



Overall quality of gluten-free *araçá* (*Psidium Acutangulum DC.*) cereal bars

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ABSTRACT. Health-conscious consumers are interested in products with an increased functional property and differentiated sensory characteristics. Processing native fruits offers promising perspectives for incoming aggregation, as well as providing foods with high nutritional value. This study evaluated the nutritional quality, physicochemical, and functional properties of gluten-free *araçá* cereal bars. Three different cereal bars formulations were prepared, containing *araçá* pulp and increasing proportions of osmotically dehydrated *araçá* (13; 20 and 27 g 100 g⁻¹). The proximate composition, physicochemical evaluation, bioactive compounds (ascorbic acid, total phenolics, tannins, and antioxidant activity), overall appearance and microbiological analyses were evaluated. In general, the gluten-free *araçá* cereal bars were presented as rich in fiber and protein source complementary nutritional information. The osmotically dehydrated *araçá* showed a decrease in the bioactive compound, with a greater loss of ascorbic acid. The cereal bar with highest proportion of *araçá* (T3 - 27 g 100 g⁻¹), exhibited higher concentrations of total phenolic compounds, total tannins, and antioxidant activity, with hydroacetic solvent presenting greater extraction efficiency. The analysis of overall appearance of the bars corresponded to 'moderately liked'. In the microbiological evaluation, the products met the legislative standards and were found to be suitable for consumption. The gluten-free cereal bar, with highest proportion of *araçá* (27 g 100 g⁻¹), presented good overall appearance, confirming the potential of this Cerrado fruit for use in functional foods, with improved nutritional value, acceptance, besides enabling local socio-economic development.

Keywords: Bioactive compounds; bioeconomy; celiac disease; cerrado fruit; new products, snacks.

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Introduction

The Cerrado of the state of Mato Grosso do Sul (Brazil) has been constantly giving way to agrosilvopastoral activities, and there is great potential for the use of native species in the production of food products. The rational use of natural resources can enable the sustainable development of family farming and small rural communities. The development of new products containing native fruits allows for an extended marketing period, better utilization of production, value addition, and encouragement of the consumption of regional foods with high nutritional value, as well as stimulating the preservation of this biome.

The existing potential in native Cerrado fruits is still underexplored. These fruits are a good source of vitamin C, fiber, and minerals, as well as containing high levels of natural polyphenolic compounds that act as potent antioxidants, with a range of biological effects that can have beneficial results for human health (Bortolotto et al., 2017).

Trends in population lifestyle changes have significantly increased the consumption of fast food and snacks due to the ease of acquiring ready-to-eat and frozen foods in the market (Janssen et al., 2018). Among these products, pizzas, biscuits, popcorn, and cereal bars stand out in global consumption.

Functional food is any natural or processed food that contains one or more substances classified as nutrients or non-nutrients, capable of affecting human metabolism and physiology, promoting health benefits (Lopez-Martínez et al., 2023). This includes delaying pathological processes that lead to chronic and/or degenerative diseases, improving the quality and lifespan of individuals. In this context, cereal bars can be considered functional foods, provided they have an adequate concentration of substances for this purpose. The introduction of osmotically dehydrated *araçá* enhances microbiological safety while preserving sensory characteristics.

The *araçá* (*Psidium acutangulum* DC.), belonging to the *Myrtaceae* family, has white, juicy, aromatic, and sweet pulp, and can be consumed fresh or used in ice creams, sweets, and beverages. The ripe fruit falls easily to the ground, where it quickly rots due to the lack of suitable technologies for extending its shelf life (Gwozdz et al., 2022).

Besides its high nutritional value, contains significant amounts of phenolic compounds, unsaturated fatty acids, and carotenoids, making it a promising plant for the pharmaceutical and food industries (Gwozdz et al., 2022).

Processing *araçá* into products offers promising opportunities for activity and income generation for rural communities and family farming, while supporting environmental preservation through the rational use of natural resources. It also provides foods with high nutritional value and extended shelf life. The formulation of cereal bars with *araçá*, based on scientific research, can promote the consumption of native fruits and their derivatives with the functional food claim.

Cereal bars prepared with soy (*Glycine max* L.) and quinoa (*Chenopodium quinoa* Willd) offer a new market option with higher protein content and convenient consumption. The needs of gluten-free products for individuals with celiac disease, are in crescent need, and the development of attractive sensory characteristics are mandatory (Aljada et al., 2021).

