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Provenient residues from industrial processing of açaí berries (*Euterpe precatoria* Mart): nutritional and antinutritional contents, phenolic profile, and pigments

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Abstract

With worldwide recognition of the açaí berry as a source of nutrients and promising raw material, its residues/co-products such as peels and seeds have become an environmental problem. The present work aimed to characterize the pulp residue (peel + pulp), fresh dreg, and respective flour, as well as the seed and respective flour. The fractions were analyzed for physical, chemical, technological parameters, antinutritional compounds, and antioxidant profiles. The results showed that the peel + pulp is a source of lipids, soluble and insoluble fiber, potassium, calcium, magnesium, and antioxidants. The fresh dreg is a source of insoluble fiber; dreg flour is a source of carbohydrates and insoluble fiber; the seed and its respective flour are sources of carbohydrates, insoluble and soluble fiber, contain phytic acid, condensed tannins, and antioxidants. Such results demonstrate the possibility of incorporating these co-products in food formulations, besides enabling an efficient destination for these agribusiness residues.

Keywords: Amazonian fruits; exotic fruits; use of co-products.

Practical Application: Discarded fractions from the açaí agribusiness can be viable from a nutritional and technological perspective.

1 Introduction

Açaí (*Euterpe precatoria* Mart.) is a palm tree native to the Brazilian Amazon rainforest, being Brazil its main producer, consumer, and exporter. The fruits measure approximately 1.0–2.0 cm in diameter and are spherical and purple when ripe (Gordon et al., 2012). There was great scientific interest in this fruit due to the beneficial effects on human health related to its phytochemical and nutritional composition. These effects are mainly related to its antioxidant, anti-inflammatory, antiproliferative, and cardioprotective capacities (Alessandra-Perini et al., 2018; Martins et al., 2018; Pala et al., 2018).

In the processing of açaí berries, the pulp is separated from the seeds (which constitute the first residue fraction). In a second stage, the pulp passes through sieves, which remove a paste made up of fibers and other solid residues produced during the pulp's separation from the core, thus forming a second fraction of the residue called dreg. Such residual fractions can be of economic interest and help with the process's sustainability (Buratto et al., 2020). However, it is opportune to verify the possibility of these as food raw material, since it is known that the açaí berry is a source of bioactive compounds (Pessôa et al., 2019), fibers, ash, and proteins, as shown by Silva et al. (2019a). Its seeds are composed of cellulose and hemicellulose, proteins, lipids, and minerals (Rogez, 2000).

In this context, the present study aimed to evaluate the nutritional and antinutritional potential, technological properties and the antioxidant capacity of açai peel + pulp (PP), fresh dreg (FD), dreg flour (DFL), fresh seed (FSE), and seed flour (SEFL), to suggest possible uses of these residues/co-products for the global food industry.

2 Materials and methods

2.1 Materials and reagents

Whole fruits from *Euterpe precatória* and dreg and seed (residues from processing) were donated by the FastAçai® Brazilian company. The whole fruits were analyzed for morphology, such as mass, transversal diameter, and length. The peel+pulp (PP) was obtained by manual pulping without the use of maceration to preserve nutrients and bioactive compounds. The dreg (FD) and the fresh seed (FSE) were divided into three lots: one lot for analysis of soluble solids, pH, acidity, and color; the second

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was stored at a temperature of -18 °C, to carry out the other analyzes; the third lot was dried in a forced-air circulation oven (TE 394/4, Tecnal, Piracicaba, Brazil), at 60 °C, until it reached 15% humidity. After drying, the dreg was ground in a knife mill (Willye START FT 50-Brazil) to obtain the flour (DFL), with a grain size of 25.40 mm. The açaí seeds were crushed in a knife and hammer mill (Nogueira OPM-JR-Brazil), and, later, they were crushed again in a knife mill (Willye START FT 50-Brazil) to reach a grain size of 25.40mm. After this procedure, the açai peel + pulp (PP), the fresh dreg (FD), the dreg flour (DFL), fresh seed (FSE), and seed flour (SEFL) were stored in bags of high-density polyethylene and vacuum-sealed, as shown in Figure 1. The bags were covered with aluminum foil and stored in a freezer at -18°C until the different analyses (physical, chemical, nutritional, antinutritional, and technological).

2.2 Physical analysis of açaí berry and its fractions

The whole fruit was analyzed concerning its mass and yield, using a semi-analytical balance (Scientch/SA 210). For the morphological study regarding the diameter and length, a digital caliper (Vernier Caliper, 0-150 mm) was used, performed on 30 fruits chosen at random.

