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Pineapple by-product and green banana flour evaluation and their application as ingredients for cake formulation

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Abstract

Brazilians appreciate cakes, and they are currently consumers who have become more demanding regarding the nutritional value of food products. Therefore, food products can be enriched or added with functional flours made from fruits or their by-products to add nutritional value. In the present study, two types of flour were developed to be used as cake mix ingredients: pineapple peel flour and green banana flour. The flours were evaluated which demonstrated an interesting nutritional profile and technological properties for use in cakes. Cakes were prepared from a mixture of peel flour, banana flour, and oat flour, replacing 40% of wheat flour, and evaluated for their chemical composition and technological characteristics. To determine the samples' simplex centroid, a mix design was used with flour mixtures in different proportions for cake preparation. Peel flour and banana flour decreased cake luminosity, while peel flour decreased specific volume and increased hardness. The results were represented by the sensory analysis, with acceptance and purchase intention above 70%, for the analyzed formulations. This promotes the development of cake mix as a new product prepared with high added nutritional value.

Keywords: by-product; resistant starch; product development.

Practical Application: There are nutritional advantages to including pineapple peel and green banana flour in cake.

1 INTRODUCTION

The global population has increased, and with it, public agencies are concerned about providing food in sufficient quantity and quality to prevent food insecurity around the world (Food and Agriculture Organization of the United Nations [FAO] et al., 2021). At the same time, due to increased knowledge about the impact of diet on health, consumers have become more discerning when it comes to choosing products with better nutritional value (Lemes et al., 2022). This scenario has recently led to extensive research aimed at developing products with functional properties for consumers seeking prepared foods with better nutritional value and attractive, healthy sensory characteristics (Kraus, 2015).

New research with different flours is being conducted to produce high-nutritional-value baked goods (Pascari et al., 2020). By-products stand out in this area because they have a nutritional value comparable to the original product, low cost, and wide availability (Lemes et al., 2022). Regarding the use of these by-products in baked goods, these ingredients are often used, especially in gluten-free baking or when a partial replacement is desired in an attempt to improve the nutritional value of the final product (Egea et al., 2023).

The objective of this work was to evaluate the flour from the green peels of pineapple (*Ananas comum* L. Merril) and banana (*Musa* spp.) and develop cake formulations.

1.1 Relevance of the work

The use of by-products offers an alternative to reducing the environmental impact of food industries. Furthermore, they can provide important ingredients for the development of food products due to their nutritional values. The development of cakes containing pineapple by-product flour demonstrated viability, although it reduced some technological characteristics. Furthermore, green banana flour has been widely used as an ingredient directly in food, although it can also be used in the development of ready-to-eat food products. The production of these flours provides an alternative to their availability as an ingredient for application.

2 MATERIAL AND METHODS

2.1 By-product flour preparation

Pineapples of the Pérola variety, green bananas of the Prata variety, oat flour (OF), and whole wheat flour were obtained

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from a local market. The fruits were washed and sanitized (200 mg/L for 15 min). The pineapples were peeled manually, and the peels were dried in an industrial electric oven with forced air circulation (Metvisa, Brusque, SC, Brazil) at 70°C for 8 h. The peeled bananas were blanched (100°C for 3 min), cooled for 3 min at room temperature, and then cut into slices approximately 0.5 cm thick and dried at 70°C for 12 h.

Separately, the dry peels and green banana were ground in a Willie knife mill with a 20-mesh sieve to obtain pineapple peel flour (PF) and green banana flour (BF), respectively, packaged in high-density polypropylene bags and frozen until analysis.

The flours were characterized according to their physicochemical aspects, proximal composition, resistant starch (RS) content, mineral composition, total phenolic compounds, antioxidant activity, technological parameters, and morphological features.

2.2 Cake formulations

The cake mix consisted of 125 g of flour (60% whole wheat flour and 40% flour blend, according to Table 1), 50 g of eggs, 50 g of margarine, 120 g of xylitol, 125 g of milk, and 8 g of baking powder, which were homogenized in a planetary mixer. The mixtures were placed in containers (450 g) previously greased with margarine and flour and baked in an industrial electric oven at 180°C, and each formulation was kept for 30 min.