This study aimed to develop gluten-free cereal bars with fresh *araçá* pulp and varying concentrations of osmotically dehydrated *araçá*, along with the addition of soy and quinoa. The goals were to determine the proximate composition, and the levels of bioactive compounds, assess the nutritional quality, and evaluate the overall appearance of the final products.

Material and methods

Raw material preparation

The *araçá* fruits were manually collected randomly in the rural area of Nioaque/Brazil (21°7'37"S; 55°49'56"W), placed in sanitized plastic boxes, and immediately sent to the laboratories of the Faculty of Pharmaceutical Science, Food and Nutrition (Federal University of Mato Grosso do Sul, Campo Grande, Brazil - 20°26'37" S; 54° 38'52" W).

The fruits were selected, washed in running water, sanitized by immersion in a 200-ppm hypochlorite solution for 10 minutes. Then, the fruits were peeled and pulped. The pulp (endocarp) was frozen at -18°C. The epicarp and mesocarp ('peel') were analyzed for the determination of bioactive compounds and antioxidant activity and subjected to osmotic dehydration.

Osmotic dehydration

The *araçá* peels were cut into triangular pieces approximately 1 × 1 × 1 cm in size, using a stainless-steel knife, and subjected to osmotic dehydration. Approximately 50 g of epicarp and mesocarp pieces were placed in beakers and received osmotic solutions (70% sucrose) in a 1:3 ratio, fruit: solution (w/w), where they remained for 4 hours at room temperature (23 ± 1°C).

After the osmotic dehydration time elapsed, the samples were drained, then distributed on trays suitable for a cabinet dryer, and subjected to 40°C for two hours with forced air circulation. They were then cooled and properly packaged separately in plastic bags and stored in a BOD at room temperature.

Cereal bars production

Three formulations of cereal bars with osmotically dehydrated *araçá* were prepared, as shown in Table 1.

Table 1. Formulations of *araçá* cereal bars.

Ingredients	T1	T2	T3
Rice flakes	10.9	10.9	10.9
Quinoa flakes	16.2	16.2	16.2
Soy bran	16.2	16.2	16.2
Corn syrup	32.3	32.3	32.3
Brown sugar	5.5	5.5	5.5
Osmotically dehydrated <i>araçá</i>	13.0	20.0	27.0
<i>Araçá</i> pulp	5.5	5.5	5.5
Soy lecithin	0.4	0.4	0.4

Incorporated osmotic dehydrated *araçá*: T1 - 13 g 100 g⁻¹; T2 - 20 g 100 g⁻¹; T3 - 27 g 100 g⁻¹.

The dry ingredients (rice and quinoa flakes, and soy flour) were separately homogenized. The binders, soy lecithin, fresh pulp, *araçá* peel, corn syrup, and brown sugar, were concentrated at a temperature of approximately 95°C for 2 min. Then, the dry ingredients were added, mixed, and heated in dry heat at 95°C for 3 min until a homogeneous mass was obtained.

The mass was added to an aluminum mold lined with plastic film and lightly pressed with a polyethylene spatula to a thickness of 1.0 cm, followed by cutting into 3.0 cm wide bars.

Proximate composition

As presented by Munhoz et al. (2014), the proximate composition of the cereal bars was carried out according to the methodology of the AOAC (2016).

The moisture content of the samples was determined by desiccation in an oven at 105°C. The lipid content was quantified by Soxhlet extraction using petroleum ether. Protein quantification was performed using the micro Kjeldahl method, which quantifies the total nitrogen content, converting nitrogen into protein by multiplying by the factor 6.25. The ashes were determined by incineration in muffle furnace at 550°C.

The sugar content was determined by titration for reducing sugars in glucose, non-reducing sugars in sucrose, and starch, according to the Lane-Eynon method based on copper reduction. Dietary fiber was determined by the enzymatic-gravimetric method.

The total energy value of the cereal bars was estimated considering the Atwater conversion factors of 4 kcal g⁻¹ for protein, 4 kcal g⁻¹ for carbohydrate, and 9 kcal g⁻¹ for lipid (Merril & Watt 1973).