The water activity was carried out in an AquaLab digital apparatus, CX-2 model, manufactured by DECAGON, at room temperature (± 25 °C). The instrumental color parameters were determined in a colorimeter (Color Quest, XE, Reston, USA), according to the CIELab system. The results were expressed in values L*, a*, b*, with L* (lightness), ranging from black (0) to white (100), a* ranging from green (-60) to red (+60), and b* ranging from blue (-60) to yellow (+60). Chroma (C) was calculated using Equation 1 and angle hue (°) using Equation 2. Thirty determinations were made in each of the açai fractions (PP, FD, DFL, FSE, and SEFL).

$$C = \sqrt{a^2 + b^2} \tag{1}$$

$$Hue(^\circ) = 90 * (arctangente\left(\frac{b^*}{a^*}\right) \tag{2}$$

2.3 Chemical analysis of the açaí

The analytical determinations were performed on PP, FD, DFL, FSE, and SEFL samples. The content of soluble solids was determined by reading the dilution (1:9) in a digital refractometer (AR200, Reichert Analytical Instruments, Depew, New York, USA). This dilution was also used to read the pH, which was determined in a potentiometer (TEC5, Tecnal, Piracicaba, São Paulo, Brazil). The titratable acidity, expressed in g/100 g of citric acid, was performed by titration with sodium hydroxide solution (NaOH) 0.1 M; the moisture and ash content was determined by gravimetric method, in an oven at 105 °C, with subsequent muffle incineration at 550 °C respectively (Association of Official Analytical Chemists, 2016, number 930.16 and 942.05); proteins using the micro-Kjeldahl method, according to AOAC (Association of Official Analytical Chemists, 2016, number 929,152); total lipids using the Bligh-Dyer method (Bligh & Dyer, 1959); total carbohydrates calculated by difference according to RDC n°360 (Brasil, 2003); caloric value calculated using the Atwater coefficients (Merril & Watt, 1973). All analyzes were performed in 10 replications. The content of soluble and insoluble fibers was determined, in 3 replications, by gravimetric-enzymatic method, using enzymes

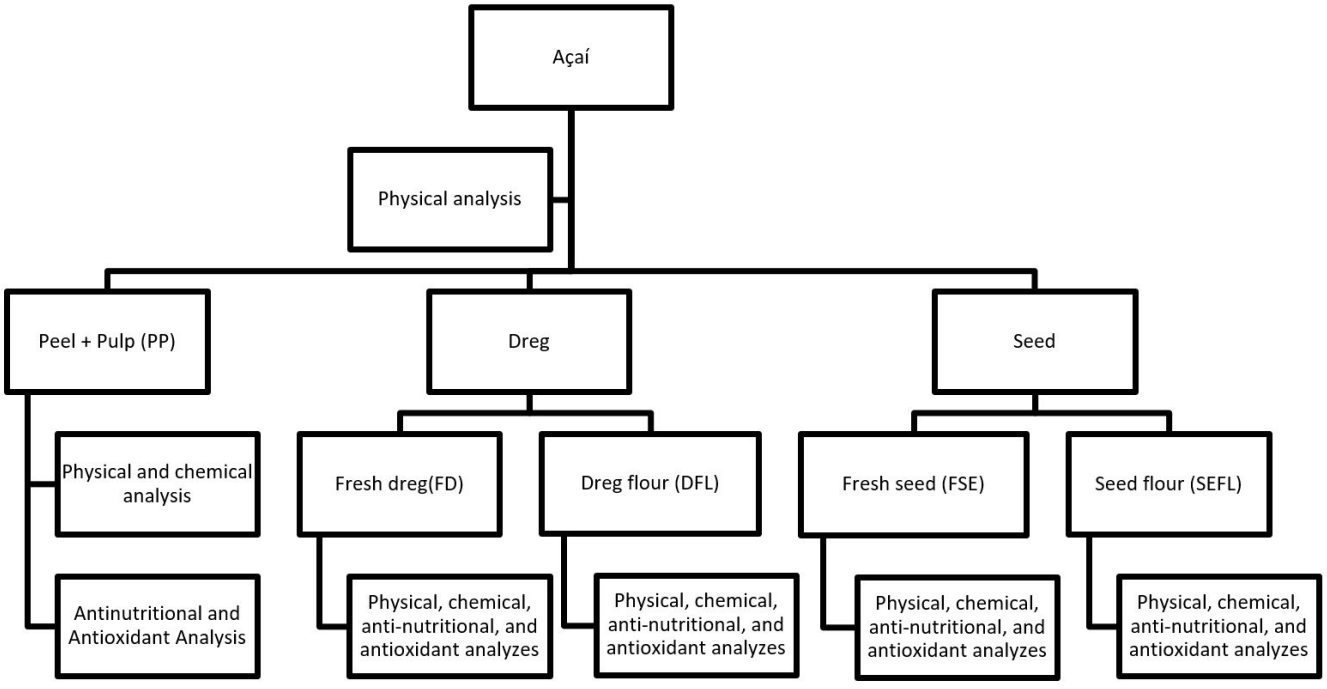

Figure 1. Flowchart of the experiment carried out with the fractions PP, fresh dreg (FD), dreg flour (DFL), seeds (FSE), and açai seed flour (SEFL), resulting from the industrial processing of açai.

α-amylase, protease, and amyl-glycosidase (Association of Official Analytical Chemists, 2016 number 992,16). The levels of reducing, non-reducing and total sugars were determined using the 3,5-dinitrosalicylic acid (DNSA) method, according to the methodology proposed by Silva et al. (2003), made in 10 replications. The minerals (calcium, magnesium, phosphorus, copper, iron, manganese, and zinc) were determined by flame spectrometry (Malavolta et al., 1997) in triplicate.