The cakes obtained from the formulations were characterized according to titratable acidity (TA), pH, moisture content, ash content, and proteins; color, specific volume, and texture parameters on the day of preparation; and microbiological and sensory aspects.

2.3 Flour and product characterization

2.3.1 Physicochemical and chemical analysis

The pH value and total soluble solids (SS) were evaluated using a potentiometer (MS Tecnopon, Luca 210 P, Piracicaba, Brazil) and a refractometer (ATAGO™ PR-101α, Fisher Scientific, Hampton, USA), respectively. TA was determined by titrating a 0.1 M NaOH standard solution and expressed in mL of molar solution per 100 g sample.

The moisture (method 925.09), protein (method 954.01), lipid (method 920.39), and dietary fiber contents of flour were determined according to the official methods (Association of Official Analytical Chemists [AOAC], 2000). Carbohydrate content was calculated by difference (100-moisture-protein-lipid-ash), and the caloric value was calculated using Atwater conversion factors.

In vitro digestibility followed the Englyst methodology (Englyst et al., 1992) with some modifications (Corgneau et al., 2019). Total starch contents were determined using the Megazyme kit, according to the AOAC method 996.11 (AOAC, 2000). Glucose content was determined using the GOPOD kit (Megazyme, Wicklow, Ireland) with spectrophotometric reading at 510 nm. Starch contents were calculated by multiplying glucose by a factor of 0.9.

The previously digested sample was evaluated for Cu, Fe, and Zn content by atomic absorption spectrophotometry, P by molybdenum blue spectrophotometry, K by flame photometry, and Ca and Mg by atomic absorption.

Extraction was carried out as previously described by Larrauri et al. (1997), and analyses of total phenolic content (TPC) and antioxidant activity were then carried out. About 40 mL of methanol:water (50:50, v/v) was added to 2 g of the sample and kept at room temperature for 60 min. The mixture was filtered, and the supernatant was mixed with 40 mL acetone:water (70:30, v/v) and kept at room temperature for 60 min. After filtration, the liquids were mixed, and the volume was adjusted to 100 mL with water.

The TPC of the crude extract was determined by the Folin–Ciocalteu method (Singleton & Rossi, 1965) with modifications, as described by Li et al. (2009). Ferulic acid was used as the standard, and the results were expressed as mg gallic acid equivalent (GAE) per 100 g (on a fresh weight basis).

The antioxidant activity was determined by the 2,20-azinobis-(3-ethyl-benzothiazoline-6-sulfonic acid (ABTS) assay (Miller et al., 1993) with modifications, as described by Rufino

Table 1. Codified and decoded variables, titratable acidity, pH, and moisture, ash, and protein contents of cake formulations containing pineapple peel flour, banana peel flour, and oat flour (mean ± standard deviation).

	Codified variables			Decoded variables			TA (mL/100 g)	pH	Moisture (g/100 g)	Ash (g/100 g)	Protein (g/100 g)
	PF	BF	OF	PF	BF	OF					
1	1	0	0	100	0	0	1.42 ± 0.01[a]	6.95 ± 0.10[b]	30.98 ± 1.79[a]	2.14 ± 0.08[ab]	0.89 ± 0.06[a]
2	0	1	0	0	100	0	0.34 ± 0.05[d]	7.83 ± 0.08[c]	30.42 ± 1.68[a]	2.41 ± 0.47[a]	0.90 ± 0.02[a]
3	0	0	1	0	0	100	0.26 ± 0.06[d]	8.05 ± 0.03[a]	29.00 ± 2.11[a]	1.74 ± 0.05[b]	1.10 ± 0.05[a]
4	0.5	0.5	0	50	50	0	0.87 ± 0.05[e]	7.12 ± 0.05[g]	32.15 ± 1.40[a]	1.95 ± 0.03[ab]	1.06 ± 0.08[a]
5	0.5	0	0.5	50	0	50	0.80 ± 0.07[e]	7.19 ± 0.01[fg]	28.49 ± 0.84[a]	1.98 ± 0.03[ab]	1.03 ± 0.04[a]
6	0	0.5	0.5	0	50	50	0.27 ± 0.04[d]	7.82 ± 0.06[c]	28.58 ± 1.42[a]	1.91 ± 0.03[b]	1.03 ± 0.10[a]
7	0.33	0.33	0.33	33.33	33.33	33.34	0.79 ± 0.02[e]	7.44 ± 0.06[d]	29.18 ± 1.50[a]	1.88 ± 0.11[b]	0.95 ± 0.08[a]
8	0.66	0.16	0.16	66.66	16.66	16.66	1.17 ± 0.05[b]	7.25 ± 0.02[efg]	32.13 ± 1.01[a]	1.91 ± 0.00[b]	0.95 ± 0.08[a]
9	0.16	0.66	0.16	16.66	66.66	16.66	0.74 ± 0.11[e]	7.34 ± 0.07[def]	28.32 ± 2.93[a]	1.93 ± 0.09[b]	1.02 ± 0.18[a]
10	0.16	0.16	0.66	16.66	16.66	66.66	0.52 ± 0.06[c]	7.42 ± 0.00[de]	30.11 ± 0.57[a]	1.79 ± 0.06[b]	1.03 ± 0.13[a]

