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ORIGINAL PAPER

Cajá-manga peel: evolution of sensory, chemical and physical characteristics from flour to bread production

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Abstract

This study aimed to carry out the physical–chemical characterization, assess the functional potential and sensory analysis of bread made with 2.10, 5, 7.1 and 10% of cajá-manga peel flour (*Spondias cytherea* Sonn.; CMPF), using a mixture experimental design. CMPF showed high antioxidant activity and content of phenolic compounds (PCs). Breads showed a reduction in PC content due to the baking process; however, it still maintained a fraction of them, in greater quantity in breads containing CMPF. In general, the formulations showed good scores for sensory acceptability, with emphasis on formulations with lower addition of CMPF, being flavor and texture the most influential attributes. Formulations containing from 5 to 10% of CMPF (presented higher correlation for physical–chemical variables and PCs) differed from those containing from 0.0 to 2.10% of CMPF (presented higher correlation for texture variables), through principal component (PCA) and hierarchical cluster analysis (HCA). Therefore, the addition of CMPF in breads, especially to a concentration of 5%, is an effective alternative for using fruit residue, obtaining a product with antioxidant potential, which contributes to the popularization of cajá-manga consumption.

Keywords *Spondias cytherea* Sonn. · Peel · Bread · Sensory properties · Physicochemical properties · Antioxidant properties

Introduction

Although Brazil stands out in food production, many losses occur in this process, mainly in the postharvest period, from transport, storage to industrialization, generating a significant amount of waste. Additionally, food waste is one of the biggest challenges to be overcome in food production [1].

Brazil is among the ten countries that most waste food in the world, with 35% of the production being wasted every year, even though 54 million Brazilians are still below the poverty line. Vegetables account for four million tons of food waste, being the fruits among the most wasted product [2]. Most fruits are highly perishable when handled incorrectly in postharvest and for this reason, in addition to the fresh consumption, they are mostly used in the production of juices, nectars, jams, and pulps. However, during the processing to obtain these products, tons of waste are generated such as peel, seed, and bagasse. Therefore, it is evident that the use/reuse of fruit residue in other products, adds economic and environmental benefits [3, 4].

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Alternatives have been studied to increase the use of by-products and residues from agricultural production. For this, strategies are developed to take advantage of new nutritional sources, by reducing losses in postharvest through the development of new products from wasted materials, such as peel, leaves, and stems [5]. These materials can be reused in the formulation of different products (baked goods, jams, supplements, among others), adding value and enriching these foods nutritional value [6, 7].

Among fruits with potential use of its residue generated during processing, cajá-manga has good sensory and chemical characteristics such as taste, aroma, elevate content of protein, presence of phenolic compounds and fibers [8].

Cajá-manga (*Spondias cytherea* Sonn., Anacardiaceae) is originating from French Polynesia, being introduced in the northeast region of Brazil in 1985 [9]. Due to its sensory characteristics and the presence of compounds with antioxidant potential, such as phenolics and vitamins, this fruit has attracted the attention of industries and researchers. Despite this, it is still little explored and known, with a lack of information on general aspects of quality [9–11].

Cajá-manga is an exotic fruit, manifesting climacteric characteristics adapted to tropical climate regions. Its pulp is highly appreciated *in natura*, presenting bittersweet, strongly aromatic and succulent characteristics. This fruit in Brazil is also known as "cajarana" and "taperebá-do-sertão", and as ambarella, in other countries. It has good aspects for industrialization and some products have already been developed from its pulp, such as jam, candies, structured or fruit gel, and fermented milk [8, 12, 13].

Considering the sensory and nutritional characteristics of cajá-manga peel [8, 14], the development of products from its residue, in addition to the use of this by-product, would also enable the supply of a food with functional potential and added value. Due to its chemical composition (proteins and fibers), an excellent alternative for applying caja-manga peels is in bakery products, considered a daily staple food and constantly demand nutritional diversification by the consumers [15, 16].

Considering bread a complex matrix where basic ingredients of its formulation can be altered, it is necessary to verify changes in its chemical and technological properties, as well as sensory acceptability [16]. Another important factor is associated with the fact that there are studies about the application of cajá-manga in a few products [8, 12, 13, 17], but no information available on the use of its peel in bread. In this context, this study aimed to prepare cajá-manga peel flour and use it as an ingredient in bread making, validating an alternative for the use this fruit residue.

Materials and methods

Sample materials and reagents

Cajá-manga fruits, considered ripe since 75% of the peel presented a yellow color, according to the fruit ripeness classification [18], were obtained from the São Paulo General Warehouses Company (CEAGESP) in Campinas, São Paulo. The fruits were washed with running water and immersed in sodium hypochlorite solution at 200 ppm for 30 min. After rinsing and draining the excess of water, the fruits were peeled.