Extract preparation

The extracts were prepared according to the methodology described by Roesler (2007), conducting aqueous extraction for both fresh fruit and osmotically dehydrated *araçá*. After homogenizing the samples, aqueous extraction was performed using distilled water at a ratio of 1:3 w/v, fruit: water. Agitation took place for 20 minutes in a dark environment, followed by filtration through gauze. The residue obtained was re-extracted under the same conditions, and both extracts were stored refrigerated in amber bottles for subsequent analysis.

For the cereal bars containing different proportions of osmotically dehydrated *araçá*, three extractions were carried out: aqueous, ethanolic, and hydroacetic, following the procedures described for fresh fruit samples. Ethanol extraction was performed using 95% alcohol, hydroacetic extraction using 80% acetone, and both extracts were stored refrigerated in amber bottles for subsequent analysis.

Bioactive compounds and Antioxidant activity

The ascorbic acid (Vitamin C) concentration was determined by titration, which is based on the reduction of 2,6-dichlorophenolindophenol (DCFI) by ascorbic acid (Instituto Adolfo Lutz [IAL], 2008).

The determination of total phenols was performed by colorimetry, using the Folin-Ciocalteu reagent. This method allows quantifying phenolic compounds present in the samples. A calibration curve was prepared with gallic acid (standard phenolic compound) by preparing a stock solution of 0.5 g L⁻¹ gallic acid, from which dilutions were carried out in test tubes with the following concentrations: 0.025; 0.075; 0.09; 0.105 (mg mL⁻¹), and 2.5 mL of 10% aqueous Folin-Ciocalteu reagent and 2 mL of 7.5% aqueous sodium carbonate solution were added.

Then, the tubes containing the solutions were incubated for 5 minutes in a water bath at 50°C. After cooling the aliquots, readings were taken at 760 nm on a spectrophotometer, as described by Roesler et al. (2007). All points were analyzed in triplicate.

Tannins were determined by a colorimetric method based on the reduction of phosphotungstomolybdic acid (Folin-Dennis). The antioxidant capacity to scavenge free radicals was evaluated using the stable radical 2,2-diphenyl-1-picrylhydrazyl (DPPH) as described by Roesler et al. (2007). Test solutions were prepared from the extracts obtained in aqueous, ethanolic, and hydroacetic extractions. Different concentrations (0.2%; 0.4%; 0.6%; 0.8%; 1%) of these extracts were then added to 1800 µL of an ethanolic solution of DPPH (0.004% w/v). The tubes were shaken and incubated at room temperature for 30 minutes in the dark. Then, the absorbances of the samples were read at 517 nm on a spectrophotometer. All points were analyzed in triplicate.

The negative control of the test consisted of ethanol added in the same volume as the DPPH solution. The mean value of the absorbances presented by the negative control represents 100% inhibition of oxidation, and based on this data, the percentage inhibition of oxidation of each absorbance value obtained can be calculated. Thus, the graph of antioxidant activity as a function of concentration (µg mL⁻¹) is determined.

The DPPH solution should be prepared only at the time of testing, stored away from light, and kept at 4°C during the testing interval. The positive control should always be prepared at the time of the test by diluting the stock solution (1 mg mL⁻¹) 20 times. The negative control was performed in triplicate for each sample. The capacity to scavenge free radicals, expressed as the percentage of inhibition, was calculated according to the (Equation 1):

$$\%Inhibition = \left[\frac{(A_{DPPH} - A_{EXT})}{A_{DPPH}} \right] \times 100 \quad (1)$$

Where A_{DPPH} = DPPH solution absorbance, and A_{EXT} = absorbance of the sample in solution (calculated based on the difference in absorbance of the test sample solution with its blank). The IC₅₀ value is defined as the final concentration of dry extract required to decrease the initial concentration of DPPH by 50%.

Sensory analysis

In the overall appearance evaluation, 50 untrained judges indicated their preference among treatments, as described by Lawless and Heymann (2010). The research was conducted according to the ethical principles involving human subjects as outlined in Resolution n° 466/2012 of the National Health Council and was approved under number CAAE - 34019914.9.0000.0021.

For each impression of the testers, recorded on the hedonic scale, a score was assigned, from 1 to 9, in increasing order of acceptance (disliked extremely = 1, disliked very much = 2, disliked moderately = 3, disliked slightly = 4, indifferent = 5, liked moderately = 6, liked slightly = 7, liked very much = 8, and liked extremely = 9).

