



Nutritional and antioxidant characterization of açai (*Euterpe oleracea* Mart.) seed flour as a sustainable functional ingredient

Elaine Cristina de Souza LIMA¹ , Ana Carolina Veiga de OLIVEIRA¹ , Ellen Mayra Menezes AYRES¹ ,
Edna Ribeiro dos SANTOS² , Márcia Barreto da Silva FEIJÓ³ , Juliana dos Santos VILAR^{4*} ,
Armando Ubirajara Oliveira SABAA-SRUR^{4,5†}

Abstract

The açai palm (*Euterpe oleracea* Mart.) is native to the Amazon region, with its berry containing 30% pulp and 70% seed. While the pulp is widely consumed, the seed, which constitutes most of the fruit's mass, is typically discarded, generating significant agro-industrial waste. This waste can be repurposed to reduce environmental impacts and promote circular economy practices. Açai berry seeds are rich in polyphenols and antioxidants, offering potential health benefits, such as preventing obesity, hepatic steatosis, and cancer. This study aims to evaluate açai berry seed flour for its nutritional and antioxidant properties, contributing to sustainability by using waste from the açai pulp production. Açai seeds were dried and ground into flour. Then, they were analyzed for fiber content, phenolic compounds, and antioxidant activity. The results showed a high content of insoluble fibers, including cellulose, hemicellulose, and lignin. The açai berry seed flour also exhibited significant antioxidant activity, with an IC50% of 3.29 mg/mL, highlighting its potential as a valuable functional ingredient.

Keywords: açai seed flour; antioxidant activity; nutritional properties.

Practical Application: Use of açai seeds as a sustainable functional ingredient.

1 INTRODUCTION

The açai palm (*Euterpe oleracea* Mart.) is a palm tree native to the Amazon region (Nascimento et al., 2008; Oliveira et al., 2000). Its berry is a globular drupe, measuring 1 to 2 cm in diameter and weighing an average of 1.5g. The epicarp, depending on the type, is purple at maturity or green when not. The mesocarp and the epicarp together make up 7% of the fruit, surrounding the large, hard endocarp, which is responsible for the shape of the fruit, containing the seed inside. Commonly, what is referred to as the seed is actually the pyrene, as the seed is still surrounded by the endocarp. The seed exhibits a solid ruminated endosperm at maturity and a small but developed embryo (Nascimento et al., 2008; Oliveira et al., 2000; Pereira et al., 2021). Notably, 30% of the açai berry corresponds to pulp, while 70% corresponds to the seed (Monteiro et al., 2019).

Brazilian production of açai reached 1,696,485 tons in 2023 (Instituto Brasileiro de Geografia e Estatística [IBGE], 2024). According to the Consumer Expenditure Survey (POF) from

IBGE, there was a decrease in the consumption of fruits such as pineapple, orange, apple, and tangerine across all income levels, while there was an increase in açai berry consumption in all income quartiles (IBGE, 2025).

The large production and, therefore, the high consumption of açai berry are due to its established nutritional, cosmetic, and pharmaceutical properties (Laurindo et al., 2023; Magalhães et al., 2020; Yamaguchi et al., 2015). Açai berry consumption occurs mainly as pulp; however, the manufacturing process for obtaining it generates approximately 85 to 93% waste. This substantial waste output indicates that the material still lacks adequate economic disposal methods, leading to its stockpiling around industrial facilities (Laurindo et al., 2023; M. A. C. N. Silva et al., 2023; Monteiro et al., 2019; M. S. Silva et al., 2023; Santos et al., 2020).

Utilization of classified waste products, such as açai seeds, is recognized as an effective measure to enhance the reduction of environmental impacts and encourage public policies for circular economies (Barbosa et al., 2019; Martinez et al., 2018;

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¹Universidade Federal do Estado do Rio de Janeiro, Rio de Janeiro, Rio de Janeiro, Brazil.

²Faculdade Bezerra de Araújo, Rio de Janeiro, Rio de Janeiro, Brazil.

³Universidade Federal Fluminense, Niterói, Rio de Janeiro, Brazil.

⁴Universidade Federal do Rio de Janeiro, Rio de Janeiro, Rio de Janeiro, Brazil.

⁵Universidade Federal Rural do Rio de Janeiro, Seropédica, Rio de Janeiro, Brazil.

[†]in memoriam

*Corresponding author: julianavilar@nutricao.ufrj.br

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Martins et al., 2021; Teixeira & Mendes, 2023; Zavarize & Oliveira, 2021).