The peels were placed into aluminum molds and dried in an oven with air circulation (Solab, model SL 102) at 60 °C for 5 h. The dried material was placed into a desiccator until reach 25 °C, before being ground using a blender. The obtained flour was then stored in vacuum-sealed plastic bags under refrigeration (10 °C).

The following ingredients were used to make the bread: crystal sugar (Alto Alegre®), wheat flour (Anaconda type I), salt (Diana), biological yeast (Saf–instant), tap water, oxidizing agents/enzymes (Magimixplus Lesafra), and vegetable fat (Qualy without salt).

The following reagents were used: absolute ethanol (Chemco), gallic acid (Sigma-Aldrich), Folin–Ciocalteau (Sigma-Aldrich), sodium carbonate (Dinamica), ABTS (Sigma-Aldrich), potassium persulfate (Vetec), Trolox (Merck), 2,2-diphenyl-1-picrilhidrazyl (DPPH) (Sigma-Aldrich), 2,4,6-Tris (2-pyridyl)-s-triazine (TPTZ) (Sigma-Aldrich), acetate buffer solution [sodium acetate (Alphatec) and glacial acetic acid (Vetec)], ferric chloride (Vetec) and methanol (Vetec).

Experimental design for bread production

A mixture design with two factors, two axial points, and two repetitions at the central point, totaling six assays, was used for the breads formulation. The proportion of each ingredient in the formulations is shown in Table 1. The assays were performed in random order.

The bread dough was prepared using the indirect sponge method, which consisted of mixing wheat flour (with 5% protein, 34,04% wet gluten, 12,40% moisture and 279×10^{-4} J) and CPMF (totalizing 100%, with percentage varying according to each formulation), 60% water, 2% salt, 4% sugar, 4% fat and 1% oxidizing agents/enzymes, as shown Table 2. This mixture was called "sponge".

The sponge was left to rest under controlled temperature (27–30 ºC and relative humidity of 80%), until it doubled in volume. Then, in a planetary mixer (Lieme), the remaining dry ingredients, vegetable fat and the sponge

Table 1 Experimental planning of mixing formulations for the development of breads with replacement of wheat flour (FT) by cajá-manga flour (FC)

Trial[#]	Component proportion (Coded levels)		Flour amount (%) (Decoded levels)	
	FC	FT	FC	FT
1 (v)	− 1	+ 1	2.1	97.9
2	− α	+ α	0	100
3(c)[##]	0	0	5	95
4	+ α	− α	10	90
5 (v)	+ 1	− 1	7.1	92.9

[#]v = vertex; c = center point

[##]Two repetitions at the center point

Table 2 Formulation used to prepare breads with cajá-manga peel flour (CPMF)

Ingredients	Formulation				
	F1	F2	F3	F4	F5
Wheat flour	97.9%	100%	95%	90%	92.9%
CMPF	2.1%	0%	5%	10%	7.1%
Water	60%	60%	60%	60%	60%
Salt	2%	2%	2%	2%	2%
Sugar	4%	4%	4%	4%	4%
Fat	4%	4%	4%	4%	4%
Oxidizing agents/enzymes	1%	1%	1%	1%	1%

were mixed. The mixture was homogenized for approximately five minutes, until gluten proper development. Afterwards, dough was divided into portions of approximately 80 g, which were moulding using a cylinder (model HB 350), placed into greased molds and taken to the oven (Progás) preheated to 180 °C for 40 min. After the baking processes, the breads were removed from the molds and stored at room temperature.

Physicochemical analyses

To assess the physico-chemical characteristics of the flour, pH, acidity, moisture, ash, carbohydrates, proteins, lipids, and crude fiber were determined according to the AOAC methods [19].

In the bread samples, acidity, moisture, ash, carbohydrates, proteins, lipids, color, and texture were analyzed. To assess texture and color, the bread crumb was cut into a parallelepiped shape (30 mm in height, 30 mm in length and 20 mm in width) and subjected to analysis at room temperature. Bread color was measured using a colorimeter (Chroma Meter CR400/410) in CIELab mode, obtaining the coordinates L*, a*, and b*. To analyze bread texture, a TAX-T Plus texturometer (Stable Micro Systems) was used. For this analysis, hardness, cohesiveness, springiness, gumminess, and chewiness were evaluated, using the following settings: (1) the dynamometer was calibrated to trigger force of 5 g; (2) the sliced sample was placed on the center of the platform and compressed twice to 50% of its initial thickness, under a pressure of 0.1 N at pre-test speed of 1 mm/s, test speed of 2 mm/s, and post-test speed of 10 mm/s, using a cylindrical aluminum probe (P/40, 40 mm diameter). The sample distance to the probe was 10 mm and the resting time between compression cycles was 5 s.