For the acceptability index (AI) of each treatment, the following expression was used: AI (%) = (AS × 100)/B, where AS = average score obtained for the product and B = maximum score given to the product.

Microbiological analysis

The microbiological analyses conducted included tests for *Bacillus cereus*, *Salmonella* sp, and Coliforms at 45°C, in accordance with Resolution-RDC n° 12, dated January 2, 2001, from the National Health Surveillance Agency of the Ministry of Health (Brasil, 2001).

Additionally, tests for *Salmonella* sp and *Escherichia coli* were performed according to Normative Instruction - IN n° 161, dated July 1, 2022, from the National Health Surveillance Agency of the Ministry of Health. These analyses were applied to flours, pasta, bakery products (industrialized and packaged), and similar items, in bar form or other shapes, with or without additions.

The methodology used was from the American Public Health Association, as described in the fifth edition of the Compendium of Methods for the Microbiological Examination of Foods (Salfinger & Tortorello, 2015).

Statistical analysis

The statistical analyses were performed using the software Statistica 8.0 (StatSoft Inc., Tulsa, USA). Experimental data were statistically analyzed using one-way variance analysis to assess differences among the treatments. Disparities between means were compared using the Tukey test. Statistical significance was expressed at the 0.95 probability level ($p \leq 0.05$).

Results and discussion

Proximate composition

The values of proximate composition of gluten-free cereal bars are presented in the (Table 2).

Table 2. Proximate composition of *araçá* cereal bars.

Proximate composition [g 100 g ⁻¹] ^a	T1	T2	T3
Moisture	13.65 ± 0.97 ^a	12.04 ± 0.41 ^b	12.15 ± 0.51 ^b
Lipid	0.99 ± 0.54 ^a	1.57 ± 0.44 ^a	3.27 ± 0.38 ^b
Protein	9.24 ± 0.51 ^a	9.20 ± 1.47 ^a	8.36 ± 1.25 ^a
Ash	1.33 ± 0.00 ^a	1.28 ± 0.01 ^b	1.23 ± 0.02 ^c
Reducing sugars in glucose	10.02 ± 0.15 ^a	9.45 ± 1.30 ^a	10.57 ± 0.05 ^a
Non-reducing sugars in sucrose	10.34 ± 0.10 ^a	10.92 ± 0.95 ^a	10.72 ± 0.30 ^a
Non-reducing sugars in starch	26.65 ± 0.05 ^a	26.69 ± 0.90 ^a	26.71 ± 0.10 ^a
Total dietary fiber	6.95 ± 0.37 ^a	7.00 ± 0.50 ^a	9.21 ± 0.49 ^b
Total caloric value (kcal 100 g ⁻¹)	108.55	113.69	126.87

Incorporated osmotic dehydrated *araçá*: T1 - 13 g 100 g⁻¹, T2 - 20 g 100 g⁻¹, T3 - 27 g 100 g⁻¹. ^aAverage value ± standard deviation. Mean followed by different letters in the same line indicate a significant difference ($p \leq 0.05$), according to Tukey's test.

As presented in Table 2, the moisture content varied from 12.04 and 13.65 g 100 g⁻¹, and statistical differences were observed ($p \leq 0.05$) for the different treatments. Despite the differences found, all showed moisture results below 15 g 100 g⁻¹, the limit established by Resolution RDC n°. 263, from September 22 (Brasil, 2005), contributing to stable storage without significant changes in product quality. High moisture content favors undesirable reactions, such as non-enzymatic browning and microbial growth, the latter being particularly important in cereals with added dried fruits (Munhoz et al., 2013).

Similar findings were reported by Hussain et al. (2023) for the orange seed powder-incorporated biscuits, with moisture reduction at higher orange seed powder addition. Damasceno et al. (2016) developed cereal bars containing pineapple peel flour and observed that the moisture ranged from 7.89 g 100 g⁻¹ (treatment without pineapple peel flour addition) to 9.40 g 100 g⁻¹ (treatment with 6% of pineapple peel flour addition).

The moisture content of the *araçá* cereal bars was similar to those found by Gonçalves et al. (2023) for cereal bar source of dietary fiber, which ranged from 8.64 to 10.45 (g 100 g⁻¹).