Different letters in the same column indicate significant differences between treatments ($p < .05$).
PF: pineapple peel flour; BF: banana peel flour; OF: oat flour; TA: titratable acidity.

et al. (2010). The results of ABTS assays were expressed as μM (Trolox equivalent antioxidant activity) per 100 g of sample.

2.3.2 Physical, technological, and morphological analyses

Granulometric analysis was carried out according to Zanotto and Bellaver (1996) using sieves with mesh sizes of 0.075, 0.106, 0.15, 0.18, 0.25, 0.425, and 0.6 mm.

Color analyses were performed with a colorimeter (Konica Minolta, Chroma Meter CR-400, Osaka, Japan), using the International Commission on Illumination (CIE) system (L* is luminosity, +a* is red, −a* is green, +b* is yellow, and −b* is blue), with an observation angle of 10° and illuminant D65. The saturation (C*) and hue angle (h*) parameters were obtained directly by the equipment.

The technological-functional properties of the flour were evaluated. The water absorption index (WAI), oil absorption capacity (OAC), milk absorption index (MAI), water solubility (WS), and least gelation capacity (Coffmann & Garciaj, 1977) were determined. Emulsifying capacity (EC) and stability (ES) were determined according to the procedure described by Yasumatsu et al. (1972).

The microstructure of the flour samples was examined at magnifications of 100 ×, 300 ×, 2,000 ×, and 8,000 × using a scanning electron microscope (SEM) operated at 5 kV (model JSM-6610, Jeol®, Japan). The equipment was coupled with an energy-dispersive spectroscopy (EDS) system (Thermo Scientific NSS Spectral Imaging). Prior to analysis, the samples were degreased.

The texture measurement was performed on all cake formulations using a texturometer (Texture Analyzer, Brookfield, CT3 25k, USA). The cake samples, with the crust removed, were cut into three cylindrical pieces, 2.5 cm in diameter, and subjected to a compression resistance test using a cell load of 25,000 g, aided by a cylinder probe TA4/100, at a tension on 30% of the sample, a contact force of 0.10 N, and a test speed of 2.0 mm/s.

2.3.3 Sensory analysis of cakes

Prior to sensory analysis, the cakes were evaluated for microbiological quality, including the presence of *E. coli* per gram of sample, coagulase-positive *Staphylococcus*, *Bacillus cereus*, molds and yeasts per gram of sample, and *Salmonella* per 25 g of sample.

Two cake formulations were evaluated for sensory acceptability using a 9-point hedonic scale and for purchase intention using a 5-point hedonic scale. The research was previously approved by the Research Ethics Committee of the IF Goiano under opinion number: 3.440.073. The acceptability index (AI) was calculated as a percentage by multiplying the average of all evaluations for each attribute by 100 and dividing by the highest score awarded. An AI was considered to be well accepted when ≥ 70% (Dutcosky, 2019).

2.4 Statistical analysis

All analyses were performed in triplicate and expressed as mean followed by standard deviation. Data were expressed as mean and standard deviation and subjected to analysis of variance (ANOVA) for treatments (samples evaluated in this study), followed by the application of Tukey's test using Statistica 6.0 software (StatSoft Inc., USA). Differences were considered significant when $p < .05$.