Total phenolic content and antioxidant activity

Cajá-manga peel flour (CMPF) and bread extracts were obtained to quantify total phenolic content (TPC) and total antioxidant activity. It was done according to the method described by Pinto et al. [20], with modifications. For this, equal amounts of sample and 80% ethanol (1:1 w/v) were homogenized for two hours at 250 rpm using a shaker (Logen, model LS4500). Subsequently, the solution was centrifuged for 20 min at 6620 rpm, at 4 °C (Hermle centrifuge, model Z326K). After centrifugation, the supernatant was collected (extract) and stored in a freezer (– 6 °C) for later analysis. All determinations were performed in an analytical quadruplicate.

The TPC in the bread and flour was determined according to the Folin–Ciocalteau method, interpolating the absorbance of the samples against a calibration curve constructed with gallic acid standards (0.010–0.045 mmol L^{-1}). The results were expressed as milligrams of gallic acid equivalent (GAE) per 100 g of extract [21].

The flour antioxidant capacity was estimated by ABTS, DPPH, and FRAP methods [22–24]. The results were expressed, respectively, as μM Trolox per 100 g of $extract^{-1}$, efficient concentration (EC_{50}), i.e., the amount of antioxidant required to decrease the initial concentration of DPPH by 50% (μg mL^{-1} of extract), and μM Trolox per 100 g of $extract^{-1}$.

Sensory analyses

To assess the preference and acceptance of the prepared breads, sensory analyses were performed using an untrained consumer panel (n = 100). The panelists were asked to indicate which of the bread they preferred, classifying what they liked the most in terms of acceptance. For this, a 9-point hedonic scale was used, as follow: 1 = Dislike extremely, 2 = Dislike very much, 3 = Dislike moderately, 4 = Dislike slightly, 5 = Neither like or dislike, 6 = Like slightly, 7 = Like moderately, 8 = Like very much, 9 = Like extremely.

Using this scale, the following attributes were evaluated: color, aroma, flavor, texture, and overall impression. The acceptability index (AI) was also calculated ((mean score × 100)/highest score).

The bread samples were divided into small cubes of approximately 5 g, labeled with random numbers and presented to the panelists. The level of preference and purchase intention was also analyzed, both using a scale ranging from 1 to 5, according to the acceptability [25].

This study was previously approved by the Research Ethics Committee of the Federal University of Technology-Paraná (Approval No. 46355415.0.0000.5547).

Statistical analyses

The data obtained were subjected to descriptive analyses to identify the position and dispersion measures of the results obtained. The significant variables were subjected to complementary analyses by Tukey test, at 5% probability. Pearson correlation with all the response variables obtained from the formulations evaluated (Supplementary 1) and Spearman correlation, stratified for each formulation effects (Supplementary 2), were also performed to identify linear trends between sensory attributes. Subsequently, the mean Euclidean algorithm was applied to construct a dendrogram using the UPGMA clustering method. Afterward, biplot for principal components was also explored, to show formulations and measured variables effects. All statistical analyses were performed using SAS and Genes software.

Results and discussion

Physico-chemical characterization and antioxidant potential of cajá-manga peel flour

The cajá-manga peel flour (CMPF) was initially submitted to a physico-chemical characterization (Table 3). Up to the present date, there are no reports in the literature on the application of this by-product in breads.

The flour presented moisture values within the limit (15%) established for fruits by the Brazilian legislation [26], pH close to those described for peel (3.32) and pulp (2.82) of cajá-manga [8, 13], and acidity values within the range (0.85–3.14 g citric acid 100 g^{-1}) found for cajá-manga (including pulp and peel) [8, 11, 13].

The ash content was higher than those reported for cajá-manga pulp (0.97%) [13] and wheat flour [26]. A higher concentration of minerals has already been recorded for the external layers of fruits [27]. Protein and lipid contents were close to those observed in cajá-manga fruits (0.78–4.47% for proteins and 0.03–1.05% for lipids) [8, 28]. On the other hand, carbohydrate and fiber contents were higher than those reported by other studies involving cajá-manga [17, 29].

The differences observed in the contents of the variables evaluated in the CMPF may be due to factors such as the tissue analyzed, variety, ripening stage, soil management, in addition to climatic factors occurred during the crop development [10].

Total phenolic content and antioxidant activity have also been explored in terms of health potential. These variables were analyzed in this study since, in addition to knowing their chemical composition, the consumption of fruits with antioxidant compounds is of paramount importance and related to the prevention of non-communicable chronic diseases [7, 30].

TPC found in CMPF was higher than the previously reported for pulp of *Spondias cytherea* Sonn. (47.86 mg of GAE 100 g^{-1}) and *Spondias mombin* L. (6.62 mg GAE 100 g^{-1}) [13, 31]. Generally, in the peel, a higher concentration of these compounds is found due to the possible migration of phenolic compounds to the epidermis of the fruit, as a means of defense against ultraviolet radiation and in protection against certain pathogens and predators, biotic and abiotic stresses in general [32].