2.4 Antinutritional factors of the açaí berry and its fractions

The presence of hydrocyanic acid was evaluated in the fractions PP, FD, and SEFL, using the Guignard test, a qualitative technique that confirms the presence or absence of cyanides. Plum seeds were used as a comparative standard, according to Araújo (2011), which has cyanogen glycosides precursors of hydrocyanic acid. The analyzes were performed in 3 replications.

For the determination of phytic acid, condensed tannins, and total tannins, three extracts were made, and, from these, 12 readings were performed in the fractions PP, FD, DFL, FSE, and SEFL separately. The content of trypsin inhibitors was determined, according to Arnon (1970), with extraction only, at neutral pH. The phytic acid content was determined by the method described by Latta & Eskin (1980), using the DOEX-Cellulose resin (ion-exchange resin), according to Vilela et al. (1973). The content of condensed tannins was estimated, spectrophotometrically, of which the extraction was made using methanol, by the method adopted by Barcia et al. (2012). The method proposed by Swain & Hillis (1959) was used to determine the total tannin content.

2.5 Technological analysis of açaí dreg flour (DFL) and açaí seed flour (SEFL)

The methodology described by Okezie & Bello (1988) and the equation described by Anderson et al. (1969). For the absorption analysis, a suspension of 25 mL (water, milk, and oil) and 0.5 g of flour was prepared in centrifuge tubes and mixed with a magnetic bar on a stirrer plate for one minute and centrifuged at 3,000 rpm for 10 min at 4 °C (Eppendorf centrifuge 5403). The supernatant was discarded, and the pellet was weighed. The difference between the sample's weight before and after represents the amount of liquid absorbed. For solubility in milk, the blank was performed in the same way as the samples, and 10 mL of the supernatant were removed and placed in plates, which were taken to an oven at 40 °C until constant weight (o consider the soluble solids of the milk in the calculations). The same procedure was carried out for water.

2.6 Extraction and analysis of pigments

The chlorophyll quantification was measured by the methodology of Engel & Poggiani (1991). The method adopted by Barcia et al. (2012) was used to determine the total anthocyanin content. Carotenoids were extracted, as described by Sérino et al. (2009), and 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), an automatic injector (SIL 20A), UV-VIS detection system (SPD - 20A) and column oven (CTO 6A). The C18 column (LiChroCART 250-4 LiChrospher® 100 RP-18 endcapped 100 x 4,6 mm-5 µm - Merck) was used, and the volume of extract injection was 20 µL. The mobile phase was composed of acetonitrile: water: ethyl acetate (53: 7: 40, v/v/v) in a flow of 1 mL/min. During the analysis, the temperature was maintained at 30 °C. 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.

2.7 Tocopherol

High-performance liquid chromatography (HPLC) was used to determine vitamin E (α-, β-, γ-, δ-tocopherol) in açaí (peel + pulp) and its byproducts (FD, DFL, FSE and SEFL), as described by Presoto et al. (2000) and Melo & Almeida-Muradian (2010). A fluorescence detector (RF-10AXL) was used, adjusted for excitation of 295 nm and emission of 330 nm. A column of Shim-pack CLC-Sil (M) silica (25 × 4.6 mm particle size 5µm) with pre-filtered and degassed mobile phase was used, consisting of hexane and isopropyl alcohol (99: 1) and 1.5 mL/ min flow. Tocopherols were identified by comparing the retention time of synthetic standards, and quantification was performed using an external standardization curve, using at least five concentration levels for each standard. To calculate vitamin E present in the samples, the equation described by Holland et al. (1991) was used based on the biological activity of vitamin E (tocopherol).

2.8 Antioxidants from açaí (PP) and their fractions (FD, DFL, FSE, and SEFL)

Preparation of extracts

The bioactive compounds from each sample were extracted according to the protocol described by Souza et al. (2018). The extracts were centrifuged (3000 g, 15 min, 4 °C) in a centrifuge (5403, Eppendorf AG, São Paulo, Brazil), filtered through a synthesized plate filter (G4), and stored in amber bottles at a temperature of -18 °C, until spectrophotometric and chromatographic analysis. The extractions were performed in 3 replications in the fractions PP, FD, DFL, FSE, and SEFL.

Identification and quantification of flavonoids and phenolic acids

The separation, identification, and quantification of flavonoids and phenolic acids were performed by HPLC-DAD-MS, using a Luna C18 (2) HST reverse 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), with an elution flow rate of 0.5 mL/min, in gradient mode: starting with A and B in the proportion 95:5 (v/v); followed by an increase of up to 8% of B in 5 min, and a rise of 15% of B in 8 min and held for 2 min; then there was a 20% increase in B in 12 min and an increase to 35% B in 15 min, and held for 3 min and; finally, the proportion of B was reduced to 5%, and held for 2 min. The extracts were filtered, transferred to vials, and the injected volume was 5µL in triplicate (Silva et al., 2019b). The flavonoids and phenolic acid were identified according to

the retention time and quantified using a commercial standard curve (Sigma Aldrich, St. Louis, USA).

