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ORIGINAL ARTICLE

Cereal bar enriched with ora-pro-nóbis (*Pereskia aculeata* Miller): physicochemical and sensory characterization

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Abstract Ora-pro-nobis (OPN) is an unconventional food plant with high nutritional value, and its nutritional composition can be altered according to cultivation. Cereal bars are a popular nutrient-poor foods, and OPN could be incorporated to improve the nutritional quality. This study aimed to evaluate the physicochemical characteristics and sensory acceptability of cereal bars enriched with OPN flour (OpnF) from different forms of cultivation. OpnF was obtained by dehydrating and grinding OPN leaves collected in rural (ROpnF) and urban (UOpnF) municipalities. Two formulations of cereal bars, peanut flavor (Bpn) and mango flavor (Bmg), each with 10% OpnF, were prepared. The macronutrients and mineral composition, oxalate content, water activity, texture, color profile, and acceptability were evaluated. ROpnF had the highest protein, iron, and manganese content, whereas UOpnF had the highest ash and magnesium content. The oxalic acid/calcium ratio was 1.43 and did not imply calcium bioavailability. In addition to nutritional and protein values, Bpn and Bmg presented a good sensory acceptability index of > 77.5% with market potential. Bmg has the highest mineral content and is a source of iron, manganese, and magnesium. OpnF can be used in cereal bars and potentially improve nutritional attributes and used in other foods in a similar way.

Keywords Cereal bar · Hyperproteic cereal bar · Ora-pro-nobis flour · Oxalate Unconventional food plant

Abbreviations

OPN	Ora-pro-nóbis
UFP	Unconventional food plants
OpnF	Powder of OPN leaves
ROpnF	OpnF from rural cultivation
UOpnF	OpnF from urban cultivation
Bpn	Cereal bars peanut flavor
Bmg	Cereal bars mango flavor

Introduction

Several species of tropical flora can be used as nutritional supplements and enhance cultural diversity. Unconventional food plants (UFP) range from native and unusual to exotic and wild plants. Due to their nutritional characteristics, these plants have been used as food options and a source of vitamins, minerals, fiber, and, in some cases, carbohydrates and proteins. One example is *Pereskia aculeata* Miller, Cactaceae family, popularly known as ora-pro-nóbis (OPN) (Da Silva et al. 2022).

OPN is a perennial plant native to tropical America, which adapts to different soil types and is not demanding in terms of fertilization (Oliveira et al. 2018). The growing

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interest of the industry and researchers in this UFP is due to its ease of use and low cost of production, in addition to its nutritional characteristics (Souza et al. 2009). Due to their high mucilage content, OPN sheets can be used in the food and pharmaceutical industries as an alternative for obtaining mucilage (Silva et al. 2019) or developing films for functional and/or edible packaging (Porto et al. 2021).

Pereskia aculeata leaves are used in folk medicine as emollients to treat skin wounds and inflammatory processes (Pinto et al. 2015), improve intestinal motility, reduce visceral fat and lipid profile, and increase high-density lipoprotein-cholesterol levels (Barbalho et al. 2016). It has protein content value, 85% digestibility, and high values of essential amino acids. The predominant amino acid in *P. aculeata* leaves is leucine, followed by phenylalanine and glutamate. The concentrations of essential and nonessential amino acids, except for methionine, are close to or higher than those recommended by the Food and Agricultural Organization for human diets (Santos et al. 2022). However, the leaves may have a different nutritional composition, depending on the soil in which the plant was grown, which may favor a greater or lesser supply of nutrients in the same species (Dimitrius et al. 2013; Queiroz et al. 2015) or present levels of antinutrients, such as calcium oxalate, ranging from 0.418 g% (Almeida et al. 2014) to 3.54 g% (Silva et al. 2013).

Its use as a food or an ingredient in food preparations can be considered an alternative to increasing the nutritional quality of foods and contributes to the lower consumption of animal proteins. The leaf of *P. aculeata* has been used in different preparations, such as bread (Alves et al. 2022), cakes (Rosa et al. 2020), and functional ice cream with high protein content (Santos et al. 2022). Incorporating dehydrated and ground OPN in foods for regular consumption is a healthy strategy to increase the intake of nutrients of plant origin (Sato et al. 2019).

In this context, cereal bars present attractive characteristics to the consumer for their nutritional composition associated with healthy products and for the convenience of consumption (Mello et al. 2012). However, the biggest challenge for obtaining a cereal bar with good acceptability is the combination of different ingredients with specific functionalities, such as vitamins, minerals, proteins, grains, fibers, thickening agents, sweeteners, and flavorings, while trying to achieve specific nutritional goals (Marchese and Novello 2017). Many protein bars are marketed with soy protein added (Freitas and Moretti 2006) or milk protein, such as whey, but the use of OPN would be an opportunity to introduce a less usual and high-value product of plant origin nutritional value; however, there is a need to verify the acceptability of consumption of this new product.