In addition to TPC, flour antioxidant activity was also determined in this study by three different methods (ABTS, DPPH, and FRAP) aiming a greater reliability and amplitude of these compounds, since the methods complement each other due to differences in the

Table 3 Descriptive analysis of cajá-manga peel flour and their respective mean and standard deviation of the different variables evaluated

Variables[#]					
Moisture (%)	pH	Acidity (%)	Ash (%)	Protein (%)	Lipids (%)
11.40 ± 0.01	3.16 ± 0.009	2.26 ± 0.02	3.31 ± 0.01	5.67 ± 0.02	0.03 ± 0.0009
Carbohydrates (%)	Fiber (%)	TPC (mg GAE 100 g^{-1})	ABTS (μM trolox 100 g^{-1})	DPPH (EC_{50} μg g^{-1})	FRAP (μM trolox 100 g^{-1})
54.36 ± 0.02	24.92 ± 0.02	291.30 ± 46.80	1153.30 ± 50.30	92.35 ± 5.52	776.55 ± 135.04

[#]Total phenolic content (TPC), ABTS (antioxidant activity by ABTS method), DPPH (antioxidant activity by DPPH method) and FRAP (antioxidant activity by FRAP method mechanisms of action. The variation between methods can be justified by the range of activity of such radicals [33, 34]. In this work, ABTS of CMPF was lower than those observed for the whole fruit of *Spondias mombin* L. (10–320.2 mM Trolox 100 g^{-1}), and higher than the result observed in pulp of *Spondias cytherea* Sonn. (221 µM Trolox 100 g^{-1}) [11, 13].

Regarding DPPH, the data are expressed as EC_{50}, which corresponds to the amount of extract required to reduce free radical activity by 50%, i.e., the lower the effective concentration value, the higher the antioxidant activity of the extract [22].

Thus, the EC_{50} value found in this work was higher than the reported for umbu seed (*Spondias tuberosa*) (39.5 µg mL^{-1}) [34], but lower than the found in cajá-manga pulp (EC_{50} = 15.6 µg mL^{-1}) [13]. Substances or extracts with EC_{50} values lower than 250 µg mL^{-1} are considered potential candidates to be used as antioxidant agents, i.e., CMPF showed good antioxidant activity by the DPPH· free radical scavenging method [35, 36].

The FRAP method, which consists of reducing Fe^{3+} to Fe^{2+} by the antioxidant metabolite [37]. The result found using this method was higher than the found in cajá-manga pulp [13] in which vitamin C, carotenoids, and especially phenolic compounds, such as tannins, are possibly responsible for the antioxidant activity in cajá-manga [11].

Physico-chemical characterization and total phenolic content in bread

Considering the good chemical characteristics observed in the CMPF, especially the presence of phenolic compounds, different bread formulations were prepared and characterized in relation to the centesimal composition, color, texture and TPC (Table 4).

The moisture content of food products is of paramount importance for their conservation, and chemical and microbiological stability. The moisture values observed in this study ranged from 26.92 to 31.84%, which are lower than those reported in wheat loaf bread (34.7%) [38]. Even so, it is in agreement with the moisture content found in breads formulated with ripe mango peel powder (MPP) (33.97–44.41%), in which an increase in bread moisture was observed increasing the amount of MPP, due to its high fiber content [5].

As presented in Table 4, all variables have shown variation between the formulations. Ash, protein, lipid, and total carbohydrates content presented the following values: 1.87–2.39%, 8.58–9.69%, 1.47–5.24% and 59.40–52.47%, respectively. There are no records in the literature in relation to bread made with CMPF or other fruits belonging to the genus *Spondias*. However, the data on breads made with flour from other fruits are similar to those found observed for breads made with MPP [5] and orange peel [39].

The formulations containing the highest concentration of CMPF (F3, F4, and F5) presented higher lipid content.

Table 4 The average results of physicochemical analysis, color, texture parameters and total phenolic content (TPC)

Formulation[#]	Moisture (%)	Ash (%)	Protein (%)	Lipids (%)	Carbohydrates (%)	Acidity (%)
F1	27.65 ± 0.05 c[1]	1.87 ± 0.01 c	9.69 ± 0.07 a	1.47 ± 0.04 d	50.96 ± 0.02 e	0.32 ± 0.01 d
F2	26.92 ± 0.24 c	2.39 ± 0.02 a	9.58 ± 0.09 b	2.16 ± 0.10 c	59.40 ± 0.02 a	0.26 ± 0.01 e
F3	30.36 ± 1.16 b	2.14 ± 0.25 b	9.05 ± 0.09 c	4.17 ± 0.55 b	54.28 ± 0.38 b	0.39 ± 0.04 c
F4	31.66 ± 0.12 ab	2.05 ± 0.02 bc	8.58 ± 0.03 e	5.24 ± 0.16 a	52.47 ± 0.01 d	0.67 ± 0.01 a
F5	31.84 ± 1.64 a	1.88 ± 0.01 c	8.81 ± 0.07 d	3.73 ± 0.17 b	53.93 ± 0.02 c	0.46 ± 0.01 b