2.8.3 Antioxidant capacity

The capacity was determined using the DPPH, FRAP, and ABTS assays. The capacity of free radicals' elimination (CFRE) was determined according to the method described by Rufino et al. (2010) in the FD, DFL, FSE, and SEFL fractions. The antioxidant capacity assessed for iron reduction power (IRP) was determined, according to Rufino et al. (2006), only in the peel + pulp (PP) fraction. The limitations of analysis by DPPH and FRAP, in the other fractions, were due to their pigmentation. For the ABTS radical reduction capacity test, this was determined according to Rufino et al. (2007a, b) methods in the fractions PP, FD, DFL, FSE, and SEFL.

2.9 Statistical analyzes

The experiment was conducted in a completely randomized design (CRD), with replications, whose treatments were carried out on the fractions PP, FD, DFL, FSE, and SEFL. For physical analyzes, the averages were presented with their respective standard deviations. For comparisons between fractions, the averages of the analyzes were subjected to analysis of variance and, when significant, Tukey's test or T-test were applied (Student), using a 95% confidence level. The SISVAR software was used for assistance (Ferreira, 2014).

3. Results and Discussion

The fruits used in this work are consider small, due to its transversal/horizontal dimensions (13.04/11.49 mm respectively) and mass (1.46g), similar to that reported by Gordon et al. (2012), whose studied açai berries sizes ranged between 10 to 20 mm. The mass of the açaí seed (1.21 g) proved to be much greater than the mass of the peel/pulp (0.31 g). The açai berry yield, harvested in the Brazilian Amazon, presented 21.52% in peel+pulp and 78.14% in seeds. After its industrialization, the percentage of the discarded residue is high, calling attention to the full use of this plant species.

The assessment of the proximal composition of the açaí berry fractions can be seen in Table 1. The FD fraction showed the highest humidity (61.55 g/100) and Aw (0.99) compared to the other fractions, precisely by adding water used in the pulping process. It is suggested to dry this fraction to avoid microbial growth and chemical reactions that will easily degrade this co-product, making it impossible to be utilized in the future. Concerning the fraction in the form of flour (DFL and SEFL), these were below 15% moisture (4.5% and 5.53%, respectively), making it possible to store and prolong their lifespan. The moisture content below 15% is recommended by Brazilian legislation concerning flour in general (Brasil, 2005). Therefore, drying the residues/byproducts of açaí at 60 °C for at least 24 hours effectively reduced moisture.

The ash content found in the PP fraction was 2.36 g/100 g, higher than those found in the other studied fractions. The protein content was higher in the PP fraction (8.26 g/100 g) when compared to the seed (1.52 g/100 g) and its respective flour (1.64 g/100 g), and the dreg (1.24 g/100 g) and its respective flour (1.30 g/100 g).

The PP fraction has a lipid content of 25.12 g/100 g, followed by the DFL fraction (4.06 g/100 g) and, finally, the other fractions, which did not differ between itself, with an average of 2.61 g/100 g.

The PP fraction (64.26 g/100 g) had the lowest total carbohydrate content but had the highest caloric value (515.92 Kcal /100 g) compared to the other açaí fractions. This can be explained by the high amount of lipids in this fraction when compared with the others. That is, the accentuated caloric value of açaí is, without a doubt, in its peel and pulp portion—another good reason for it to be subjected to the drying process and stored properly.

The DFL (88.07 g/100 g) and SEFL (81.14 g/100 g) presented higher levels of dietary fiber than the other fractions. The reference value of daily total fiber intake for men and women between 19 and 50 years old varies between 25 and 38g/day, according to the Institute of Medicine (2010). Therefore, the intake of 100 g of DFL or SEFL flours provides 88% of the daily recommendation for fibers. It is worth mentioning that insoluble fibers are predominant in any of the fractions studied, and they help in intestinal transit, helping to prevent various diseases related to food digestion. The same fiber behavior was observed in a study of the açaí pulp, carried out by Rufino et al. (2011), whose presence of insoluble fiber (64.49 g/100 g) was greater than that of soluble fiber (2.75 g/100 g).

It was observed that among the fractions studied of the açaí fruit, the seed, and its respective flour, have a higher pH (5.23 and 5.82 respectively). According to Santos et al. (2008), the fractions of açaí are classified as low acidity foods (pH ≥ 4.50), enabling the development of sporulating microbial forms, therefore requiring care in storage and proper choice in the packaging. As for the pH and acidity values found in the peel + pulp fraction of this work (4.87 and 1.68 g/100 g citric acid), they are consistent with those found by Santos et al. (2008) in commercial açaí pulps, ranging from 3.55 to 4.80 for pH and 0.20 to 0.94 g/100 g for citric acid, respectively. As for the content of total sugars, the variation found in this study (1.70 to 2.68 g/100 g) is in accordance with the Brazilian legislation (Brasil, 2018), which determines the maximum value of total sugars for thick, medium, and fine up to 40.00g/100g, precisely to prevent or inhibit future microbial fermentations.

The value of L* in the PP fraction (24.86), as expected, was lower, showing less clarity when compared to the seed fraction (48.63) and its respective flour (54.55), a fact reinforced by the negative value of b* (-1.12) in PP; for the fraction FD (28.27) and DFL (43.16), the values of L* prove that the drying changed the color, either in the açaí dreg flour or in the seed flour. Positive values of a* and b* indicate brown in both samples. Therefore, it was observed that among the fractions of açaí residues, the seed (25.42) and its flour (22.07) have a more accentuated color concerning the peel + pulp (1.94), dreg (10.81), or dreg flour (13.77).