Therefore, this study aimed to evaluate the physicochemical characteristics and acceptability of cereal bars enriched with dehydrated and ground OPN leaves from rural and urban cultivation.

Methods

Preparation of P. aculeata leaves

Pereskia aculeata leaves were harvested in winter in rural areas (− 11.733071, − 39.304876; Riachão do Jacuípe, interior of Bahia, Brazil) and urban areas (− 12.8934913, − 38.3082858; Lauro de Freitas, metropolitan region of Salvador, Bahia, Brazil). OPN sheets were washed and immersed in sodium hypochlorite solution (250 ppm) for 15 min and subjected to dehydration in an oven with air circulation at 60 °C (Quimis, Brazil) for 24 h, according to the procedure adopted by Rodrigues et al. (2013). The obtained material was ground in a food processor (Phillips, Brazil) until a powder similar to flour was obtained. The powder of OPN leaves from rural (ROpnF) and urban (UOpnF) cultivation was subjected to physicochemical analysis before preparing the cereal bars; after mixing, they were coded as OpnF.

Preparation of cereal bars enriched with OpnF

Two formulations of cereal bars were prepared: peanut flavor (*Arachis hypogea* L.; Bpn) and mango flavor (*Mangifera indica* L. var. Tommy; Bmg) according to the formulation presented in Table 1. The ingredients were mixed and distributed manually in metal baking sheets until 1 cm thick, which was then submitted to baking (10 min at 150 °C), followed by manual cutting.

Analysis of centesimal and mineral composition

The centesimal composition of ROpnF, UOpnF, Bpn, and Bmg was determined according to the Association of Official Analytical Chemists (AOAC 2019) standards. Moisture, protein, lipid, and ash content were performed in triplicate. The total nitrogen content was determined by the Kjeldahl method with a conversion factor of 6.25 to obtain the total protein content. Carbohydrate was determined by difference.

The samples were dried in an oven (FANEM, Model 320-SE, São Paulo, Brazil), and the mass was measured on an analytical balance (CP2245 Sartorius®; Germany). About 0.2 g of each sample was digested in a microwave oven (MARS-6, CEM®; USA) according to Gomes-Junior et al. (2020) for mineralization. Concomitantly with the samples, four analytical blanks were processed. Optical emission spectrometry with inductively coupled plasma (iCAP PRO; Thermo Fisher, Waltham, MA, USA) was used for determination. The operational parameters and analytical

Table 1 Percentage ingredients of the cereal bars formulation with ora-pro-nobis flour

Ingredients	Bpn	Bmg
Mango jelly*	–	50%
Peanut butter**	25%	–
Glucose	25%	–
Oat flakes	15%	15%
Oats in slices	5%	10%
Sugar	8%	–
OpnF	10%	10%
Raisin grape	5%	6%
Flaxseed and sesame seed mix	3%	4%
Corn starch	3%	4%
Rice flake	1%	1%

Bpn, cereal bar with peanut-flavored OpnF; Bmg, cereal bar with mango flavored OpnF; OpnF, dehydrated and ground leaf of *P. aculeata* (ora-pro-nobis); Mango Jelly*, 50% mango pulp (*Mangifera indica*), 25% crystal sugar and 25% glucose; Peanut Butter**, Power 1one® commercial product; 1:1 mixture of brown flax (*Linum usitatissimum* L.) and white sesame (*Sesamum indicum* L.) seeds

wavelengths were as follows: cyclonic spray chamber and concentric nebulizer with a radiofrequency power of 1.15 kW; the flow of plasma, auxiliary, and nebulizer gas was 12.5, 0.5, and 0.5 L/min, respectively; and the wavelengths were Ca (I) 422.673, Fe (II) 238,204, K (I) 769,897, Mg (I) 285.213, Mn (II) 257,610, No. (I) 589,592, P (I) 177.434, and Zn (II) 202,548, with (I) as the atomic emission line and (II) as the ionic emission line. The multi-element solutions for the analytical curve were prepared from stock solutions containing 1000 mg/L of different elements at concentrations from 0.1 to 300.0 mg/L. The contents were expressed considering the samples on a wet basis as mg mineral/100 g sample (mg %).