	Color a*	Color b*	Color L*	Color c*	Hue°	TPC (mg GAE 100 g^{-1})
F1	−0.43 ± 0.03 d	16.90 ± 0.06 d	70.89 ± 0.45 a	16.90 ± 0.06 c	91.28 ± 0.13 b	0.00 ± 0.00 d
F2	−0.81 ± 0.02 e	13.22 ± 0.29 e	70.82 ± 0.67 a	12.50 ± 0.42 d	93.62 ± 0.23 a	0.00 ± 0.00 d
F3	0.57 ± 0.20 c	22.43 ± 1.14 c	70.31 ± 0.83 a	22.35 ± 1.27 b	88.04 ± 1.46 c	26.03 ± 9.72 c
F4	2.44 ± 0.03 a	26.11 ± 0.22 a	63.72 ± 0.11 c	26.06 ± 0.12 a	84.68 ± 0.07 e	47.39 ± 1.00 a
F5	1.41 ± 0.06 b	23.55 ± 0.13 b	66.68 ± 0.26 b	23.41 ± 0.13 b	86.51 ± 0.19 d	40.98 ± 0.59 b

	Hardness (N)	Cohesiveness	Springiness (%)	Gumminess (N)	Chewiness (N)
F1	11.04 ± 0.96 c	0.50 ± 0.01 a	88.79 ± 0.70 b	5.24 ± 0,65 c	4.65 ± 0.54 c
F2	10.40 ± 0.69 c	0.51 ± 0.01 a	89.81 ± 1.91 ab	5.48 ± 0.47 c	4.94 ± 0.29 c
F3	10.78 ± 1.92 c	0.53 ± 0.03 a	91.73 ± 1.98 a	5.37 ± 0.91 c	4.93 ± 0.85 c
F4	30.05 ± 3.92 a	0.44 ± 0.01 b	84.22 ± 0.60 c	13.13 ± 1.88 a	11.06 ± 1.59 a
F5	24.78 ± 1.23 b	0.46 ± 0.02 b	90.41 ± 1.58 ab	10.43 ± 0.36 b	9.34 ± 0.23 b

[#]Different letters in the same column indicate significant differences ($P < 0.05$), according to Duncan's test

F2 (wheat flour only) had higher protein and lower lipid contents. However, an opposite behavior was observed for breads containing CMPF. This behavior can be explained based on the chemical composition differences observed in the formulations (wheat × cajá-manga). Nevertheless, more detailed information regarding the chemical composition of cajá-manga, and its peel, would provide further explanations for a deeper understanding of the metabolites involved.

All breads made from F1, F3, F4, and F5 formulations presented lower carbohydrate content in comparison with those from F2. This is a positive result in terms of nutrition/calories ratio. The lower concentration of carbohydrate found in CMPF (54.36%) compared to wheat flour (87.16%) explains these results (Table 3).

Peel acidity directly influenced bread acidity, since F4 (formulation with the highest concentration of CMPF) presented higher acidity than F2 formulation (without CMPF). Based on the centesimal composition, the formulations have characteristics within the values expected for food products made by replacing wheat flour with by-product flours from fruit [40].

In addition to chemical composition, bread color and texture were also evaluated (Table 4). All color results showed difference between the formulations. Color parameters (a*, b*, and c*) were significantly lower in breads from F2, comparing to other formulations.

This indicates that samples containing lower concentration of CMPF, or no addition (F1 and F2), resulted in values closer to the scale of green (− a) and blue (− b) colors, and less saturated in terms of color intensity (c). The color of F3, F4, and F5 samples was closer to red (+ a) and yellow (+ b), presenting higher saturation (c) than the other two formulations. These results may be associated with the absence or lower concentration of cajá-manga peel pigments (phenolic compounds and carotenoids) in F1 and F2 formulations, which are found in higher concentrations in F3, F4, and F5 [11, 41].

The highest values of luminosity and °H were found in the formulations F1, F2, and F3 (70.89, 70.82, and 70.31 for L* and 91.28, 93.62, and 88.04 for °H, respectively) and the lowest ones in F4 (63.72 for L* and 84.68 for °H). All formulations presented luminosity values closer to the dark color. This result was possibly influenced by the presence of CMPF pigments and browning reactions occurred during the baking process. For all formulations, the Hue angle was close to 90°, indicating a trend towards yellow color. The lower the H° value the higher the proximity to yellow and red color, as well as the higher the values of a* and b*, the higher the proximity to CMPF (red-yellow).

F2 (without CMPF) presented higher concentrations of proteins and total carbohydrates than the other formulations (Table 4), which possibly provided the highest occurrence of non-enzymatic browning reactions. The baking temperature of the bread generally ranges from 180 to 250 °C. In the middle of the crumb the temperature reaches 98 °C, with non-enzymatic browning reactions (caramelization and Maillard reactions) being accelerated when sugars are part of the formulation, contributing to the browning of the baked product [42].