The PP (-36.22) and FD (34.63) samples are in the quadrant between 0° to 40°, evoking a hue between pink and red, while

Table 1. Nutritional composition (g/100 g), caloric value (kcal/100 g), physical and minerals composition (mg/100 g) of the fractions PP, FD, DFL, FSE, and SEFL and technological properties of DFL and SEFL, in dry basis.

Parameters	PP	FD	DFL	FSE	SEFL
Humidity	39. 80 ± 0.57^{b}	61.46 ± 0.39^{a}	4.50 ± 0.21^{e}	33.69 ± 0.29^{c}	5.53 ± 0.28^{d}
Ashes	2.36 ± 0.25^{a}	1.24 ± 0.12^{d}	1.30 ± 0.13^{dc}	1.52 ± 0.16^{cb}	1.64 ± 0.29^{b}
Proteins	8.26 ± 0.39^{a}	3.6 ± 0.44^{c}	3.12 ± 0.19^{c}	5.02 ± 0.45^{b}	5.32 ± 0.15^{b}
Lipids	25.12 ± 1. 54^{a}	3.00 ± 1.14^{cb}	4.06 ± 0.23^{b}	2.03 ± 0.47^{c}	2.80 ± 0.58^{c}
Total Carbohydrates	64.26 ± 1.65^{c}	92.16 ± 1.38^{a}	91.52 ± 0.33^{ab}	91.40 ± 0.41^{ab}	90.24 ± 0.5^{b}
Total caloric value	515.92 ± 7.98^{a}	410.08 ± 5.83^{bc}	413. 74 ± 2.07^{b}	404.06 ± 2.25^{c}	407.43 ± 3.63^{bc}
Insoluble Fiber	43.72 ± 0.36^{d}	33.32 ± 0.70^{e}	86.89 ± 1.81^{a}	53.77 ± 0.00^{c}	80.77 ± 0.00^{b}
Soluble Fiber	3.10 ± 0.68^{ab}	0.46 ± 0.23^{d}	1.19 ± 0.59^{cd}	2.24 ±0.14^{bc}	3.37 ± 0.21^{a}
Total dietary fiber	46.82 ± 1.04^{d}	33.78 ± 0.92^{e}	88.07 ± 2.4^{a}	55.81 ± 0.14^{c}	84.14 ± 0.21^{b}
Reducing Sugars	2.29 ± 0.16^{a}	0.28 ± 0.00^{c}	0.29 ± 0.00^{c}	1.60 ± 0.09^{b}	1.69 ± 0.10^{b}
Sucrose	0.39 ± 0.23^{c}	1.42 ± 0.09^{a}	1.49 ± 0.09^{a}	0.60 ± 0.13^{b}	0.64 ± 0.14^{b}
Total sugars	2.68 ± 0.30^{a}	1.70 ± 0.09^{c}	1.78 ± 0.09^{c}	2.20+ 0.17^{b}	2.33 ± 0.18^{b}
pH	4.87 ± 0.14^{c}	4.63 ± 0.02^{d}	4.70 ± 0.02^{d}	5.23 ± 0.04^{b}	5.82 ± 0.02^{a}
TA[2]	1.68 ± 0.08^{d}	1.36 ± 0.25^{c}	2.43 ±0.47^{b}	3.13 ± 0.30^{a}	3.34 ± 0.03^{e}
SS[3]	5.85 ± 1.20^{b}	2.34 ± 0.46^{d}	3.60 ±0.00^{c}	8.28 ± 0.38^{a}	8.10 ±0.00^{a}
Aw	0.98 ± 0.00^{a}	0.99 ± 0.00^{a}	0.38 ± 0.03^{c}	0.94 ± 0.00^{b}	0.36± 0.01^{d}
L	24.86 ± 2.10^{e}	28.27 ± 1.13^{d}	43.16 ± 2.16^{c}	48.63 ± 0.78^{b}	54.55± 1.22^{a}
A*	1.54 ± 0.32^{e}	8.89 ± 0.87^{c}	6.90 ± 0.31^{d}	12.08 ± 0.30^{a}	11.29 ± 0.41^{b}
b*	-1.12 ± 0.31^{e}	6.15 ± 0.76^{d}	11.92 ± 0.49^{c}	22.36 ± 0.32^{a}	18.96 ± 1.03^{b}
Chroma	1.94 ± 0.21^{e}	10.81 ± 1.12^{d}	13.77 ± 0.55^{c}	25.42 ± 0.40^{a}	22.07 ± 1.09^{b}
Angle Hue (°)	-36.22 ± 7.94^{b}	34.63 ± 1.58^{c}	59.93 ± 0.78^{a}	61.58 ± 0.42^{a}	59.16 ± 0.60^{a}
Potassium	659.24 ± 125.83^{a}	220.00 ± 0.00^{c}	230.37 ± 0.00^{c}	340.00 ± 11.5^{b}	359.90 ± 12.22^{b}
Phosphorus	75.88 ± 0.72^{b}	26.00 ± 7.09^{c}	27.23 ± 7.43^{c}	104.00 ± 7.55^{a}	110.09 ± 7.99^{a}
Calcium	385.59 ± 7.18^{a}	100.00 ± 0.00^{b}	104.71 ± 0.00^{b}	**ND	**ND
Magnesium	211.46 ± 7.18	**ND	**ND	**ND	**ND
Iron	5.61 ± 0.06^{c}	**ND	**ND	6.65 ± 0.85^{a}	7.04 ± 0.90^{a}
Copper	2.10 ± 0.00^{a}	0.90 ± 0.14^{b}	0.94 ± 0.15^{b}	1.20 ± 0.23^{b}	1.27 ± 1.24^{b}
Manganese	43.53 ± 0.402^{a}	5.95 ± 1.45^{c}	6.23 ± 1.52^{c}	9.8 ± 1.20^{b}	10.37 ±1.27^{b}
Zinc	2.84 ± 0.06^{a}	0.35 ± 0.11^{c}	0.37 ± 0.12^{c}	1.12 ± 0.15^{b}	1.19 ± 0.16^{b}
Sulfur	497.54 ± 16.17^{a}	33.00 ± 2.08^{c}	34.55 ± 2.18^{c}	116.00 ± 32.33^{b}	122.79 ± 34.32^{b}
	Technological parameters				
	WSI[4] (%)	**WAI[5] (g. gel/g)**	**OAC[6] (%)**	**MSI[7] (%)**	**MAI[8] (g. gel/g)**
DFL	3.94 ± 1.54^{b}	3.12 ± 0.25^{a}	2.47 ± 0.15^{a}	30.45 ± 1.53^{a}	1.25 ± 0.09^{b}
SEFL	8.69 ± 0.75^{a}	2.77 ± 0.15^{b}	1.99 ± 0.10^{b}	3.41 ± 0.22^{b}	2.03 ± 0.11^{a}