Soluble oxalate content of UOpnF and ROpnF

The quantification of the oxalate content of ROpnF and UOpnF samples was performed in triplicate according to the procedure for separating the insoluble oxalate adopted by Rocha (2009). First, the aqueous extracts of the samples were obtained, followed by the precipitation step with saturated calcium chloride solution by cooling for 12 h. After the period, the samples were centrifuged to separate the soluble oxalate. The precipitate was filtered, solubilized in sulfuric acid, and titrated with potassium permanganate ($KMnO_4$). Solution preparation, $KMnO_4$ standardization, and sample titration were in accordance with the AOAC (2019). The result was expressed as g oxalate/100 g sample (g%).

Texture profile of Bpn and Bmg

Bpn and Bmg were submitted to instrumental texture analysis in a TA.XTExpress texturometer (Stable Micro Systems) under the following conditions: pre-test speed 1.0 mm/s, test speed 2.0 mm/s, post-test speed 10.0 mm/s, and penetration distance 7.0 mm/s. Each sample was analyzed separately in eight replicates as they presented a heterogeneous texture aspect. For this test, the samples were standardized at 7 × 2 cm in size and 1 cm in height.

Water activity and colorimetric profile of Bpn and Bmg

Bpn and Bmg were submitted in triplicate to analyze the water activity in a Decagon instrument model Aqualab Lite. For instrumental evaluation of the color of the cereal bars by the parameters L* (luminosity), a* (red-green component) b* (yellow-blue component), C* chroma [(a*2 + b*2)1/2], hab angle [tangent arc (b*/a*)], and color difference = $DE^* = \{(DL^*)^2 + (Da^*)^2 + (Db^*)^2\}^1/^2$, the BYK colorimeter was used (Series 199968; Gardner, Germany (Pathare et al. 2013). Analyses were performed at six different points in the samples.

Sensory analysis and purchase intent

The prepared cereal bars were sensorially evaluated according to an acceptance test by a team composed of 51 volunteer judges, with different gender and age, using a hedonic scale from 1 to 9 points, with hedonic terms corresponding to "I liked it extremely" and "extremely disliked" in the upper and lower extremes, respectively, considering the attributes, including overall appearance, color, texture, aroma, and flavor. A product purchase intention test was also applied using a five-point scale of categories inserted in the same form, with terms corresponding to "certainly would buy" and "certainly not buy," respectively, at the upper and lower ends of the scale. The judges signed an informed consent form, approved by the Ethics Committee and Research with Human Beings of the UFBA School of Nutrition (CAAE 20214219.4.0000.5023). The inclusion criteria for participants were ages between 18 and 60 years, regular consumers of cereal bars, individuals not allergic to the ingredients of cereal bars, and those free from health problems that could interfere with the sensory analysis.

The average data of the registered grades and the acceptability index [AI (%) = A × 100/B, where A is the average grade obtained for the product and B is the maximum grade given to the product] were evaluated (Damasceno 2016).

Statistical analysis

One-way analysis of variance and Tukey's correction as post-test (for data with normal distribution), Kruskal–Wallis and Dunn's correction as post-test (for data without normal distribution), and t-test paired samples were used to determine the statistical significance of the analyses of proximate composition, mineral and oxalate content, and physical and sensory analyses of the samples analyzed by GraphPad version 5 (GraphPad Software, Inc., San Diego, CA, USA).

Results and discussion

Centesimal, mineral, and oxalate content of ROpnF and UOpnF

Table 2 presents the centesimal composition data and mineral and oxalate content of UOpnF and ROpnF. The yield was 18% in relation to fresh leaves and met the maximum requirement of 15% moisture, as specified by Resolution 263/2005 (Brasil 2005) for the definition of flours and bran. The proximate contents obtained from the analyses of both samples showed similar proportions or within limits determined in other studies on *P. aculeata*, such as moisture content between 7.5% and 13.5%, ash from 18.8% to 32.5%, protein from 15.2% to 26.5%, and lipids from 4.4% to 11.9% (Vargas et al. 2017; Queiroz et al. 2015; Santos et al. 2021). However, differences in composition were observed between samples analyzed from different municipalities for moisture ($p < 0.01$), ash, and protein ($p < 0.05$).

The moisture content in the flours showed a difference of 2.3% between the average, with ROpnF presenting a lower content, despite the collection of *P. aculeata* leaves during the rainy season. The rural municipality is located in a semi-arid area with low rainfall (Weather Spark 2019). Queiroz et al. (2015) justified the difference in moisture content in *P. aculeata* leaves due to the time of sun exposure suffered by the plantation, which is directly proportional to the dry mass of the sample.