Reactions that produce dark pigments during thermal processes in food are dependent on factors such as pH, temperature, water activity, chemical composition, sugar/amino acid ratio. In addition, the compounds produced by such reactions contribute significantly to sensory characteristics, such as the taste, color and aroma of food [43, 44].

The texture is another important characteristic for bread quality, whose rheological properties can be measured using different variables. All samples presented significant differences in texture parameters (hardness, cohesiveness, springiness, gumminess, and chewiness).

Hardness, which represents the force required for a predetermined deformation (related to the force exerted during the chewing process), was higher in breads from F4 formulation (30.05 N), followed by those from F5 (24.78 N). The other formulations did not differ from each other, presenting values ranging from 10.78 to 11.04 N. The formulations containing higher concentration of CMPF (F4 and F5, with 10 and 7.1%, respectively) significantly influenced bread hardness. This fact may be related to the increase in fiber content due to the addition of CMPF (Table 3) [5].

Starch, due to the gelatinization process, provides greater softness to bakery products [45]. Therefore, possibly, the lower amount of wheat flour in F4 and F5 formulations may have resulted in the higher hardness observed in the baked product.

Similar to hardness (HAR), gumminess (GUM) and chewiness (CHE) parameters also demonstrated that F4 and F5 formulation resulted in the toughest samples. Both texture variables presented values within the range already observed by other studies on wheat bread added with different vegetable materials [46–48]. The chewiness is the value corresponding to the energy required to disintegrate a solid food into a state that allows swallowing [49]. Therefore, F4 and F5 formulations required more energy to disintegrate, i.e., they are more integrate. These variables (GUM and CHE) presented a negative correlation with protein content (− 0.74 for gumminess and − 0.76 for chewiness) (Supplementary 1). This because, F2 formulation presented the highest concentration of proteins and, consequently, lower CHE and GUM.

Springiness, which corresponds to the capacity of a deformed material to return to its original condition after removing the deformation force [50], presented values ranging from 84.22 to 91.73% (Table 4). F4 had the lowest springiness value, indicating lower elasticity compared to other formulations, which is usually associated with a lower concentration of wheat proteins that presents viscoelastic properties [51].

Cohesiveness, related to food viscosity, presented values ranging from 0.44 to 0.53, being the lowest values observed for F4 and F5. Samples from these formulations were less "sticky" than the other ones, even though they presented the highest moisture content. These cohesiveness values are similar to those found by other study [5] who, evaluating bread added with mango peel flour, reported values ranging from 0.26 to 0.82.

TPC, in addition to CMPF, was also quantified in the breads (Table 4), considering the wide discussion about the importance of the presence and consumption of these compounds [52]. It was possible to verify an intense reduction in PCs content in the bread formulations, compared to CMPF (291.30 mg 100 g^{-1}), which resulted in a non-detection of these compounds in breads from F1 and F2 (2.1 and 0% of CMPF, respectively). Decreases in PCs content have already been reported by other studies addressing heat treatment, such as in mango juice [53] and grape juice [54]. However, despite the reduction, the values observed in this study are higher than those found in breads added with rice flour [55] and similar to those observed in breads made with pseudocereal flour [56]. On the other hand, even if the heat treatment has resulted in PCs losses, increasing the amount of CPMF in bread can be used as a strategy to linear increase the levels of PCs.

Although breads have had lower PC values, compared to the CMPF, this study provides an alternative product for the consumption of such compounds, in addition to allowing the use of residues, such as the cajá-manga peel.

Sensory analysis

The results shown in Table 5 reveal that the breads made from the formulations containing the highest amounts of CMPF (F4 and F5) had significantly lower scores in all evaluated attributes. On the other hand, breads from the other formulations had scores close to those obtained for F2 (without CMPF), being F1, F2, and F3 statistically similar, including for the overall acceptance, except for color, for which F1 and F2 had higher scores than F3.

The lowest scores were attributed mainly to F4 formulation, a fact possibly explained by the CMPF acidity, which may have influenced the sensory evaluation of the breads. Indeed, this acidity is not a common feature for traditional salt bread consumers. However, this fact does not prevent the product from being accepted in other places or by people less attached to the traditional pattern of salt bread.

In terms of purchase intention, F1 and F2 achieved scores close to 5 (I would certainly buy), closely followed by F3. Samples from F4 and F5 formulations had scores closer to 1 (I would certainly not buy). This information corroborates with the results obtained in the preference analysis, in which formulations F1, F2, and F3 had the highest scores, whereas F4 and F5 samples had the lowest values.