[1]All Values correspond to the means ± standard deviation. Lower case letters in the same line and column for technological parameters do not differ statistically by the Tukey test at 5% probability ($p < 0.05$); [2]Titratable acidity expressed in g citric acid/100 g; [3]Soluble solids (°Brix); [4]Water solubility index; [5]Water absorption index; [6]Oil absorption capacity; [7]Milk solubility index; [8]Milk absorption index. ND (not detected). **ND – Not Detected

the DFL samples (59.63), FSE (61.58) and SELF (59.16) changed from the 40° red to the 90° yellow quadrant.

In general, the cause of the browning of dry products, thermally, is mainly due to the Maillard reactions, caramelization, and ascorbic acid oxidation that normally occur during the thermal drying process (Michalska et al., 2018). This darkening, however, does not preclude the use of açaí co-products, since the inclusion of ingredients, with dark coloring in food products, can be associated, by consumers, as integral ingredients and, therefore, healthier (Walker et al., 2014). The average daily requirement of minerals for adults aged 19 to 70 years (men and women), according to the Institute of Medicine (2010), are as follows: manganese, 1.8 to 2.3 mg/day; copper 0.9 mg/day; iron 14 mg/day; magnesium 260 mg/day; phosphorus 700 mg/day; calcium 1000 mg/day and potassium 4700 mg/day. Therefore, consuming 100g of PP, the daily requirement is met in 10.84% for potassium; 14.02% for calcium; 81.33% for magnesium; for the fractions FSE or SEFL, considering that they are statistically equal, it is noted that the daily needs of 15.72% for phosphorus and 50% for iron are met by ingesting 100 g of either one.

Based on the technological parameters (Table 1), it is known that the water solubility index (WSI) refers to the number of soluble solids. The water absorption index (WAI) measures the amount of water absorbed by the starch and can be used as a gelatinization index (Turan et al., 2015). It is also worth remembering that WSI depends on the presence and availability of hydrophilic groups and the ability to form a macromolecular gel (Hatamian et al., 2020). In this context, the SEFL (8.69%) is diluted better than the DFL (3.94%) in the WSI case. However, the DFL (3.12g.gel/g) is better to absorb water than the SEFL

(2.77 g.gel/g). In studies conducted by Santana et al. (2017), the WAI of oat flour (0.85% to 1.20%) was almost two times lower than the WAI of DFL or SEFL flour, suggesting an effective replacement of oatmeal by flours from açaí byproducts in food products. According to Brandão et al. (2019), wheat flour, used worldwide in several food segments, has a WSI of 13.2 and a WAI of 1.68%, lower rates than those found for the DFL and SEFL fractions, showing, once again, the efficiency of these flours in the total or partial replacement of wheat flour in foods such as whole-grain cakes, bread, biscuits, macaroni and-so-forth.

The Oil Absorption Capacity is mainly conferred to the binding of protein parts of the sample to the oil molecules, being an important factor in the use of flours in meat products or emulsified products such as cake dough, mayonnaise or salad dressings, soups, processed cheeses, and meat extenders (Silva-Sánchez et al., 2004; Porte et al., 2011). It is observed that the DFL fraction (2.47%) obtained better results than the DFL (1.99%) for OAC, showing the preference of this first when used as an ingredient in emulsified or meat foods such as hamburgers, nuggets, sausages, and-so-on.