The Scheffé canonical equation (Equation 1) was used to model the experimental data:

$$Y = \beta_1 X_1 + \beta_2 X_2 + \beta_2 X_3 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 + \beta_{123} X_1 X_2 X_3 \quad (1)$$

Where Y is the studied response, β1, β2, β3, β12, β13, β23, and β123 are the regression parameters, and X1, X2, and X3 are the levels of flour in the blends. Positive values for binary coefficients, βij, indicate synergistic effects, while negative values represent antagonism. The results obtained were evaluated using the response surface methodology and screened using the desirability tool with the highest levels of each response variable.

3 RESULTS AND DISCUSSION

3.1 Evaluation of the physicochemical, chemical, and technological properties of by-product flour

Table 2 presents the results obtained from the physicochemical analyses, proximal composition, RS content, mineral

Table 2. Physicochemical analyses and chemical composition of pineapple peel and green banana flours (mean ± standard deviation).

Variable	PF	BF
pH	4.04 ± 0.01	5.18 ± 0.01
Total soluble solids (°Brix)	4.46 ± 0.02	0.62 ± 0.016
Titratable acidity (g/100 g)	3.56 ± 0.10	0.65 ± 0.01
Moisture (g/100 g)	11.80 ± 0.04	4.96 ± 0.04
Ash (g/100 g)	4.92 ± 0.03	2.71 ± 0.05
Lipids (g/100 g)	0.59 ± 0.01	0.43 ± 0.01
Proteins (g/100 g)	4.16 ± 0.04	2.16 ± 0.14
Carbohydrates (g/100 g)	78.53 ± 0.10	89.74 ± 0.22
Total caloric value (kcal)	336.08 ± 0.04	371.50 ± 0.10
Total dietary fiber	45.82 ± 0.40	44.38 ± 1.25
Soluble dietary fiber	0.69 ± 1.22	1.40 ± 0.45
Insoluble dietary fiber	45.13 ± 1.13	42.98 ± 0.63
Mineral content		
Phosphorus (mg/100 g)	1.05 ± 0.07	0.75 ± 0.07
Potassium (mg/100 g)	6.55 ± 1.06	5.90 ± 1.27
Calcium (mg/100 g)	4.45 ± 0.07	0.35 ± 0.35
Magnesium (mg/100 g)	0.85 ± 0.21	0.75 ± 0.21
Sulfur (mg/100 g)	0.65 ± 0.07	0.70 ± 0.14
Iron (mg/100 g)	0.09 ± 5.09	0.07 ± 1.13
Manganese (mg/100 g)	0.010 ± 5.09	0.004 ± 0.21
Copper (mg/100 g)	0.006 ± 2.19	0.002 ± 0.49
Zinc (mg/100 g)	0.002 ± 1.06	0.002 ± 0.14
Resistant starch (g/100 g)	-	56.77 ± 0.91
Total phenolics (mg EAG/100 g	0.33 ± 0.08	0.01 ± 0.001
Antioxidant activity (μmol Trolox/g)	7.22 ± 0.86	7.24 ± 0.52

PF: pineapple peel; BF: banana flours.

composition, total phenolic compounds, and antioxidant activity of the pineapple PF and green BF.

The pH values of PF and BF ranged from 4.04 and 5.18, respectively, which were higher than what had been reported for the Cerrado cashew by-product ingredient (~2.9) (Lima et al., 2021) and close to what was reported for okara (soybean by-product) (5.4–5.9) (Guimarães et al., 2020). However, the pH values of PF and BF were close to what had been reported for pineapple bagasse flour (4.3) (Selani et al., 2016) and for green BF of other varieties (5.0–5.8) (Kumar et al., 2019).

The TA values found in the present work were close to what had been reported for dry pineapple pomace (1.9–2.1 g/100 g) (Selani et al., 2014) and green BF (0.6–0.8 g/100 g) (Kumar et al., 2019). These acidity values, combined with the TA values, can characterize these flours as acidic, which can contribute to their preservation by reducing the possibility of microbial attack, since their acidic pH is considered beneficial for food preservation (Fernandes et al., 2008).

The soluble solids content of PF was higher than that reported for the Cerrado by-product ingredient, cashew (2.3–3.1) (Lima et al., 2021), while BF was lower. The soluble solids content of BF was close to the value reported for okara (soybean by-product) (0.6–1.3) (Guimarães et al., 2020) and for green BF (0.5–0.8) (Savlak et al., 2016).