Significative differences ($p \leq 0.05$) were obtained for lipid concentration (Table 2). The lipid content in the bar with the highest content of dehydrated *araçá* (T3) showed higher values than in the other bars, which can be explained by the higher concentration of soy flour and quinoa bran in the sample used, due to the difficulty of distributing the dough proportionally in all the bars. Soy flour contains approximately 22 g 100 g⁻¹ of lipids (Vieira et al., 2015).

With respect to the protein content, no statistical differences ($p > 0.05$) were observed. The protein content is like that observed in commercial cereal bars, averaging 6.5 g 100 g⁻¹. The protein levels ranged from 8.36 to 9.24 g 100 g⁻¹, higher than those obtained by Damasceno et al. (2016) during the development of cereal bars containing pineapple peel flour, which ranged from 6.31 to 7.08 g 100 g⁻¹.

The mineral content of the samples is related to the ash content. According to Table 2, the treatments were significantly different from each other ($p \leq 0.05$). T3 presented the lowest ash content. This difference may be due to the osmo-dehydrated *araçá* pulp incorporation. According to Caldeira et al. (2004), the *araçá* presents low ash content (0.85 g 100 g⁻¹), and its addition reduces the total mineral content of the bars. Similar values were found in study by Munhoz et al. (2014) whose values in g per 100 g ranged from 1.29 to 1.30, for cereal bars of bocaiuva.

Table 2 shows that no statistical differences ($p > 0.05$) were observed for the carbohydrates (reducing sugars in glucose, non-reducing sugars in sucrose and non-reducing sugars in starch). The total carbohydrate content of the cereal bars ranged between 48 and 50 g per 100 g and was the nutrient with the highest concentration due to the high percentage of corn glucose (32.3%) and brown sugar (5.5%), in addition to other ingredients such as rice flakes.

Samakradhamrongthai et al. (2021) developed high energy cereal bar formulated with cereals and fruits and obtained total carbohydrate content of the samples ranging from 39.64 to 64.26 g 100 g⁻¹. During the elaboration of cereal bars with different cereals and nuts (oat, white maize, yellow maize, millet and guinea corn), Eke-Ejiofor & Okoye (2018) obtained total carbohydrates (g 100 g⁻¹) ranging from 36.6 to 41.4.

T3 had the highest dietary fiber content at 9.21 g 100 g⁻¹ and differed from the other formulations ($p < 0.05$), as presented in the Table 2. Although a difference is shown, all the bars can still be considered a product rich in fiber (Brasil, 2012). The Complementary Nutritional Information on labeling can state 'source of fiber' or 'high fiber content/rich in fiber,' the first corresponding to a minimum value of 3 g of fiber per 100 g of solid product, while the latter corresponds to a minimum value of 6 g of fiber per 100 g of solid product.

The fiber content of cereal bars varies according to the ingredients used in processing. Eke-Ejiofor & Okoye (2018) utilized nuts and dehydrated fruits in cereal bars elaborations and obtained dietary fiber content ranging from 3.89 g 100 g⁻¹ (oat bar) to 6.08 g 100 g⁻¹ (millet bar).

Regarding the estimated total caloric value, slight differences were reported (Table 2). Considering that all cereal bars had the same basic formulation and that the variable ingredient was the osmotically dehydrated *araçá* content, the small difference in their energy contents can be attributed to the proximate composition of this ingredient.

The values of pH and titratable acidity of gluten-free cereal bars are presented in the Table 3.

The *araçá* cereal bars showed Table 3 an average pH of 4.83 and a titratable acidity of 0.425 g of citric acid per 100 g. These analyses are of great importance as the evaluated parameters are directly related to the product's shelf life. Titratable acidity considers most of the acids present in the fruit, being directly responsible for the stage of ripeness.

Table 3. pH and titratable acidity of *araçá* cereal bars.

	T1	T2	T3
pH	5.00 ± 0.05 ^a	4.80 ± 0.05 ^b	4.70 ± 0.01 ^c
Titratable acidity (g citric acid 100 g ⁻¹)	0.422 ± 0.046 ^a	0.440 ± 0.022 ^a	0.412 ± 0.034 ^a

Incorporated osmotic dehydrated *araçá*: T1 - 15 g 100 g⁻¹, T2 - 20 g 100 g⁻¹; T3 - 27 g 100 g⁻¹. Average value ± standard deviation. Mean followed by different letters in the same line indicate a significant difference ($p < 0.05$), according to Tukey's test.