The milk absorption index (MAI) is a crucial parameter for producing milk-based products such as desserts, curd, sweets, or instant infant foods (Morais et al., 2019). According to Table 1, it is noted that the DFL's ISL (30, 45 g.gel/g) was substantially higher than the SEFL (3.41 g.gel/g), in contrast to DFL (1.25 %) absorbs less milk than the SEFL (2.03%). In other words, the use of açaí dreg flour is very interesting in products that require insoluble fibers insolubility.

Regarding the antinutritional present in the fractions of the açaí berry co-products (Table 2), it is possible to notice cyanogen compounds' total absence. As for the presence of phytic acid and condensed tannins, these are present only in the seeds (141, 87 mg/100 g, and 43.92 mg tannic acid/100 g) and in their respective flours (150.24 mg/100 g and 45.54 mg acid tannin/100 g). There are reports in the literature of methods of reducing this compound, such as that by Mohamed et al. (2007), who autoclaved the millet and, after 24 hours, there was a reduction of up to 28% in phytates. According to Coulibaly et al. (2011), the average intake of phytates in the United States and the United Kingdom varies between 631 and 746 mg/day respectively; the average in Finland is 370 mg/day, in Italy, it is 219 mg/day and in Sweden only 180 mg/day. Therefore, if a fermentation or even maceration process is applied, possibly the phytate content would reduce. On the other hand, studies show that this compound has its beneficial side, acting as an antioxidant, inhibiting oxidative reactions mediated by iron, and limiting DNA damage (Midorikawa et al., 2001). Condensed tannins have also been shown to be beneficial to human health, as they may be linked to the presence of procyanidins (Table 3), a large group of polyphenols present in woody plants, and some herbaceous (Ferreira et al., 2010). Zhang et al. (2011) observed an anti-diabetic effect of grape seeds or peel procyanidins by inhibiting α-glucosidase activity. Therefore, the presence of phytic acid and/or tannins in the seed and its flour do not limit its use in human food.

There are no reports in the literature of quantification in the açaí berry and/or its fractions for the trypsin inhibitor. When we use soy flour as a parameter (8 to 10 ITU/100 g) (He & Chen, 2013), as this is one of the legumes with the highest amount of trypsin inhibitor, the similarity with the SEFL fraction (10. 11 ITU/100 g), this value can be reduced by up to 50% if ultrasound treatment is applied at 20 kHz for about 20 min, as suggested by Huang et al. (2008).

No chlorophyll and α-Tocopherol capable of being quantified were found in the methods adopted in this work in all analyzed fractions. Carotenoids were found, in equal amounts, in FD (16.52 mg β-carotene/mg) and DFL (16.95 mg β-carotene/mg), whose values were lower than that found by Lucas et al. (2018) in açaí pulp (41.43 mg β-carotene/mg). Regarding anthocyanins, the concentration in the PP fraction (48.53 mg cyanidin 3-glycosidium) stand out. The DPPH method, to assess the antioxidant activity of the açaí fractions, was not efficient, as well as the FRAP method.

Table 2. Antinutritional compounds, pigments, total condensed tannins (mg/100 g), and antioxidants of the fractions PP, FD, DFL, FSE, and SEFL in dry basis.

Parameters	PP	FD	DFL	FSE	SEFL
Cyanogenic acids	Absent	Absent	Absent	Absent	Absent
Phytic Acid (mg phytic acid)	*ND	*ND	*ND	141.87 ± 23.57^{a}	150.24 ± 25.22^{a}
Trypsin Inhibitor (UI)	1.83 ± 0.85^{c}	1.95 ± 0.52^{c}	2.04 ± 0.42^{c}	9.54 ± 0.05^{b}	10.11 ± 0.08^{a}
Condensed Tannins (mg catechin)	*ND	*ND	*ND	43.92 ±7.16^{a}	45.54 ± 7.43^{a}
Total Tannins (mg tannic acid)	2.76 ± 0.26^{b}	0.54 ± 0.01^{c}	0.56 ± 0.01^{c}	12.21 ± 0.76^{a}	12.93 ± 0.84^{a}
Chlorophyll	*ND	*ND	*ND	*ND	*ND
Anthocyanins (mg cyanidin 3-glycosidium)	48.53 ± 3.00^{a}	2.51 ± 0.65^{c}	2.63 ± 0.68^{c}	15.92 ± 2.10^{b}	16.86 ± 2.20^{b}
Carotenoids (mg β-carotene/mg)	*ND	16.52 ± 1.12	16.95 ± 1.15^{b}	*ND	*ND
α-Tocopherol (mg/g)	*ND	*ND	*ND	*ND	*ND
DPPH (EC_{50} mg/L)	-	5.90 ± 0.30^{a}	6.95 ± 2.09^{a}	0.10 ± 0.01^{b}	0.10 ± 0.00^{b}
FRAP (μM of ferrous sulfate/mg)	4719.01 ± 365.21	-	-	-	-
ABTS (μM Trolox/mg)	3510.02 ± 303.13^{c}	254.50 ± 72.29^{d}	266.58 ± 68.78^{d}	10142.21 ± 337.32^{b}	10679.30 ± 359.11^{a}

[1]All the values correspond to the means ± standard deviation of ten replications. TIU (trypsin inhibiting unit); [2]Lower case letters on the same line do not differ statistically by the Tukey test ($p < 0.05$) or T-test ($p < 0.05$) at 5% probability. (-) Analysis was not performed due to fraction pigmentation. *ND – Not Detected

Table 3. Phenolic and flavonoid acids identified and quantified (mg/100 g of sample) by HPLC-DAD of the fractions PP, FD, DFL, FSE, and SEFL in dry basis.