The flour developed in this study demonstrated low moisture content (11.80 and 4.96 g/100 g for PF and BF, respectively). The low water content of the flour and the high acidity limit contamination by microorganisms more efficiently. Moisture content below 15% can prevent microbial growth as well as chemical and enzyme-catalyzed reactions (Sandulachi, 2012). Consequently, the flour can be stored for a long time.

The PF presented higher contents of ash (4.92 g/100 g), lipids (0.59 g/100 g), proteins (4.16 g/100 g), and total dietary fiber (45.82 g/100 g), while the BF presented contents of 2.71 g/100 g, 0.43 g/100 g, 2.16 g/100 g, and 44.38 g/100 g, respectively. These variations are mainly attributed to the fruit variety, soil type, and climatic conditions (Lombardi-Boccia et al., 2004). The carbohydrate content was higher in BF (89.74 g/100 g) compared to PF (78.53 g/100 g), which was also reflected in the higher energy value of BF (371.50 kcal) compared to PF (336.08 kcal). The presence of RS was detected only in BF (56.77 g/100 g), standing out as a functional ingredient with prebiotic potential and application in diets with fat and sugar restriction (Colantonio et al., 2020).

PF had a higher TPC (0.33 mg GAE/100 g) compared to BF (0.01 mg GAE/100 g), while antioxidant activity was similar for both flours. This activity may be related to the presence of phenolic compounds or other compounds such as proteins and minerals, which, even in low concentrations, are known to neutralize free radicals and promote metabolic and anti-inflammatory benefits, especially in diets aimed at preventing chronic diseases (Fang et al., 2002).

Regarding mineral composition, potassium was the most abundant element in both flours, followed by calcium. Lower levels were observed for copper and zinc. Factors such as soil type, maturity stage, and agronomic growing conditions can explain the differences in mineral content (Managa & Nemadodzi, 2023). Overall, the results highlight the nutritional and functional potential of the flours studied, with BF being a good source of RS and carbohydrates and PF presenting relevant levels of fiber and antioxidant compounds.

3.2 Evaluation of the physical, technological, and morphological properties of by-product flour

Regarding particle size, PF demonstrated a more concentrated distribution in intermediate meshes, mainly in mesh 60 (41.76%) and 80 (23.51%), which indicates a predominant medium to fine particle size. Meanwhile, BF presented a higher percentage of particles retained in coarser meshes, such as 0 (8.88%) and 28 (13.94%), showing a coarser particle size (Supplementary Table 1).

The color parameters (Table 3) showed that PF is darker, more intense in yellow-reddish tones, and has greater color saturation, while BF has a lighter and less saturated color, with lower a* and b* values, indicating a more neutral tone. Despite the

Table 3. Colorimetric parameters of pineapple peel and green banana flour and color, specific volume, and hardness parameters of the developed cake formulations (mean ± standard deviation).

Flour or formulations	Specific volume	Firmness (N)	L	a*	b*
PF		-	53.81 ± 1.28	5.76 ± 0.15	26.82 ± 0.21
BF		-	75.01 ± 2.29	2.80 ± 0.19	15.00 ± 0.25
1	1884.23 ± 0.02^{d}	10.81 ± 1.97^{b}	34.14 ± 5.36^{a}	7.96 ± 3.34^{a}	21.63 ± 4.83^{a}
2	1829.26 ± 0.02^{f}	10.79 ± 3.26^{b}	45.82 ± 5.86^{a}	10.87 ± 4.56^{a}	20.86 ± 1.78^{a}
3	1881.17 ± 0.01^{e}	5.59 ± 0.15^{ab}	49.88 ± 2.52^{a}	11.93 ± 1.19^{a}	27.18 ± 0.54^{a}
4	2067.28 ± 0.02^{a}	10.88 ± 0.06^{b}	38.35 ± 5.31^{a}	8.93 ± 3.85^{a}	23.05 ± 3.31^{a}
5	1763.93 ± 0.02^{i}	6.84 ± 0.68^{ab}	42.10 ± 3.58^{a}	8.02 ± 1.21^{a}	26.85 ± 2.56^{a}
6	1904.74 ± 0.02^{c}	4.26 ± 0.60^{a}	49.75 ± 8.65^{a}	8.87 ± 4.18^{a}	22.71 ± 1.58^{a}
7	1794.53 ± 0.02^{h}	8.67 ± 1.75^{ab}	43.92 ± 5.45^{a}	8.38 ± 4.70^{a}	25.07 ± 0.69^{a}
8	1819.50 ± 0.02^{g}	6.67 ± 1.20^{ab}	40.55 ± 5.12^{a}	8.95 ± 4.54^{a}	25.30 ± 2.32^{a}
9	1749.98 ± 0.02^{j}	7.76 ± 3.46^{ab}	43.57 ± 9.35^{a}	8.46 ± 4.86^{a}	21.81 ± 0.73^{a}
10	1939.98 ± 0.02^{b}	3.74 ± 2.43^{a}	48.07 ± 9.81^{a}	8.82 ± 5.31^{a}	23.45 ± 1.43^{a}