The acceptability indexes (AI) are shown in Table 6. Although flavor, texture, and overall acceptance for F4 samples presented an AI lower than 70%, these attributes were awfully close to this value. The other formulations had AI, for all attributes, higher than the minimum value recorded in the literature (70%), presenting excellent application potentials [57]. Therefore, the use of CMPF as an ingredient to make bread contributed positively to the sensory quality of

Table 6 Acceptability index (AI) for the color, aroma, taste, texture and overall acceptance of different bread formulations

Formulation	Attributes				
	Color	Aroma	Taste	Texture	Overall acceptance
F1	84.89*	83.33	83.11	82.44	84.22
F2	85.11	82.89	82.11	80.56	83.44
F3	80.50	80.11	79.76	78.94	81.22
F4	71.78	75.11	63.78	69.89	67.67
F5	77.33	76.89	74.67	73.56	74.22

*The values were obtained by the equation: AI = (average score × 100)/highest score

Table 5 The average results of sensorial analysis for the attributes: color, aroma, taste, texture, overall acceptance, purchase intention and preference test

Formulation[#]	Score average attributes						
	Color	Aroma	Taste	Texture	Overall acceptance	Purchase intention	Preference test
F1	7.64 ± 1.27 a	7.50 ± 1.26 a	7.48 ± 1.34 a	7.42 ± 1.45 a	7.58 ± 1.25 a	4.02 ± 0.99 a	2.93 ± 1.65 c
F2	7.66 ± 1.24 a	7.46 ± 1.31 a	7.39 ± 1.38 a	7.25 ± 1.38 a	7.51 ± 1.37 a	3.75 ± 1.01 a	3.23 ± 1.67 c
F3	7.24 ± 1.29 b	7.21 ± 1.36 ab	7.17 ± 1.47 a	7.10 ± 1.37 a	7.31 ± 1.27 a	3.67 ± 0.99 b	3.31 ± 1.51 c
F4	6.46 ± 1.83 c	6.76 ± 1.70 c	5.74 ± 2.00 c	6.29 ± 1.78 b	6.09 ± 1.79 c	3.01 ± 1.26 c	4.25 ± 1.69 a
F5	6.96 ± 1.45 b	6.92 ± 1.60 bc	6.72 ± 1.56 b	6.62 ± 1.73 b	6.68 ± 1.61 b	3.27 ± 1.15 d	3.98 ± 1.58 b

[#]Different letters in the same column indicate significant differences ($P < 0.05$), according to Duncan's test the final product. Furthermore, it is important to emphasize that the use of cajá-manga residue adds value to this fruit and provides good prospects for its use in the food industry, especially in formulations containing 2.1 and 5% CMPF (F1 and F3).

Moreover, aiming to identify a linear trend between sensory attributes and the effects of each formulation, by the Spearman's analysis, significant values (5%) and those above 0.7 were considered and addressed. Considering the answers in general, all formulations showed a correlation of the overall impression with some specific attributes (Supplementary 2). For F1, the overall impression showed a significant correlation with flavor (0.81) and texture (0.80), being that these parameters had the lowest AI (Table 6), which may be related to the results of the overall impression.

Formulations F2, F3, and F4 showed a significant correlation only between overall impression and flavor, presenting values of 0.79, 0.80, and 0.77, respectively. F5 showed a correlation between overall impression and texture (0.83). Therefore, flavor and texture were possibly the attributes that most influenced the evaluation of breads regarding the overall impression, corroborating with the AI results shown in Table 6.

In an attempt to assess the set of responses obtained in this study and identify the most influential variables for each formulation, the principal component analysis was used to graphically express such information (Fig. 1A), i.e., to perform a general correlation between all the variables analyzed with each formulation (physicochemical, color, texture, and TPC). The first and second principal components