Studies on the utilization of açaí berry seeds have been conducted from a nutritional perspective, focusing on the treatment and prevention of diseases, primarily due to the higher amount of polyphenols compared to its pulp (Alencar, 2020; Soares et al., 2020). Hence, açaí seeds have been associated with the prevention of obesity (Santos et al., 2020) and obesity-induced hepatic steatosis (Silva et al., 2021). Due to their high antioxidant capacity, they may also be related to cancer prevention (Martinez et al., 2018; M. S. Silva et al., 2023; Silva et al., 2021).

The great amount of waste produced by the high consumption of açaí pulp requires a more effective management. Therefore, this research aimed to analyze açaí seed flour as a source of nutrients derived from unconventional parts—in terms of human consumption—reducing environmental impacts, creating financial resources, and exploring new applications for the waste, thereby contributing to sustainability in the production and marketing of this berry.

1.1 Relevance of the work

The present work promotes the utilization of the açaí seed, an abundant and usually discarded by-product. By characterizing the flour obtained from açaí seeds, this study contributes to the valorization of agro-industrial residue, aligning with sustainable development goals. The results highlight the potential of açaí seed flour as an ingredient with antioxidant potential to be used for human consumption, promoting innovation, sustainability, and upgraded value to the açaí production chain.

2 MATERIAL AND METHODS

2.1 Raw material

The berries were pulped at an agricultural facility in the State of Pará (Northern region of Brazil), and their seeds were supplied to be used in this study. After being solar dried, they were sent packaged in cardboard boxes to the Food Processing Laboratory (LAPAL) of the Josué de Castro Institute of Nutrition (INJC) – UFRJ, Rio de Janeiro (Southeastern region of Brazil).

2.2 Production of açaí berry seed flour

Initially, the açaí seeds were sanitized in potable water and dehydrated in a ventilated oven at 60 °C for 40 h. After drying, the central seed was removed, and the remaining material was ground in a hammer mill (TECNAL TE-360). The obtained flour was packaged in plastic bags made of nylon and polyethylene, providing high protection against water vapor and atmospheric oxygen. Once vacuum-sealed, the bags were labeled and stored under refrigeration (Lima et al., 2021).

2.3 composition (characterization) of açaí berry seed flour

- Total Fiber (Soluble and Insoluble): The dietary fiber fractions were determined according to the recommendations

of the Physico-Chemical Methods for Food Analysis from the Adolfo Lutz Institute (Instituto Adolfo Lutz, 2008).

- Glucose, Cellulose, Hemicellulose, and Lignin: Their content was established according to the methodologies established by Sluiter et al. (2008) and Ververis et al. (2007).

- Total Anthocyanins: The total anthocyanin content was measured via spectrophotometric reading of the extract in buffers at pH 1.0 and pH 4.5, based on the sensitivity of these compounds to pH (Fuleki & Francis, 1968a, 1968b).

- Analysis of Cyanidin-3-O-Glucoside and Cyanidin-3-O-Rutinoside: The extraction conditions used methanol at 100 °C and 10.3 MPa pressure in a solvent-assisted extractor. The obtained extracts were analyzed for cyanidin-3-O-glucoside and cyanidin-3-O-rutinoside using the liquid chromatography coupled with tandem mass spectrometry (LC-MS/MS) method (Dupureur et al., 2012).

- Antioxidant Activity by the ABTS•+ Radical Scavenging Method [2,2-Azino-bis (3-ethylbenzothiazoline)-6-sulfonic Acid]: Antioxidant activity equivalent to Trolox was determined according to the procedure proposed by Re et al. (1999), with modifications. Initially, the ABTS+ radical was generated from the reaction of 7 mM ABTS with 140 mM potassium persulfate, homogenized, and stored at room temperature and in the absence of light for 16 h. After this period, the solution was diluted in ethanol until an absorbance of 0.70 nm (± 0.02) was obtained. For the analyses, a 30 μ L aliquot of each dilution of the extract was added to test tubes containing 3.0 mL of the ABTS+ radical and homogenized in a tube shaker. The reading (734 nm) was taken after 6 min of mixing, using ethanol as a blank to calibrate the spectrophotometer. As a standard solution, the synthetic antioxidant Trolox was used at concentrations ranging from 100 to 2000 mM in ethanol. The results were expressed in mM of Trolox per gram of sample (Alves et al., 2013).

- Antioxidant Activity: The methodology used to determine total activity was adapted from the descriptions by Brand-Williams et al. (1995), Rufino et al. (2007), and Sánchez-Moreno et al. (1998). Extracts were prepared from the samples using 80% methanol at 70 °C for 10 min, homogenized and filtered through repeated operations, and subsequently concentrated in a rotary evaporator at 40 °C for 15 min. Absorbance was measured at 517 nm after 15, 30, and 60 min of reaction.