Different letters in the same column indicate significant differences between treatments ($p < .05$).
PF: pineapple peel; BF: banana flours.

difference in intensity and luminosity, the hues (h*) are similar, suggesting that both have a coloration in the same hue range, but with different intensities.

Figure 1 presents the technological characteristics of flours. PF stands out for its high absorption of water (17.76%), milk (33.96%), and solubility (8.32%). Greater water absorption is desirable for use in products that require hydration and moisture retention in their structure, such as meat and bakery products, and can also improve yield and modify texture (Schur, 1987).

Although BF has lower water (8.19%) and milk (6.53%) absorption, it presents better emulsifying stability (84.68%) and is more suitable for stable emulsified formulations, such as sauces, mayonnaises, and dairy products with low hydration (Sikora et al., 2008).

PF showed weaker gelation capacity starting at a concentration of 14%, while concentrations between 18 and 20% resulted in strong gel formation. Conversely, BF showed weak gel formation only at concentrations of 18–20%, thus demonstrating lower gelation capacity compared to PF.

Starch gelatinization directly influences food quality, affecting characteristics such as texture (elasticity and softness), digestibility, palatability, volume, and shelf life (Chiang & Johnson, 1977). This process promotes important structural modifications, such as the destruction of polymer chains and the release of their components (Gomez & Aguilera, 1983).

Figure 2 presents the morphological analysis of PF (Figures 2A, 2B, 2C, and 2D) and BF. Figure 2A demonstrates an amorphous mass with a cohesive structure and a less compact and more irregular surface. Figure 2B shows a spongy structure, and Figures 2C and 2D demonstrate a fibrous nature and a rough surface. These structures are consistent with a high-fiber by-product flour (Table 1), corroborating what was reported by Brito et al. (2020) for pineapple by-product flour.

Figures 2E and 2F demonstrates rounded oval structures with a smooth surface that may be structures of starch granules in BF. Figures 2G and 2H also shows a cohesive structure with some holes on the surface that may be related to the characteristics of RS, as demonstrated in Table 1. Similar results of starch granules were demonstrated for corn bran (Sousa et al., 2019).

The physicochemical properties of the green BF and pineapple PF used in this study's cake mix production demonstrated that they have good technological properties for preparing bakery products.

3.3 Physicochemical and chemical characteristics of the developed cakes

Table 1 shows the results of TA, pH, and moisture, ash, and protein contents, while Table 3 shows the results of specific volume, color, and texture of cake formulations containing PF, BF, and OF. Table 4 presents the mathematical modeling of the response variables studied for cake formulations containing the flour mixture.

The cake formulations' TA content varied between 1.42 (F1) and 0.26 (F3) mL/100 g. PF was the independent variable that had the greatest effect (two and three times greater) on the cake's TA content compared to BF and OF (Table 4). This corroborates the result obtained for the TA of PF reported in Table 2.

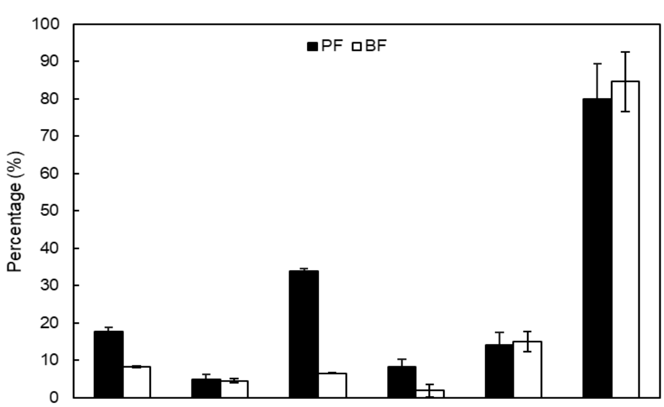

Figure 1. Water absorption index, oil absorption capacity, milk absorption index, water solubility, emulsifying capacity, and stability of pineapple peel flour and green banana flour.