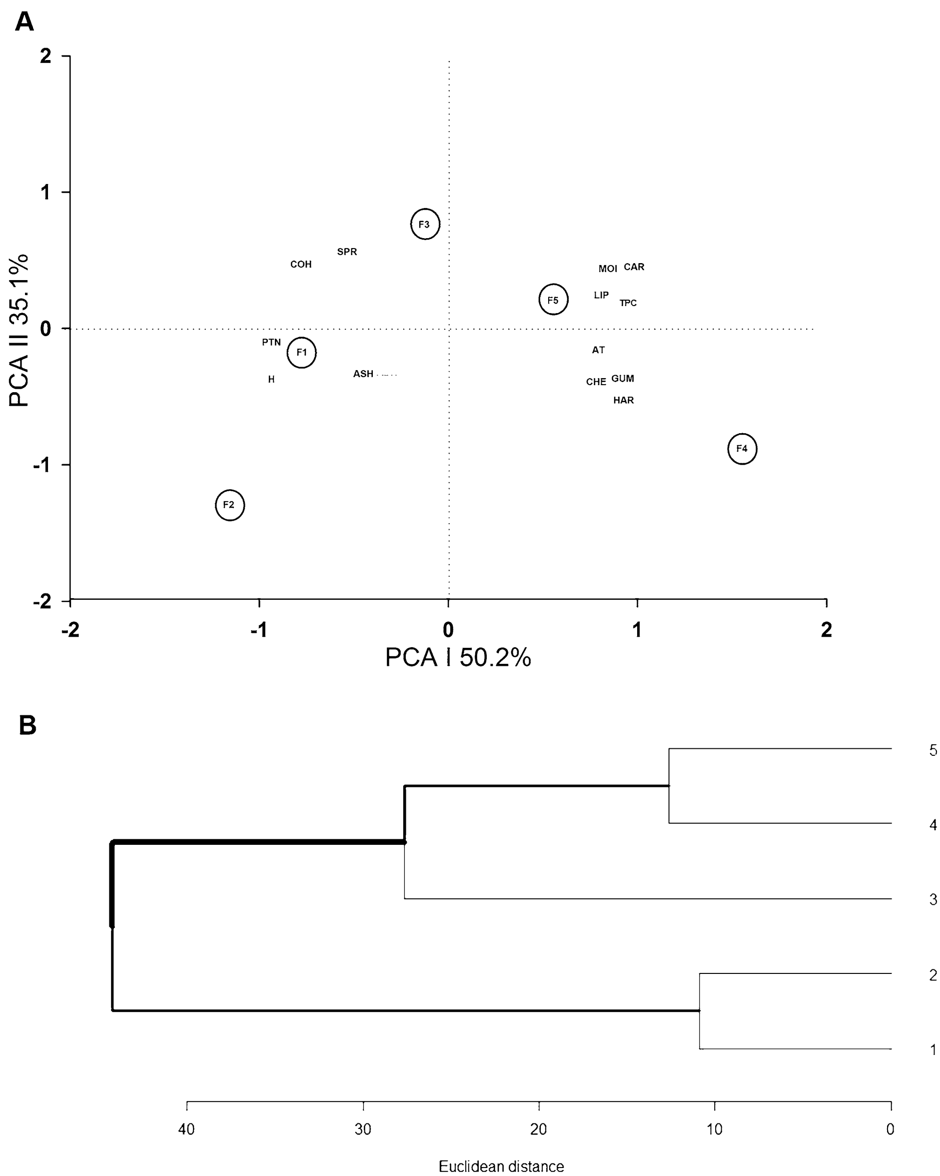

Fig. 1 Main components and dendogram of breads formulations. Main components by PCA illustrating the evaluated variables and the formulations (**A**). Dendogram from the UPGMA grouping method considering all the variables analyzed in the formulations (**B**). Hue angle (H°), hardness (HAR), cohesiveness (COH), springiness (SPR), gumminess (GUM), chewiness (CHE), acidity (AT), carbohydrates (CAR), lipids (LIP), ashes (ASH), protein (PRO), moisture (MOI) and total phenolic content (TPC)

accounted for 50.2% and 35.1%, respectively, generating a total response of 85.3%.

In general, F1 and F2 were the most similar formulations in terms of responses for protein, °H, and ash, possibly because they were formulated with a lower amount of CMPF; the other formulations appeared in separate quadrants. F3 showed a higher correlation with variables related to texture (springiness and cohesiveness); F4 was more distant from the variables in general, but closer to acidity, CHE, GUM, and HAR, corroborating with the data presented in Table 4, especially acidity; and F5 was most correlated with moisture, carbohydrate, lipids, and TPC. Corroborating with the data obtained in this study, especially those from sensory analysis, in which formulations F4 and F5 were the ones that most differed from the others.

In order to obtain a more distinct separation of the formulations and reliability regarding their elaboration, Fig. 1B shows the degree of dissimilarity between formulations considering all the variables analyzed in this study. Therefore, the formulations can be grouped as follows: F1 and F2 are the closest ones, since they contain the lowest concentration (F1) and no addition of CMPF (F2); F3, F4, and F5 are in another macro category, but close to each other. F3, despite corresponding to a subcategory together with F4 and F5, showed central dissimilarity between the formulations.

Finally, the CMPF produced and used to replace wheat flour in bread making, can be used as an innovative product with appropriate physical and chemical characteristics, as well as good acceptability by consumers, contributing to the promotion of fruits consumption.

Conclusion

The addition of cajá-manga peel flour in bread formulations positively and significantly affected the TPC in the final product, once it presented levels of these compounds similar to those found in other studies, maintaining a fraction of these compounds even after bread baking. Additionally, cajá-manga peel flour modified the physico-chemical characteristics of the breads. Indeed, higher concentration of protein and carbohydrates were observed in breads made with no addition of this flour.

The addition of cajá-manga peel flour in bread formulations increased the TPC, perhaps being considered a potential functional ingredient. Breads containing 2.1 and 5.0% of cajá-manga peel flour had good sensory acceptance and purchase intention by the panelists.

The production of bread using cajá-manga peel flour is an alternative for the use of this fruit in a new product, highlighting its functional potential additionally to the use of residues, such as peel.

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Declarations

Conflict of interest The authors declare that there is no conflict of interest.

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