The high ash content found in both flours was noteworthy. Conventional vegetables mostly have an ash content close to 10% in a dry sample (NEPA 2011), whereas the analyzed flours presented contents between 17.89 g% and 22.88 g%, respectively, for ROpnF and UOpnF, with a significant difference ($p < 0.05$, paired t-test; Table 1). Queiroz et al. (2015) also observed that *P. aculeata* plantations located in places with a predominance of shade from the sun have higher ash content in dry matter (32.5%) compared to more sunny places (18.8%). These data corroborated the contents identified in this study because the rural municipality has greater solar incidence than the urban one (Weather Spark 2019).

The lipid levels found in the analysis of ROpnF and UOpnF samples (4.51 g% and 4.39 g%) were similar (Table 1) and in line with the literature and the characteristics found in other vegetables, such as kale (*Brassica oleracea* Acephala; 4.1%; NEPA 2011), whereas Moringa (*Moringa oleifera*), another type of UFP, has an even higher content of 7.1% (Teixeira et al. 2014).

The flours showed high protein content, 23.45 g% and 20.4 g%, respectively, for ROpnF and UOpnF ($p < 0.05$, paired t-test; Table 1). Santos et al. (2021), Souza et al. (2016), and Vargas et al. (2017) identified similar levels of protein (23.8%, 21.9%, and 17.9%, respectively). *P. aculeata* is a UFP source of proteins, presenting levels of 100 g of dry sample close to the values found in other vegetable sources of protein, such as taioba (*Xanthosoma sagittifolium* Schott) (Araújo et al. 2019). The intake of 50 g of dried taioba leaves can provide 60% of the recommended daily intake of protein for adults and 86% for children (Araújo et al. 2019). 21.2 g%) and oilseeds, such as raw peanuts (27.2%; NEPA 2011), beans (*Cajanus cajan* L.; 22.06 g%), and mangalo beans (*Phaseolus lunatus* L.; 26.45 g% (Benevides et al. 2019). The protein content of the leaves can vary depending on the luminosity of the plantation, in which the greater the shading, the greater the protein content (Queiroz et al. 2015),

Table 2 Centesimal, mineral and oxalate content of ora-pro-nobis flour samples from two different forms of cultivation

	ROpnF	UOpnF
Centesimal composition (g%)		
Moisture	3.69 ± 0.8**	5.99 ± 0.13**
Ashes	17.39 ± 0.3*	22.88 ± 0.29*
Lipids	4.51 ± 0.79	5.39 ± 0.6
Protein	23.45 ± 0.66*	20.4 ± 1.06*
Carbohydrates	50.96	45.34
Mineral composition (mg%)		
Calcium (Ca)	83.26 ± 2.90**	109.61 ± 4.23**
Iron (Fe)	9.93 ± 0.34*	6.48 ± 0.96*
Potassium (K)	33.73 ± 1.28*	36.44 ± 0.80*
Magnesium (Mg)	509.71 ± 36.95*	669.62 ± 47.28*
Manganese (Mn)	13.04 ± 0.72***	5.52 ± 0.42***
Sodium (Na)	52.33 ± 4.23**	36.08 ± 1.65**
Phosphorus (P)	215.45 ± 10.23*	243.51 ± 17.63*
Zinc (Zn)	2.75 ± 0.16	2.89 ± 0.15
Oxalates content (g%)		
Insoluble oxalate	1.27 ± 0.11	1.48 ± 0.08

Mean data g% or mg% ± standard deviation

OpnF, ora-pro-nóbis (Opn) (*Pereskia acuelata*) flour; ROpnF, Flour from Opn leaves harvested in the rural municipality; UOpnF, Flour from Opn leaves harvested in the urban municipality

*, ** and *** on the same line indicate statistical significance, with *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$ (Paired t test by GraphPad Prism v5)

which does not corroborate this study, because a higher content of proteins was identified in ROpnF. Another factor contributing to protein differences in plants is the nitrogen content available in the cultivated soil, which is directly proportional to the protein content of the leaf and, consequently, of its flour (Dimitrius et al. 2013).

The carbohydrate content showed a difference of 5.6% between the samples, comprising fiber and carbohydrate fractions together (Table 1). Ribeiro et al. (2019) determined the fiber fractions in OPN and identified insoluble fiber contents, on average, six times higher than the contents obtained in soluble fiber.

Regarding the content of the determined minerals, the flours showed a significant difference, except only for zinc. UOpnF showed higher calcium, potassium, magnesium, and phosphorus levels, whereas ROpnF showed higher iron, manganese, and sodium levels. Considering the averages of the content of each mineral in the flours and the requirements of nutritional attributes of foods specified in the IN75 of 2020 (Brasil 2020), the consumption of 25 g OpnF meets the designation as a flour source of iron and high in magnesium and manganese content.