- Total phenolics: The determination of total phenolics in ASF followed the methodology described by Singleton & Rossi (1965). A 500 μ L aliquot was mixed with 2.5 mL of 10% Folin-Ciocalteu reagent, allowed to stand at room temperature for 2 min, and then 2 mL of sodium carbonate solution was added. The tubes were homogenized in a vortex and placed in a water bath at 50 °C for 15 min. Subsequently, the tubes were placed in an ice bath for 30 s, and absorbance was measured at 760 nm. The time between the addition of the Folin solution and the spectroscopic reading did not exceed 30 min. The total phenolic content was calculated using a gallic acid standard curve. The results were expressed in g/100g of gallic acid per sample on a dry weight basis.

2.4 Scanning electron microscopy

A small portion of the ASF was taken and examined under a scanning electron microscope (SEM) for microstructure analysis. The microscope used for sample visualization was the JSM-6460LV Scanning Electron Microscope. The images generated by secondary electrons, accelerated at a voltage of 5 kV, were evaluated. The images were captured in digital format (Toneli et al., 2008).

2.5 Nuclear magnetic resonance

For the analysis, a Bruker Avance DRX300 nuclear magnetic resonance (NMR) spectrometer was used, equipped with a 7 mm cross-polarization with magic angle rotation (CPMAS) probe. The ASF was ground to obtain a fine powder of 500 μ m. It was placed in a 7 mm rotor and centrifuged at 5 kHz. The operating frequency was 300.13 MHz for protons and 75.48 MHz for carbon (Dixon et al., 1982).

2.6 Statistical analyses

The analysis of variance and mean comparison test, including the Tukey test, were conducted using the XLSTAT software (2021).

3 RESULTS AND DISCUSSION

Brazil is a major producer of fruits and vegetables; however, the processing of these edibles generates by-products such as seeds, peels, and pulp, which are generally discarded or used as fertilizers. If not properly utilized, they can cause environmental problems due to their organic matter composition (Araújo & Santos, 2022; Sette et al., 2020). Studies indicate that the composition of açai berry seeds is valuable, as they contain compounds of great interest to the pharmaceutical industry. If effectively exploited, instead of being disposed of into the environment, causing pollution side effects, they could bring notable advantages (Magalhães et al., 2020; Miranda et al., 2022).

Therefore, in this study, açai berry seeds were used to produce a flour that stood out for its insoluble fiber content, total phenolics, and antioxidant capacity. Thus, it can be an alternative for the enrichment of food products, such as beverages (Melo et al., 2021).

Table 1 presents the composition (g/100g) of fibers in the ASF, emphasizing the significant content of total insoluble fiber, hemicellulose, and lignin.

The total fiber content of the ASF was lower than that found in the study conducted by Melo et al. (2021), which reported

86%. However, the insoluble fiber content found in the ASF (62.13%) is higher than that observed in flours obtained from residues, such as tangerine peel flour (48.94%), grape pomace flour (36.27%), green banana flour (7.3%), eggplant flour (34.22%), acerola seed flour (26.54%), and mango peel flour (17.25%) (Ramos et al., 2020, 2021, 2023).

The cellulose content found in the ASF was 5.4 g%, the hemicellulose 33.25g%, and the lignin 23.41g%. These values are higher than the hemicellulose content of grape pomace (5.2%), apple pomace (10.6%) (Sette et al., 2020), apple biomass (27.77%), grape biomass (6.9%), pineapple leaf (19.5%), and mango peel (14.51%) (Gowman et al., 2019).

Table 2 provides the values of 2,2 diphenyl-1-picrylhydrazyl (DPPH) reduction according to the dilution, as well as the equation of the line used to calculate the IC50%. The observed IC50% was 3.29 mg/mL. The results were expressed as the capacity to capture/reduce the DPPH radical in percentage and by the IC50 value, which is an indicative parameter of the inhibitory concentration needed to reduce the free DPPH radical by 50% (Arbos et al., 2010).

The results shown in Table 2 indicate that there was no significant difference ($p < .05$) between the time intervals and the concentration of the analyzed extract; however, a greater efficiency in the sequestration of the free radical was observed at a concentration of 0.1 mg/mL of extract after 30 min.

Table 3 reports the average values of phenolic compounds and antioxidant activity of the ASF. No cyanidin 3-O-glucoside and cyanidin 3-O-rutinoside were detected in the methanolic extracts obtained from the ASF. The antioxidant capacity of the ASF, expressed in DPPH consumption, indicated this product as an excellent source of antioxidants (94.9 ± 0.4).