As expected, the increase in the addition of *araçá* reduced the pH of the cereal bars ($p \leq 0.05$), although no significant difference was observed in the titratable acidity of the evaluated samples (Table 3). The reduction in pH likely occurred due to the increase in the concentration of organic acids, such as citric acid, which is the main organic acid reported for *araçá* fruit (Damiani et al., 2011).

Silva et al. (2018) developed cereal bars with marolo (*Annona crassiflora* Mart.) fruit flour and observed that the titratable acidity of the samples increased significantly ($p \leq 0.05$) and proportionally with the concentration of marolo flour in the bars. Ramos et al. (2021) developed cereal bars with 12.5% and 25% pequi fruit almond (pH 6.7) and reported a significant increase ($p \leq 0.05$) in pH from 5.0 to 5.5 with higher fruit addition.

Bioactive compounds

The effect of processing stages on bioactive compounds is presented in Table 4. Ascorbic acid content differed significantly between treatments, with a 32.66% reduction after osmotic dehydration (OD).

The drying process caused a loss of 40.82%, leading to a 60.15% reduction in ascorbic acid content compared to the fresh fruit. The ascorbic acid content increased with higher concentrations of osmotically dehydrated guava in the formulation, with the content in T3 being statistically higher ($p \leq 0.05$) than in T1, as presented in the Table 4.

The highest levels of tannins and total phenols also occurred in T3 and differed significantly ($p \leq 0.05$) from T2 and T1. These values were reflected in the IC₅₀, with a lower statistical value in T3, indicating greater antioxidant capacity due to the lower concentration required to achieve 50% inhibition of the DPPH free radical.

Table 4. Ascorbic acid content, total phenols, total tannins, and antioxidant capacity of *araçá* cereal bars.

	T1	T2	T3
Ascorbic acid (mg 100 g ⁻¹)	32.72 ± 2.05 ^b	34.61 ± 3.65 ^{ab}	38.88 ± 2.13 ^a
Total phenols (mg GAE 100 g ⁻¹)	107.96 ± 0.84 ^b	109.53 ± 0.85 ^b	130.26 ± 0.60 ^a
Total tannins (mg TAE 100 g ⁻¹)	95.06 ± 0.81 ^c	102.40 ± 0.81 ^b	170.47 ± 0.65 ^a
Antioxidant capacity (IC ₅₀ g g ⁻¹ DPPH)	326.40 ± 3.54 ^a	261.40 ± 4.39 ^b	112.64 ± 6.53 ^c

Incorporated osmotic dehydrated *araçá*: T1 - 15 g 100 g⁻¹, T2 - 20 g 100 g⁻¹; T3 - 27 g 100 g⁻¹. Average value ± standard deviation. Mean followed by different letters in the same line indicate a significant difference ($p \leq 0.05$), according to Tukey's test.

Favaro et al. (2020) evaluated cereal bars with anthocyanin extract from *Jussara* palm fruit (*Euterpe edulis*) and observed that the cereal bars with added anthocyanin extract presented an increment in the antioxidant activity, from 74.70; 87.8; 86.6% with the addition of 0.25, 1.0, and 2.0%, respectively.

Expressed in tannic acid equivalents (TAE), the tannin contents also differed across the processing stages, with a 7.68% reduction after osmotic dehydration and an additional 7.75% reduction after drying. Similarly, the TAE values decreased with the osmotic dehydration stages but stood out for showing less variation in these contents.

Gwozdz et al. (2022) reported that *araçá* contains significant amounts of phenolic compounds, with epicatechin and gallic acid being its main components. It is considered a promising plant for the pharmaceutical and food industries due to its potential applications. Recent studies suggest a possible correlation between antioxidant activity and phenolic compound content, with lower IC₅₀ values indicating better inhibitory activity of the stable synthetic DPPH radical. The IC₅₀ values indicate higher inhibitory activity in the extract from the fruit peel that underwent osmotic dehydration and drying, which may be the result of moisture reduction and concentration of these compounds, as shown in Table 4.

The results of using different solvents to extract bioactive compounds in cereal bars with *araçá* are presented in Table 5.

In general, the ethanol extraction showed lower levels of all bioactive compounds compared to the other solvents (Table 5). In relation to the different formulations, it was possible to verify that the increase in the amount of osmodehydrated *araçá* in the prepared bars is directly related to the increase in the bioactive contents analyzed in the present study, with emphasis on T3, which differed statistically ($p < 0.05$) from T1 and T2 in the three solvents evaluated.