As for oxalate levels (Table 2), there was no significant difference between the analyzed samples, and the results were not similar to those of Almeida et al. (2014) (41.79 mg%). Such differences can be justified by the place of cultivation and type of oxalate analyzed (soluble or total) and how the analysis procedure was performed. In this study, oxalate was determined based on the separation of insoluble oxalate, which interferes more with calcium bioavailability (Rocha 2009).

The biggest implication of consuming vegetables with high levels of oxalate is the decrease in calcium absorption (Higashijima et al. 2022). According to Guil et al. (1996), the oxalic acid/calcium ratio should be < 2.5. Considering the mean values of calcium (0.964 g%) and oxalates (1.38 g%) of the two flours in this study, this ratio was 1.43, suggesting that the content of this antinutrient will not affect the bioavailability of the calcium present in OpnF.

Table 3 Physicochemical parameters of cereal bars enriched with ora-pro-nobis flour (OpnF)

	Bpn	Bmg
Centesimal composition (g%)		
Moisture	8.87 ± 0.91*	12.98 ± 0.68*
Ashes	3.40 ± 0.15	3.28 ± 0.02
Lipids	15.88 ± 0.89*	3.89 ± 0.14*
Protein	15.02 ± 0.37	13.55 ± 0.41
Carbohydrates	56.8	66.3
Mineral composition (mg%)		
Calcium (Ca)	3.9 ± 1.41**	10.03 ± 0.42**
Iron (Fe)	3.57 ± 0.27**	5.13 ± 0.46**
Potassium (K)	6.34 ± 0.55**	11.57 ± 0.56**
Magnesium (Mg)	132.11 ± 2.43***	223.17 ± 12.17***
Manganese (Mn)	1.05 ± 0.02**	3.65 ± 0.27**
Phosphorus (P)	171.66 ± 6.11***	360.98 ± 29.07***
Zinc (Zn)	0.64 ± 0.05***	1.79 ± 0,23***
Water activity	0.54 ± 0.02	0.40 ± 0.00
Color profile		
(L*)	28.25 ± 1.52	30.89 ± 4.86
(a*)	4.60 ± 0.43*	5.60 ± 0.73*
(b*)	8.95 ± 3.51*	16.24 ± 5.36*
(C*)	10.13 ± 3.23*	17.23 ± 5,19*
(h_{ab})	61.04 ± 8.86*	70.10 ± 5.33*
Texture profile		
Hardness (N)	5669.64 ± 1760.77*	3578.99 ± 472.66*
Springiness (m)	0.66 ± 0.19	0.85 ± 0.12
Chewiness (N/m)	432.96 ± 206.02	639.86 ± 96.64
Cohesiveness	0.12 ± 0.03**	0.21 ± 0.04**

Mean data g% or mg% ± standard deviation

Bpn, cereal bar with peanut-flavored OpnF; Bmg, cereal bar with mango flavored OpnF; OpnF, dehydrated and ground leaf of *P. aculeata* (ora-pro-nobis); (L*), luminosity; (a*), red-green component; (b*), yellow-blue component; (C*), Chroma [(a*2 + b*2)1/2]; (hab), arc tangent angle; N, Newton; m, Meter; N/m, Newton/meter

*,** and *** on the same line indicate statistical difference where *p < 0.05, **p < 0.01 and ***p < 0.001 (Paired t test, GraphPad Prism v5)

Physicochemical characterization of Bpn and Bmg

Table 3 presents the proximate composition, mineral content, water activity, texture profile, and color of Bpn and Bmg. Bmg and Bpn showed protein contents of 13.55 g% and 15.0 g%, respectively (Table 2). A serving of commercial cereal bars with 50 g will contain 6.8 and 7.5 g of protein, respectively, reaching 9.1% and 10% of the recommended daily value (%DV) of protein intake (Brasil 2020). In addition to OpnF present in 10% of the formulations of the cereal bars developed, oats (15% to 30%) and, for Bpn, also peanut butter (25%) are ingredients that increase the protein content of the products. The protein content of oats is 13.9 g% (NEPA 2011). Its characteristic amino acid profile of cereal is complemented with the amino acid profile of a peanut legume, which can reduce the limiting factor of amino acids. Additionally, OPN flour has already been described with a relevant concentration of essential amino acids (Santos et al. 2022); therefore, it´s probably that Bpn is complete in essential amino acids. Normative Instruction 75 of 2020 (Brasil 2020) specifies that food is a source of protein if it has a content of ≥ 10% of the %DV (75 g) per portion or unit and meets the amounts of essential amino acids established. Thus, Bpn (a portion of 50 g) resulted in a preparation with the potential to be considered a protein source. Adjustments in the formulation, such as a percentage increase in OpnF, could characterize this potential also in Bmg.

