Barros et al. (2017) in a study of bacaba peel, pulp, and seeds (average content of 15.47 mg β-carotene/mg). The antioxidant activity, measured by the DPPH and ABTS tests, was significantly higher in the fractions of the seed and its flour. The seed fraction showed an extremely low DPPH IC50 (0.20 ± 0.12A mg/L), indicating strong

Table 3. Anti-nutritional compounds, pigments, and antioxidant activity of the peel+pulp *in natura* (CPB), peel+pulp flour (FCPB), seed *in natura* (SB), and seed flour (FSB), on a dry basis, of bacaba (*Oenocarpus bacaba* Mart.), 2018/2019 harvest, collected in the state of Tocantins, Brazil.

Parameters	CB	FCPB	SB	FSB
Cyanogenic acids	Absent	Absent	Absent	Absent
Phytic acid (mg phytic acid/100 g)	ND	ND	115.92 ± 18.06^{A}	125.80 ± 19.73^{A}
Trypsin inhibitor (ITU/100 mg)	0.51 ± 0.12^{a}	0.52 ± 0.12^{a}	1.01 ± 0.48^{A}	1.09 ± 0.49^{A}
Condensed tannins (mg catechin/100 mg)	ND	ND	15.08 ± 3.90^{A}	15.09 ± 3.93^{A}
Total tannins (mg tannic acid/100 g)	0.46 ± 0.07^{a}	0.47 ± 0.08^{a}	1.31 ± 0.08^{B}	1.42 ± 0.10^{A}
Anthocyanins (cyanidin 3-glycoside/100 g)	3.27 ± 0.77^{a}	3.33 ± 0.78^{a}	4.78 ± 1.05^{B}	5.19 ± 1.14^{A}
Carotenoids (mg β-carotene/mg)	11.60 ± 0.37^{a}	11.90 ± 0.38^{a}	ND	ND
DPPH (IC_{50} mg/L)	18.68 ± 0.85^{a}	2.89 ± 0.33^{a}	0.26 ± 0.12^{A}	0.20 ± 0.12^{A}
ABTS (μM ETrolox/mg)	910.04 ± 53.33^{b}	939.82 ± 51.36^{a}	4494.47 ± 79.94^{B}	5307.87 ± 75.78^{A}

[1]The values correspond to the means ± standard deviation of 10 repetitions. ITU (trypsin inhibitor unit); *Lowercase and uppercase letters on the same line do not differ statistically from each other in the Tukey test at 5% ($p < 0.05$) or the t-test at 5% ($p < 0.05$); ND: not detected.

antioxidant activity. Similarly, the antioxidant activity measured by the ABTS test was higher in the seed fractions, with 5,307.87 ± 75.78 μM ETrolox/mg in the seed flour.

Santos et al. (2022) found higher values for anthocyanins (21.32 and 17.15 mg/100 g), carotenoids (1,068.30 mg/100 g and 908.17 mg/100 g), and antioxidant capacity (ABTS: 75.50 and 63.45 μmolTrolox g^{-1}, DPPH: 1,550.10 and 1,757.30 g g^{-1}) for freeze-dried bacaba and convection-dried bacaba, respectively. This suggests that the type of processing and drying method used may influence the content of these pigments and antioxidant activity.

Table 4 shows the phenolic acid and flavonoid content of the fractions studied. The results reveal a marked variation in the profile and quantity of phenolic compounds between the different fractions of the fruit. In CPB, six phenolic acids and four flavonoids were detected, which is close to the findings of Finco et al. (2012), also for bacaba fruit. In the CPB, the levels of protocatechuic acid (5.18 mg/100 g), synaptic acid (8.0 mg/100 g), epicatechin (8.04 mg/100 g), and procyanidin A2 (13.32 mg/100 g) stood out. As to the seed (SB) and its flour (FSB), the highlights were the content of epicatechin (32.64 mg/100 g and 35.4 mg/100 g, respectively), procyanidin A2 (45.75 mg/100 g and 49.64 mg/100 g, respectively), and catechin (14.26 mg/100 g and 15.47 mg/100 g, respectively).

These results corroborate those of antioxidant capacity, suggesting that these compounds may play a relevant role in the antioxidant capacity of the fractions. Zanwar et al. (2014) reported a detailed study on the antioxidant capacity of catechins and epicatechins, confirming the promising action of each of them through both in vitro and in vivo methodologies.