Regarding total phenolics, the ASF showed higher levels than residues from zucchini, eggplant, broccoli, cabbage, and green beans (Vasconcelos et al., 2023). It also presented higher levels than those found in pineapple peel powder extract (Souza et al., 2021). When compared to avocado seeds, the

Table 1. Fiber composition of the açai berry seed flour.

Component	ASF (g/100 g)
Total soluble fiber	0.86 \pm 0.02
Total insoluble fiber	62.13 \pm 1.19
Cellulose	5.47 \pm 1.15
Hemicellulose	33.25 \pm 1.55
Lignin	23.41 \pm 0.16

ASF: açai berry seed flour.

Table 2. Antioxidant capacity as % of 2,2 diphenyl-1-picrylhydrazyl consumed from different concentrations of açai seed extract after 15, 30, and 60 minutes of reaction with 2,2 diphenyl-1-picrylhydrazyl.

Extract (mg/mL)	% 2,2 diphenyl-1-picrylhydrazyl consumed		
	15 min	30 min	60 min
1	86.33 \pm 0.11	86.25 \pm 0.22	85.72 \pm 0.50
0.1	94.91 \pm 0.11	94.94 \pm 0.44	94.39 \pm 0.51
0.01	94.36 \pm 0.45	94.87 \pm 0.42	94.04 \pm 0.78

There was no statistical difference between the times and concentrations studied according to analysis of variance and Tukey test ($p < .05$).

ASF exhibited higher contents of phenolic compounds and antioxidants, with 57.3 mg GAE/g for avocado seeds and 410.7 $\mu\text{mol TE/g}$ for avocado seeds (Daiuto et al., 2014).

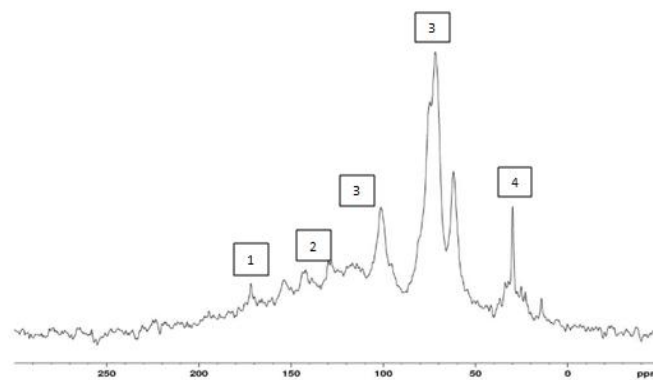
The antioxidant capacity of the ASF, expressed as DPPH consumption, identified this product as an excellent source of antioxidants. However, this antioxidant capacity can be considered lower when compared to the hydroalcoholic extract of guava pulp (0.421 mM.g^{-1}), acerola (0.743 mM.g^{-1}), soursop (0.136 mM.g^{-1}), bacuri (0.0735 mM.g^{-1}), and cupuaçu (0.240 mM.g^{-1}) (Vieira et al., 2011).

Small polyhedral bodies ranging from 1 to 50 μm were observed on the surface of ASF (Figure 1), which are electronically charged and are distinguished from the main matrix by a significant contrast. Based on the fiber content found through chemical analyses, it is suggested that these may be fibers, particularly cellulose or lignin.

The NMR spectra of hydrogen H^1 -decoupled C^{13} -MAS (Magic Angle Spinning) CPMAS (cross-polarization with magic angle rotation) performed on the ASF are shown in Figures 2 and 3.

The MAS spectra produced peaks with greater intensity due to the presence of aliphatic carbon atoms; in contrast, the CPMAS spectra showed better sensitivity and resolution for the other peaks. In Figures 2 and 3, we can observe peaks corresponding to $\text{C}=\text{O}$ (172 ppm), $\text{C}=\text{C}$ (104–153 ppm), glycosidic (56–104 ppm), and aliphatic carbons (14–34 ppm). In contrast, peaks of relatively different sizes were observed due to the glycosidic characteristics of the sample, attributable to the presence of cellulose and hemicellulose, also detected in the chemical fiber analyses and scanning electron microscopy of this study. The glycosidic carbon peaks are larger when compared to the other peaks.