Compound	Retention time (mim)	λ (nm)	PP	FD	DFL	FSE	SEFL
Gallic acid	2.3	271	2.78 ± 0.20[a]	0.68 ± 0.06[b]	0.72 ± 0.06[b]	*ND	*ND
Protocatechuic acid	4.4	259	*ND	1.16 ± 0.11[b]	1.21 ± 0.12[b]	4.22 ± 0.77[a]	4.46 ± 0.82[a]
4-Hydroxybenzoic acid	7.1	254	*ND	3.84 ± 0.12[b]	4.02 ± 0.13[b]	9.87 ± 2.50[b]	10.45 ± 2.65[a]
Vanillic Acid	9.1	259	7.58 ± 0.67[c]	3.15 ± 0.07[b]	3.30 ± 0.07[b]	1.02 ± 0.28[c]	1.07 ± 0.30[c]
Ferulic acid	13.4	322	0.65 ± 0.02[c]	0.89 ± 0.27[c]	0.93 ± 0.0.29[c]	3.63 ± 0.98[b]	3.84 ± 1.04[a]
Ellagic Acid	13.4	270	0.67 ± 0.06[a]	0.23 ± 0.01[b]	0.24 ± 0.01[b]	0.27 ± 0.02[b]	0.28 ± 0.02[b]
p-Coumaric acid	11.1	305	1.89 ± 0.23[a]	0.75 ± 0.09[b]	0.78 ± 0.09[b]	*ND	*ND
Chlorogenic acid	8.6	326	3.36 ± 0.44	*ND	*ND	*ND	*ND
Sinapic acid	13.4	324	2.19 ± 0.07[b]	*ND	*ND	11.98 ± 2.80[a]	12.68 ± 2.96[a]
Epicatechin	10.2	276	7.38 ± 0.89[b]	*ND	*ND	17.57 ± 2.93[a]	18.60 ± 3.11[a]
Procyanidin A2	8.1	235	687.29 ± 54.01[a]	*ND	*ND	236.68 ± 20.68[b]	250.53 ± 21.89[b]
Procyanidin B2	10.2	235	19.84 ± 2.05[a]	*ND	*ND	27.04 ± 12.69[a]	28.62 ± 13.43[a]
Catechin	8.3	276	957.51 ± 77.69[a]	*ND	*ND	125.58 ± 41.87[b]	132.93 ± 44.32[b]

[1]All the values correspond to the means ± standard deviation. Lower case letters on the same line do not differ statistically by the Tukey test ($p < 0.05$) or t-test ($p < 0.05$) at 5% probability. *ND – Not Detected

Through the ABTS method, significant levels of antioxidant activity were observed in the SEFL fraction (10679.30 μM Trolox/mg). The hypothesis is that the high concentration and variety of phenolic compounds found in the SEFL may be the basis for its high antioxidant capacity, mainly catechin (138.93 mg/100 g) and procyanidin A2 (250.63 mg/100 g) (Table 3).

Also, açaí seed extracts are rich in proanthocyanidins (PAs), a class of polyphenols, also known as condensed tannins (Barros et al., 2015; Melo et al., 2021). According to Martins et al. (2020), the procyanidins of açaí seeds are present only in the tegument inside the endosperm; that is, these compounds are not dispersed throughout the seed structure, which may facilitate its future extraction.

Among the various substances detected, procyanidin A2 and catechin are noteworthy, being present in the PP (687.29 and 957.51 mg/100 g), FSE (236.68 and 125.58 mg/100 g), and SEFL (250.53 and 132.93 mg/100g) (Table 3).

Increasingly, the composition in antioxidant substances draws the scientific community's attention since significant levels can preserve the raw material for longer periods, inhibiting or delaying the effects of hydrolytic and/or oxidative oxidation.

4. Conclusion

The peel + pulp is a source of lipids, soluble and insoluble fiber, minerals, anthocyanins and antioxidants, such as procyanidin A2 and catechin. The fresh dreg is a source of insoluble fiber and carotenoids. The dreg flour is a source of carbohydrates and insoluble fiber, having carotenoids and good solubility in milk and oil. The seed and its respective flour are a source of carbohydrates, insoluble fiber, phytic acid, and condensed tannins, anthocyanins, and antioxidants such as procyanidin A2 and catechin. The antinutritional product with the greatest impact was the trypsin inhibitor, found in all evaluated fractions. Therefore, the use of the fractions discarded from the açaí agribusiness can be viable from a nutritional and technological perspective.

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