PF: pineapple peel flour; BF: banana flour; WAI: water absorption index; OAC: oil absorption capacity; MAI: milk absorption index; WS: water solubility; EC: emulsifying capacity; ES: stability.

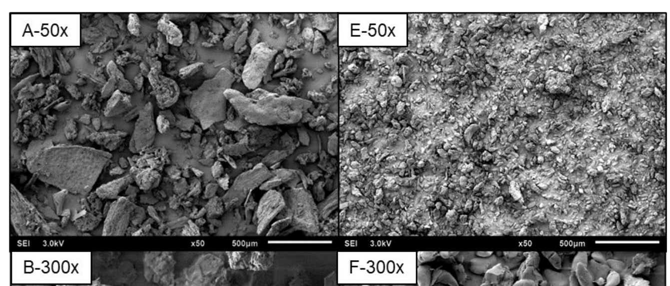

Figure 2. Morphological analysis of pineapple peel flour (left) **(A to D)** and green banana flour (right) **(E to H)** at magnifications of 50x, 300x, 1000x, and 2500x, respectively.

The pH value ranged from 6.95 (F1) to 8.05 (F3), corroborating the behavior demonstrated by TA. OF had the greatest effect on pH; that is, the higher the OF content added to the cake formulation, the higher the pH value. Meanwhile, the lower the amount of PF added to the cake, the lower the pH value of the formulation (Table 4).

The moisture content varied from 28.32 (F9) to 32.15 (F4) g/100 g, while the ash content varied from 1.74 (F23) to 2.41 (F2) g/100 g (Table 1). Mathematical modeling was not significant; that is, it is not possible to mathematically explain the effects found by the independent variables. The ash content of the cake formulations developed in this work was close to the values reported for the fiber-enriched cake (2.97 g/100 g) (Erukainure et al., 2014).

The protein content varied from 0.89 (F1) to 1.10 (F3) g/100 g (Table 1), and OF was the flour that presented the greatest effect on this response variable (Table 4).

Specific volume ranged from 1749.98 (F9) to 2067.28 (F4). BF was the flour that contributed most to the increase in specific volume (Table 4), which may be related to the higher fiber and RS contents present in these flours (Table 2).

The hardness value varied from 3.74 (F10) to 10.88 (F4) N (Table 1). Hardness is directly related to the maximum force applied in the first cycle of sample compression. The F4 cake hardness value is mainly due to the different macromolecules (starch, protein, and non-starch polysaccharides) present in each flour (Magallanes-Cruz et al., 2020). Furthermore, it was possible to observe that PF has almost twice the effect on hardness when compared to OF (Table 4).

For the color parameters L*, a*, and b* of the cake formulations, there were no significant differences at the 5% level. L* values ranged from 34.14 (F1) to 49.88 (F3), indicating that all samples were closer to black. A* values indicated a redder color, ranging from 7.96 (F1) to 11.93 (F3). B* values indicated a tendency toward a more yellow color, ranging from 20.86 (F2) to 27.18 (F3). Lower L* and a* values were associated with increased PF, as indicated by the effect of this flour, which was the smallest when compared to BF and OF. Oh et al. (2017) reported higher L* values than those reported in the present study (58.19–84.48) and similar a* and b* values to those reported in the present study (−1.09 to 10.92 and 18.75 to 33.50, respectively). The color attribute has a great impact on the evaluation and acquisition of food products, both for the consumer and for the food industry. The lighter the flour, the greater its acceptance and interest, since when incorporated as ingredients in the preparation of food products, it will cause little change in the final color (Castilho et al., 2010).

Table 4. Mathematical modeling of the response variables of cake formulations containing pineapple flour, green banana flour, and oat flour.