Table 5. Quantification of total phenols, total tannins, and antioxidant capacity of *araçá* cereal bars.

	T1	T2	T3
Aqueous extract			
Total phenols (mg GAE 100 g ⁻¹)	107.96 ± 0.84 ^b	109.53 ± 0.85 ^b	130.26 ± 0.60 ^a
Total tannins (mg TAE 100 g ⁻¹)	95.06 ± 0.81 ^c	102.40 ± 0.81 ^b	170.47 ± 0.65 ^a
Antioxidant capacity (IC ₅₀ g g ⁻¹ DPPH)	326.40 ± 3.54 ^a	261.40 ± 4.39 ^b	112.64 ± 6.53 ^c
Ethanol extract			
Total phenols (mg GAE 100 g ⁻¹)	39.57 ± 0.88 ^b	34.79 ± 0.89 ^c	50.61 ± 0.54 ^a
Total tannins (mg TAE 100 g ⁻¹)	45.06 ± 0.84 ^b	42.71 ± 0.84 ^c	68.75 ± 0.52 ^a
Antioxidant capacity (IC ₅₀ g g ⁻¹ DPPH)	538.40 ± 1.78 ^a	287.06 ± 3.43 ^b	230.48 ± 2.59 ^c
Hydroacetic extract			
Total phenols (mg GAE 100 g ⁻¹)	134.01 ± 0.85 ^c	186.45 ± 0.89 ^b	263.40 ± 0.90 ^a
Total tannins (mg TAE 100 g ⁻¹)	99.21 ± 0.81 ^c	131.39 ± 0.82 ^b	178.10 ± 0.66 ^a
Antioxidant capacity (IC ₅₀ g g ⁻¹ DPPH)	57.75 ± 5.74 ^a	30.93 ± 6.93 ^b	19.29 ± 4.04 ^b

Incorporated osmotic dehydrated *araçá*: T1 - 13 g 100 g⁻¹, T2 - 20 g 100 g⁻¹, T3 - 27 g 100 g⁻¹. Average value ± standard deviation. Mean followed by different letters in the same line indicate a significant difference ($p \leq 0.05$), according to Tukey's test.

These results express the extraction capability of the hydroacetic solvent regarding the phenolic compounds present in the *araçá* bars. For the total phenols, it was observed highest results in the hydroacetic extraction: T3 (263.40 ± 0.90 mg GAE 100 g⁻¹), followed by T2 (186.45 ± 0.89 mg GAE 100 g⁻¹) and T1 (134.01 ± 0.85 mg GAE 100 g⁻¹).

The hydroacetic extracts from T2 and T3 presented total tannins values of 178.10 ± 0.66 and 131.39 ± 0.82 mg TAE 100 g⁻¹, respectively, and IC₅₀ values of 19.29 and 30.93 g g⁻¹ DPPH, respectively. This indicates a correlation between high tannins and phenolic content and high antioxidant activity, as reported in the literature (Roesler et al., 2007). *Araçá* is known as a source of bioactive compounds, especially phenolics, which are associated with its antioxidant activity (Gwozdz et al., 2022).

The results obtained for antioxidant capacity, expressed as the ability to reduce 50% of the DPPH radical, extracted with aqueous, ethanol, and hydroacetic extracts Table 5, indicate a high antioxidant power for the formulations that achieved 50% reduction of the free DPPH radical at the lowest concentration. Each formulation exhibited different behavior depending on the type of extract, showing the need for varying concentrations to reduce the free radical (DPPH) activity.

The results indicate that the formulation with the best ability to reduce the free radical by 50% was T3, which contained the highest proportion of osmotically dehydrated *araçá*. The highest antioxidant potential was observed in the hydroacetic extract, followed by the aqueous extract, showing that, in addition to total phenols, other compounds are also influencing the antioxidant capacity.

Sensory analysis

The three cereal bar formulations with *araçá* were evaluated sensorially to determine the most accepted sample by the evaluators. Regarding the overall appearance of the three formulations, the average ratings given by the testers were above 7.0, indicating 'moderate liking,' and were considered acceptable for consumption. No statistical difference ($p > 0.05$) was found between the average ratings for the three formulations evaluated.