The significant difference ($p < 0.05$, paired t-test) in the lipid content between Bmg and Bpn samples is noteworthy (3.89 g% and 15.88 g%, respectively; Table 3) due to the lipids from commercial peanut butter (46.7 g% specified on the label). This ingredient option also resulted in the difference between the carbohydrate contents (66.3 and 56.8 g%) and moisture content of the cereal bars, with a significant difference ($p < 0.05$, paired t-test), with Bmg being wetter than Bpn. Mango jelly has a high carbohydrate content in its composition, in addition to the soluble fibers of the fruit, which contribute to greater moisture in the final product. The difference in the moisture content may reflect the acceptability of these products because the moisture content is within parameters that allow the maintenance of crispness (Baú et al. 2010).

Regarding the determined minerals, Bmg showed higher contents of all elements with a significant difference compared to Bpn. In addition to the fruit (mango), Bmg has a higher percentage of oats, raisins, and seed mix in its formulation, which may have contributed to the higher levels. Considering a portion of 50 g of cereal bar, Bmg has an attribute as a source of iron, and both cereal bars are a source of manganese and magnesium, according to the requirements of Brazil (2020).

The cereal bars prepared showed similar values of water activity (0.54 and 0.4 for Bpn and Bmg, respectively) and were below the range established for the growth of most microorganisms (0.90 and 0.99 (Vidal et al. 2022) and thus might have good microbiological stability, in addition to also influencing nutritional and sensory stability. Jelly, a colloidal system formed by incorporating water by pectin, especially due to hydrogen bonds, may favor a lower water activity value. However, it may present even higher humidity (Ahmed 2015).

Regarding the color parameters analyzed, there were no significant differences between the two formulations of cereal bars prepared (Table 3). The values found in L* and a* were very similar between the two formulations. Considering the parameter L*, the cereal bars presented low luminosity, characterizing a dark color. Although OpnF has a perceptible dark green color, the values of a* and b* indicated that the cereal bars have a greater tendency to be red and yellow, respectively, with higher intensities for Bmg (Table 2), which may be due to the addition of jelly of mango. The hab angle is a qualitative attribute of color and confirms the data of a* and b*; in this way, Bpn and Bmg present a shade closer to yellow (90° angle) (Pathare et al. 2013). However, Bpn and Bmg showed low saturation, as indicated by the C* parameter; therefore, the reddish and yellowish colors were barely visible. This may be related to the presence of OpnF in the formulations, which can decrease the brightness and intensity of the colors of the preparation.

Texture analysis results showed that there was a significant difference in hardness and cohesiveness ($p < 0.05$ and $p < 0.01$, respectively, paired t-test) between Bpn and Bmg (Table 3), and the groupings of the analyses are shown in Fig. 1. The cereal bar formulations analyzed in this work have a heterogeneous texture, especially for Bpn, as evidenced by hardness and chewiness (Fig. 1A and C). This heterogeneous characteristic is similar to other cereal bars with a high protein and vitamin content (Farinazzi-Machado et al. 2018) and quinoa grains (Da Silva et al. 2011) due to the mixture of different ingredients, which, in themselves, already have a variety of textures. The mango jelly may have contributed to a better uniform texture of Bmg. Bpn showed higher hardness and lower cohesiveness than Bmg (*$p < 0.05$ and **$p < 0.01$, paired t-test; Fig. 1).

Sensory analysis and purchase intention of Bpn and Bmg

Figure 2 shows the sensory profile of Bpn and Bmg according to the average scores attributed by the judges to the attributes of color, flavor, texture, aroma, and overall acceptance. There was no difference in the average score of the attributes of the two different samples; however, there was a difference between the score of different attributes evaluated in the same sample.

Sensorial analysis results showed that there was a significant difference between flavor, general acceptance, and texture ($p < 0.05$) with the color attribute in Bpn and texture and aroma ($p < 0.05$) with the color attribute in Bmg (Kruskal–Wallis and Dunn's test). The heterogeneity observed in the texture profile for Bpn and higher hardness (Fig. 1) did not influence a negative evaluation of this attribute. Although there was no difference between the grades of the two formulations of cereal bars, the average grade of the Bpn texture was still higher than that of Bmg (Fig. 2B). Both cereal bars presented low saturation (C*) associated with low luminosity (L*; Table 3), which can decrease the brightness and intensity of the colors of the samples. Consequently, the color was the attribute that least pleased the evaluators and showed the lowest score (Fig. 2B); however, the color can be modulated with the use of coatings on the cereal bars or other ingredients with greater luminosity.