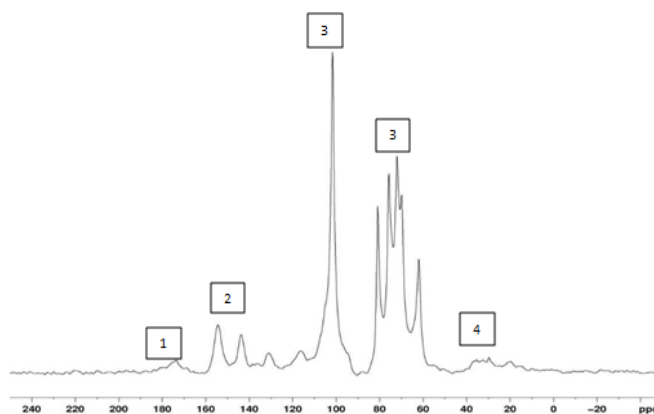
As described by Araújo et al. (2023), scanning electron microscopy of açaí berry seeds detected a hexagonal-shaped



Source: Author, 2024.

1: $\text{C}=\text{O}$; 2: $\text{C}=\text{C}$; 3: glycosidic $\text{C}-\text{O}$; 4: aliphatic carbons.

Figure 2. C^{13} magic angle spinning nuclear magnetic resonance of the açai berry seed flour.



Source: Author, 2024.

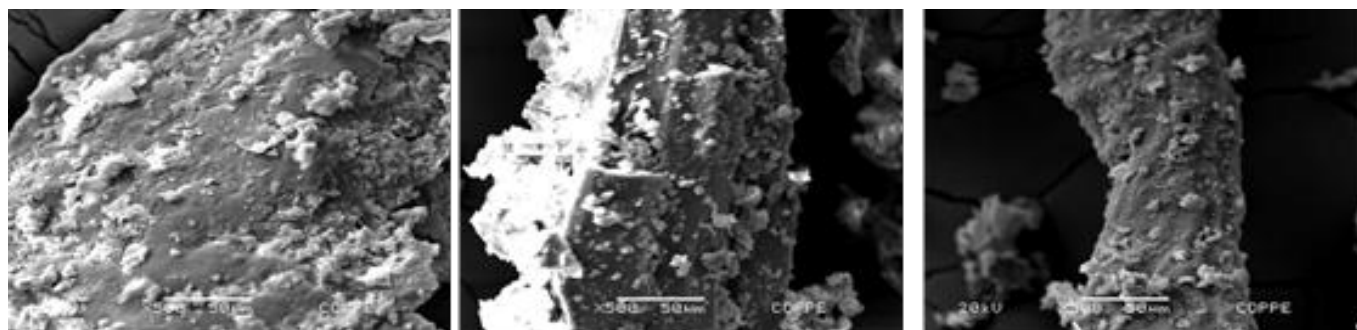
1: $\text{C}=\text{O}$; 2: $\text{C}=\text{C}$; 3: glycosidic $\text{C}-\text{O}$; 4: aliphatic carbon.

Figure 3. H^1 -decoupled C^{13} -magic angle spinning nuclear magnetic resonance of the açai berry seed flour.

Table 3. Phenolic compounds and antioxidant activity of açai berry seed flour.

Analyses	Results
Total anthocyanins (mg/100g)	2.8 \pm 0.1
Total phenolics(mg gallic acid/100g)	8966.5 \pm 38.0
Antioxidant activity ($\mu\text{mol Trolox/g}$)	456.6 \pm 27.0
Antioxidant capacity (% 2,2 diphenyl-1-picrylhydrazyl consumed) ¹	94.9 \pm 0.4

¹2,2 diphenyl-1-picrylhydrazyl 30 min, extract concentration 0.1.



Source: Author, 2024.

Figure 1. Micrograph of açai berry seed flour.

lignocellulosic surface structure, with some fibers scattered throughout the biomass structure.

Thus, the scanning electron microscopy and NMR analyses indicated the presence of hemicellulose and lignin in the ASF, which could enable the utilization of seeds for obtaining xylitol and activated charcoal, respectively (Leal et al., 2025; M. A. C. N. Silva et al., 2023; Rambo et al., 2021). Consequently, there is a promising research trend focusing on the use of açai berry seeds, a by-product still considered a significant technological challenge, but one that could generate jobs and income and reduce the environmental impacts of the uncontrolled disposal of seeds (Leal et al., 2025).

4 CONCLUSIONS

Açai consumption and production have experienced significant growth in Brazil, but its pulp is the most used part, generating waste that is still underused. Nevertheless, the low cost and high availability of these residues, when used appropriately, could generate jobs and income, as well as contribute to reducing environmental impacts.

The analyses conducted in the study indicated that ASF contains significant levels of fiber and phenolic compounds and antioxidant capacity, making it suitable for the production of food and cosmetic products, as well as an alternative for energy generation.

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