Variable	Equation	R^2	R_{adj}	*p*
Acidity	1.30PF + 0.53BF + 0.31OF	61.18	50.09	.04
pH	6.88PF + 7.62BF + 7.82OF	64.68	54.59	.03
Protein	0.94PF + 0.94BF + 1.10OF	51.63	37.82	.07
Firmness	10.11PF + 8.57BF + 4.12OF	45.39	29.79	.12
L*	35.82PF + 45.03BF + 49.99OF	67.24	57.88	.02
a*	7.43PF + 9.84BF + 10.08OF	43.91	27.88	.13

PF: pineapple peel; BF: banana flours; OF: oat flour.

Considering the maximization of the response variables and the use of the flours developed in the present work, two formulations were evaluated separately, with formulation 4 containing 50% PF and BF, and F7 containing 33.33% of each flour studied.

3.5 Sensorial profile of the developed cakes

The results of the microbiological analyses indicated that all ready-to-eat cake samples complied with the standards established by current Brazilian legislation.

Sensory tests were performed on 100 panelists, 78 women and 24 men, aged 18–47 years. Although both cake formulations showed acceptable AIs (> 70%), F7 had a higher cetabiid index than F4 for all evaluated attributes. As previously discussed, this may have been caused by the color and texture changes resulting from the addition of PF and BF caused in the developed cakes (Figure 3).

Corroborating the results obtained from the cetability index of the cake formulations, formulation F4 demonstrated a higher percentage of respondents who indicated negativity regarding purchase intention.

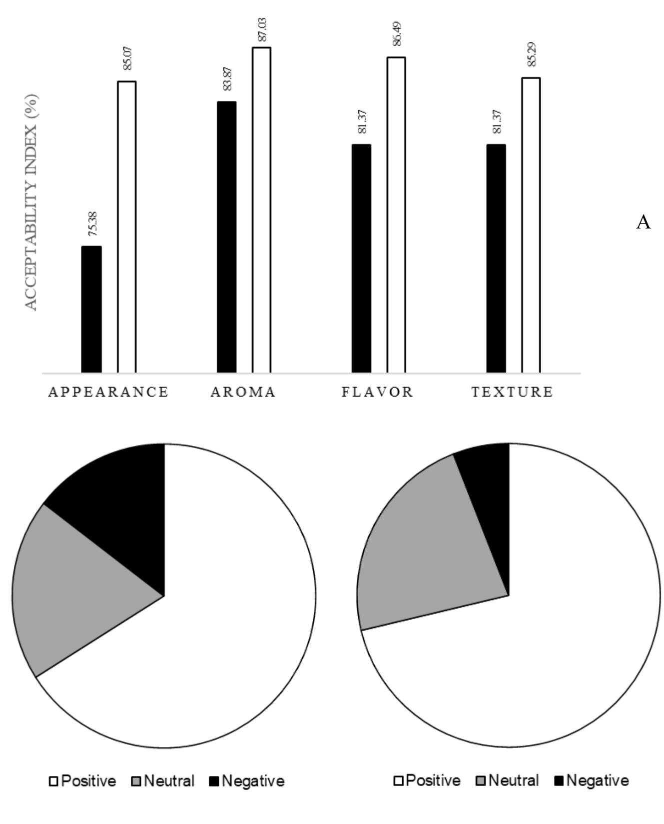

Figure 3. **(A)** Acceptability index of formulation 4 (50% pineapple peel flour + 50% banana flour) (black bar) and 7 (33% of pineapple peel flour, banana flour, and oat flour) (white bar), and **(B)** purchase intention of formulation 4 and **(C)** formulation 7.

4 CONCLUSIONS

The flours developed in this study—pineapple PF from the Pérola cultivar and green BF from the Prata cultivar—demonstrated significant potential for commercial-scale production.

These flours have a high fiber content, and in the case of green BF, a high RS content is also noteworthy. The excellent nutritional and technological characteristics identified justify the use of these flours in food preparations with functional food claims.

Analysis of the physicochemical characteristics of cakes made with mixtures containing different proportions of these flours showed that they met the identity and quality standards established by current legislation.

The cake mix formulations, in which 40% of the whole wheat flour was replaced by functional flours from pineapple peel, green banana, and oats, in different proportions, demonstrated good sensory acceptance, with an AI exceeding 70%, and excellent purchase intention for all three versions evaluated.

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