The AI was 77.5% for Bmg and 83.4% for Bpn, which were > 70%; the cereal bars showed good acceptability (Bastos et al. 2014). In addition, in the purchase intent test, 86.3% and 78.4% of the judges recorded that they would "certainly buy/buy" Bpn and Bmg, respectively, which showed that, in addition to their good acceptability, the cereal bars also showed market potential.

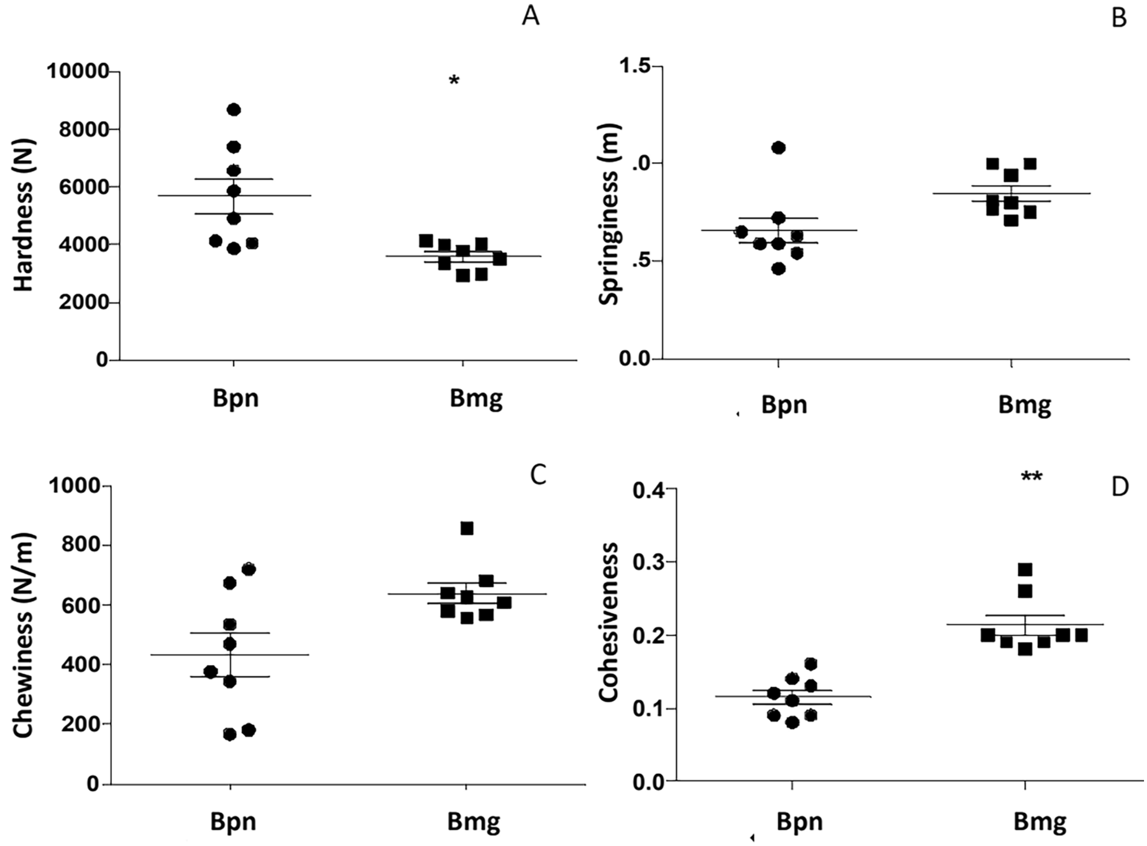
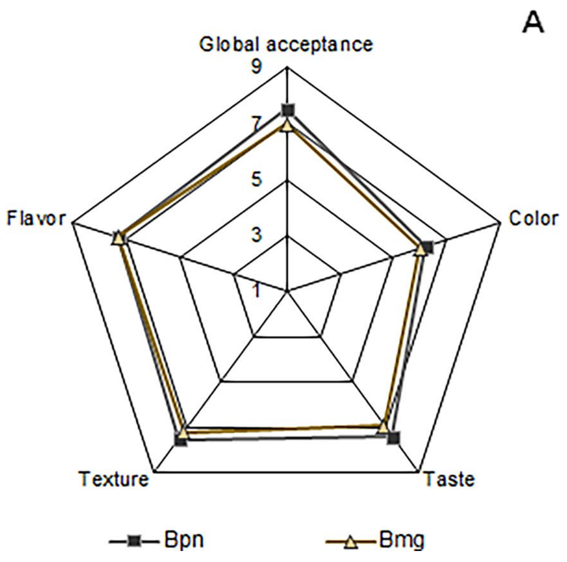