LC-MS/MS analyses were carried out to confirm the identities of the phenolic compounds in the bacaba genotypes, identifying the catechin compounds in both HPLC-DAD and MS, while the others were not confirmed. According to Rijke et al. (2006), such a result is linked to the fact that many phenolics and flavonoids exhibit low sensitivity in MS analyses in positive ionization mode, thus being preferentially detected in negative ionization mode. There are not many studies in the literature on bioactive compounds identified by MS in bacaba. Therefore, it would be interesting to use bacaba fruit fractions in food production, especially in the form of flours, as these compounds, whose presence may be beneficial to health, could act on the food itself, preventing its oxidation and stabilizing lipids, thus avoiding losses in nutritional, sensory, and/or technological quality, increasing shelf life, and preserving attributes such as color, texture, aroma, flavor, and the overall quality of the product (Damodaran & Parkin, 2018).

4 CONCLUSION

The physical, chemical, nutritional, anti-nutritional, and technological characterization of the fractions of the Brazilian Amazonian fruit bacaba revealed remarkable aspects that emphasize its potential for integral and sustainable use. The peel+pulp fraction is rich in lipids, and its flour is a promising source of dietary fiber with good solubility in milk. The bacaba seed and its flour are high in total carbohydrates and dietary fiber, with the iron content and water solubility of the flour standing out. All fractions have antioxidant capacity, with the presence of compounds such as epicatechin and procyanidin A2. Concerning anti-nutritionals, no cyanogenic acids were detected in any of the fractions evaluated; however, there is a trypsin inhibitor and total tannins in the peel+pulp fraction, as well as phytic acid, trypsin inhibitor, and tannins in the seeds and seed flour.

In short, our results reinforce the importance of bacaba as a promising food resource, with significant implications for nutrition, health, and sustainability. The industrialization and full use of this Amazonian fruit offer valuable opportunities from a nutritional, environmental, and social point of view, contributing to the valuation of regional foods and the diversification of agri-food chains.

ACKNOWLEDGMENTS

The authors would like to thank USP and UFG for the structure provided, allowing all the analyses to be carried out, and the National Council for Scientific and Technological Development (CNPq, Brazil) for its financial support, through the granting of a master's degree scholarship and a productivity scholarship.

Table 4. Content of phenolic acids and flavonoids (mg/100 g of sample, on a dry basis), quantified by HPLC-DAD, in the peel+pulp in natura (CPB), peel+pulp flour (FCPB), seed *in natura* (SB), and seed flour (FSB) of bacaba (*Oenocarpus bacaba* Mart.), 2018/2019 harvest, collected in the state of Tocantins, Brazil.

	T_R (mim)	λ (nm)	CPB	FCPB	SB	FSB
Gallic acid	2.3	271	0.33 ± 0.11[a]	0.21 ± 0.12[a]	ND	ND
Protocatechuic acid	4.4	259	5.18 ± 0.26[b]	9.99 ± 0.70[a]	4.56 ± 0.52[A]	4.95 ± 0.57[A]
p-hydroxybenzoic acid	7.1	254	0.97 ± 0.01[b]	2.94 ± 0.17[a]	3.76 ± 0.42[A]	4.07 ± 0.46[A]
Vanillic acid	9.1	259	1.58 ± 0.20[a]	1.57 ± 0.11[a]	0.75 ± 0.05[A]	0.81 ± 0.05[A]
Ferulic acid	13.4	322	2.57 ± 0.38[a]	1.10 ± 0.03[b]	ND	ND
Synaptic acid	13.4	324	8.00 ± 0.68	ND	ND	ND
Epicatechin	10.2	276	8.04 ± 0.36[a]	6.16 ± 0.53[a]	32.64± 2.59[A]	35.41 ± 2.81[A]
Procyanidin A2	8.1	235	13.32 ± 0.98	ND	45.75 ± 12.53[A]	49.64 ± 13.60[A]
Rutin	13.9	354	1.53 ± 0.26	ND	ND	ND
Catechin	8.3	276	4.72 ± 0.58	ND	14.26 ± 2,51[A]	15.47 ± 2.72[A]

[1]The values correspond to the means ± standard deviation of 10 repetitions; *Lowercase and uppercase letters on the same line do not differ statistically from each other in the Tukey test at 5% ($p < 0.05$) or the t-test at 5% ($p < 0.05$); ND: not detected.

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