The analysis did not show a positive correlation between sensory perception and the concentration of dehydrated *araçá* in the cereal bars and their acceptability. The lowest rating, 6.7, was given to T2, which had 20% addition of the dehydrated fruit, followed by 7.2 for T1, with 13% *araçá* added. The T3, with 27% osmotically dehydrated *araçá*, received the highest average sensory evaluation score of 7.4, making it the preferred option among the evaluators.

Correlating the sensory analysis with the nutrient composition and bioactive compounds, T3 also showed the highest levels of lipids, reducing sugars, fibers, and caloric value, as well as the greatest antioxidant capacity, indicating higher technological potential and quality in its composition.

Silva et al. (2018) studied the sensory acceptance of cereal bars with marolo (*Annona crassiflora* Mart.) pulp flour and found overall appearance scores ranging from 7.36 to 8.45, which increased with the addition of the fruit in the formulation.

Vanin et al. (2021) developed cereal bars with dehydrated and crushed *araçá* pulp in proportions of 10%, 15%, and 20%, and obtained overall appearance scores ranging from 7.24 to 7.53. The authors did not report any statistical difference in the evaluation of color, aroma, taste, and overall appearance, but they observed a highly positive correlation between the amount of *araçá* flour added and the scores for taste and texture, which are important quality parameters for this type of product.

All three formulations achieved an acceptability index of over 95.5%, which, according to Dutcosky (2007), indicates good market acceptance of the product.

As a general remark, Białek et al. (2016) pointed that the newly designed bars, with their enhanced nutritional value, could offer a promising alternative to the snacks currently found in school shops.

Microbiological analysis

The results presented in Table 6 indicate that the *araçá* bars comply with the microbiological standards established by item '10 m' of RDC n° 12, January 2001, and item '19 i' of Normative Instruction - IN n° 161, July 1, 2022. These findings confirm their suitability for consumption, highlighting the quality of the ingredients used and the rigorous hygienic-sanitary control during the production of the cereal bars.

Table 6. Microbiological analyses of *araçá* cereal bars, after 9 months of storage and maximum permissible value (MPV) according to Resolution RDC n° 12, January 2, 2001 (Brasil, 2001) and Normative Instruction - IN n° 161, July 1, 2022 (Brasil, 2022).

Samples	Coliform count at 45°C and <i>E. coli</i> (CFU g ⁻¹)	<i>Bacillus cereus</i> count (CFU g ⁻¹)	Absent of <i>Salmonella</i> sp. (25 g)
T1	< 3 × 10	< 1 × 10 ⁻¹	absent
T2	< 3 × 10	< 1 × 10 ⁻¹	absent
T3	< 3 × 10	< 1 × 10 ⁻¹	absent
MPV	< 5 × 10	< 5 × 10 ²	absent

Incorporated osmotic dehydrated *araçá*: T1 - 13 g 100 g⁻¹, T2 - 20 g 100 g⁻¹; T3 - 27 g 100 g⁻¹. CFU: Colony-forming units.

Similarly, previous studies, such as Guimarães and Silva (2009) on cereal bars with murici-passa, and the works of Santos et al. (2022) and Cerny et al. (2024) on other types of cereal bars, also reported the absence of *Salmonella* sp. and results below 1×10 CFU g⁻¹ for *Bacillus cereus* and Coliforms at 45°C, including *E. coli* counts.

The results of the microbiological analyses suggest that proper thermal processing, combined with high-quality raw materials, correct handling, and low moisture content, are key factors in ensuring the sanitary quality of the produced cereal bars.

Conclusion

The cereal bars meet the moisture standards set by Brazilian legislation. Total phenol and tannin levels show good stability, remaining close to those of the fresh fruit even after processing and in the cereal bar. IC₅₀ values indicate good antioxidant activity, which is related to the total phenol content in bars. Hydroacetic extracts have the highest concentrations of total phenols, total tannins, and antioxidant activity. All cereal bar formulations received positive sensory evaluations and excellent acceptability scores. All the treatments met the microbiological standards in accordance with Brazilian legislation. The increase in osmotically dehydrated *araçá* resulted in higher levels of lipids, reducing sugars, fibers, caloric value, and antioxidant capacity in the cereal bars, indicating a high technological potential for using this Cerrado fruit in food formulation and contributing to local socioeconomic development.

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Data availability

Data will be made available upon request.

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