Fig. 1 Texture profile parameters of cereal bars enriched with OpnF. **A** Hardness (N). **B** Springiness (m). **C** Chewiness (N/m). **D** Cohesiveness. OpnF: ora-pro-nóbis (*Pereskia aculeata*) leaf flour. Bpn, cereal bar enriched with OpnF peanut flavor; Bmg, cereal bar enriched with mango-flavored OpnF. *$p < 0.05$ and**$p < 0.01$ (Paired t-test, GraphPad Prism v5)



B

Atributes	Bpn	Bmg
Color	6,20 ± 2,20^{a}	6,00 ± 2,20^{a}
Taste	7,40 ± 1,70^{b}	6,90 ± 1,90^{ab}
Texture	7,50 ± 1,70^{b}	7,20 ± 1,80^{b}
Flavor	7,30 ± 1,80^{ab}	7,30 ± 1,80^{b}
Global acceptance	7,51 ± 1,19^{b}	6,98 ± 1,69^{ab}

Fig. 2 Sensory profile of Bpn and Bmg. Average score of the judges for the attributes listed in the sensory analysis sheets. OpnF, ora-pro-nóbis (*Pereskia aculeata*) leaf flour; Bpn, cereal bar enriched with OpnF peanut flavor; Bmg, cereal bar enriched with mango-flavored OpnF. Different letters in the same column indicate a statistical difference, with *$p < 0.05$ in relation to the color attribute (Kruskal–Wallis and Dunn's test, GraphPad Prism v5)

Conclusion

OPN cultivated in different locations showed differences in nutrient contents. The leaves grown in the rural municipality had lower moisture and ash contents and higher protein content than those grown in the urban municipality. There was no difference in the oxalate content of the flours, and they did not seem to affect the bioavailability of calcium (an oxalic acid/calcium ratio of 1.43). OpnF presented high nutritional value, especially in relation to protein content, and ash is a source of iron and high magnesium and manganese content.

Cereal bars made with OpnF also have important nutritional value. They have potential as a protein source and a good sensory AI of > 77.5% with market potential. Bmg has the highest mineral content and is a source of iron, manganese, and magnesium. OpnF can be used as an ingredient in cereal bar preparations, of different flavors, or in other food preparations to improve the nutritional attributes of these products.

In addition to the macro and micronutrients present in the *P. aculeata* leaves, many phenolic compounds have already been identified, with caftaric acid being its main phenolic constituent (Garcia et al. 2019), in addition to carotenoids (α and β-carotene, lutein, zeaxanthin, and violaxanthin) (Agostini-Costa, et al. 2014). The presence of mucilage in the leaves characterizes this species as the potential for processing of natural emulsifiers and biomaterials for the pharmaceutical and food industries (Nogueira Silva et al. 2023). Some studies have evaluated the presence and technofunctional properties of phytonutrients from *P. aculeata* leaves after processing, such as cooking methods and obtaining flour. Vieira et al. (2020) observed beneficial anthropometric effects after the consumption of a dairy beverage developed with 5% of *P. aculeata* flour. Neves et al. (2021) evaluated how different methods of cooking *P. acuelata* leaves (frying, microwave, and steaming) could promote changes in the composition of phytochemicals. In general, the results demonstrated that some methods contributed to greater extraction of phenolics and carotenoids and better bioaccessibility. Considering that the process adopted to obtain the OpnF in the present study was at temperatures below cooking, while preparing the cereal bars was by baking at moderate temperatures, it is expected that there were no relevant losses of plant phytonutrients in the final product and that these processes are essential for sensory improvement and health safety of new products developed, such as cereal bars.

Author contributions Gabriela S. C. and Clara N. P. S. performed the literature search, formal and data analysis, and writing-original draft preparation. Erival A. G. J., Thaís L. S., Abdon L. O. T., Luis F. P. S., Leonardo F. M. performed the formal analysis and methodology. Giani A. L., Nelson B. C., Jose A. M. F. and Clícia M. J. B. performed the data curation and review writing. Laise C. P. performed the conceptualization, data curation, formal analysis and review.

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Data availability Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

Declarations

Conflict of interest The authors report there are no competing interests to declare.

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