TECHNOLOGICAL CHARACTERISTICS OF BREADFRUIT FLOUR (*Artocarpus altilis* L.) IN THE QUALITY OF GLUTEN-FREE BREAD

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ABSTRACT: This study aimed to characterize the physicochemical properties and develop gluten-free breads using breadfruit flour (BFF). Three bread formulations were developed: a control bread (CB) with base flour (BF - composed of rice flour, corn starch, and cassava starch), and two variations with partial replacement of BF by 15% and 25% of BFF designated respectively as BFFB15 and BFFB25. For BFF, particle size, water solubility index (WSI) and water absorption index (WAI) were determined. The proximate composition was determined in the BFF and in the breads, as well as the sensory analysis of the breads. BFF showed that 85.10% of its particles were smaller than 250μm. The WAI (g/g) increased from 1.27 to 4.76, while the WSI (%) decreased from 16.10 to 8.80 as the temperature rose from 30 to 95°C. The contents (g/100g) of the BFF proximate composition were: moisture (3.97±0.20); proteins (2.89±0.08); lipids (0.81±0.10); ash (1.15±0.12); carbohydrates (91.33±0.25), while for CB, BFFB15 and BFFB25 there was a variation in moisture from 47.24±0.21 to 51.88±0.21; proteins (5.29± 0.10 to 5.39±0.11); lipids (4.97±0.07 to 5.40±0.47); ash (0.87±0.06 to 1.29±0.06) and carbohydrates (35.91±0.10 to 42.21±0.07). The data suggest that the breads produced have low lipid content and high mineral content. The weight loss of the breads post-cooking was 6.44 and 6.03%, for BFFB15 and BPFFB25, respectively. Sensory analysis showed that both breads presented good acceptance, with BFFB15 having the highest scores. The BFF proved to be nutritionally viable, and with good acceptability in the products evaluated. It also proved to have important technological characteristics for application in gluten-free bakery products, to promote volume and increase the yield of post-baking doughs.

KEYWORDS: Gluten-free breads; Breadfruit flour; Technological characteristics.

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CARACTERÍSTICAS TECNOLÓGICAS DA FARINHA DE FRUTA-PÃO (*Artocarpus altilis* L.) NA QUALIDADE DO PÃO SEM GLÚTEN

RESUMO: Este trabalho objetivou a caracterização físico-química e elaboração de pães isentos de glúten com farinha de fruta-pão (BFF). Foram realizadas três formulações de pães, sendo um controle (CB) com farinha base (BF - farinha de arroz e amido de milho e de mandioca) e outras duas com substituição parcial da BF por 15% e 25% da BFF, designados respectivamente como BFFB15 e BFFB25. Para a BFF foram determinados granulometria, índice de solubilidade em água (WSI) e Índice de absorção de água (WAI). A composição centesimal foi determinada nas BFF e nos pães, assim como a análise sensorial dos pães. A BFF apresentou 85,10 % de partículas menores que 250µm. O WAI (g/g) aumentou de 1,27 para 4,76 e o WSI (%) reduziu de 16,10 para 8,80 à medida que aumenta a temperatura de 30 para 95ºC. Os teores (g/100g) da composição centesimal da BFF foram: umidade (3,97±0,20); proteínas (2,89±0,08); lipídios (0,81±0,10); cinzas (1,15±0,12); carboidratos (91,33±0,25), enquanto que para o CB, BFFB15 e BFFB25 houve uma variação da umidade (47,24±0,21 a 51,88±0,21); proteínas (5,29± 0,10 a 5,39±0,11); lipídios (4,97±0,07 a 5,40±0,47); cinzas (0,87±0,06 a 1,29±0,06) e carboidratos (35,91±0,10 a 42,21±0,07). Os dados sugerem que os pães produzidos apresentam baixo teor lipídico e alto teor de minerais. A perda do peso dos pães na pós-cocção foi de 6,44 e 6,03%, para o BFFB15 e o BFFB25, respectivamente. A análise sensorial mostrou que ambos os pães apresentaram boa aceitação, sendo o BFFB15 com as maiores notas. A BFF mostrou-se nutricionalmente viável, e com boa aceitabilidade nos produtos avaliados. Também se mostrou com características tecnológicas importantes para aplicação em produtos de panificação sem glúten, para promover volume e aumentar o rendimento das massas pós-forneamento.
PALAVRAS-CHAVE: Pães sem glúten; Farinha de fruta-pão; Características tecnológicas.

CARACTERÍSTICAS TECNOLÓGICAS DE LA HARINA DE FRUTA DEL PAN (*Artocarpus altilis* L.) EN LA CALIDAD DEL PAN SIN GLUTEN

RESUMEN: Este trabajo tuvo como objetivo la caracterización fisicoquímica y preparación de panes libres de gluten con harina de fruta del pan (BFF). Se elaboraron tres formulaciones de pan, un control (CB) con harina base (BF - harina de arroz y almidón de maíz y yuca) y otras dos con sustitución parcial de BF por 15% y 25% de BFF, designadas respectivamente como BFFB15 y BFFB25. Para BFF se determinó el tamaño de partícula, el índice de solubilidad en agua (WSI) y el índice de absorción de agua (WAI). Se determinó la composición próxima en los BFF y panes, así como el análisis sensorial de los panes. BFF mostró un 85,10% de partículas menores a 250µm. El WAI (g/g) aumentó de 1,27 a 4,76 y el WSI (%) se redujo de 16,10 a 8,80 a medida que la temperatura aumentó de 30 a 95ºC. Los contenidos (g/100 g) de la composición aproximada de BFF fueron: humedad (3,97 ± 0,20); proteínas (2,89±0,08); lípidos (0,81±0,10); ceniza (1,15±0,12); carbohidratos (91.33±0.25), mientras que para CB, BFFB15 y BFFB25 hubo una variación en la humedad de 47.24±0.21 a 51.88±0.21; proteínas (5,29±0,10 a 5,39±0,11); lípidos (4,97±0,07 a 5,40±0,47); cenizas (0,87±0,06 a 1,29±0,06) y carbohidratos (35,91±0,10 a 42,21±0,07). Los datos sugieren que los panes

producidos tienen bajo contenido de lípidos y alto contenido de minerales. La pérdida de peso de los panes después del horneado fue de 6,44 y 6,03%, para BFFB15 y BFFB25, respectivamente. El análisis sensorial mostró que ambos panes fueron bien aceptados, siendo BFFB15 el que obtuvo las puntuaciones más altas. BFF demostró ser nutricionalmente viable y con buena aceptabilidad en los productos evaluados. También demostró tener importantes características tecnológicas para su aplicación en productos de panadería sin gluten, para favorecer el volumen y aumentar el rendimiento de las masas postcocción.
PALABRAS CLAVE: Panes sin gluten; Harina de fruta del pan; Características tecnológicas.

1. INTRODUCTION

In food preparation and the food industry, there is a tendency to use co-products such as flour obtained from seeds, fruits, leaves and roots to replace wheat flour in various food formulations (Mahloko *et al*., 2019; Martínez *et al*., 2021; Susman *et al*., 2021; Weng *et al*., 2021).

In addition to the important nutritional value and presence of bioactive compounds in various flours obtained from plant species (Kulushtayeva *et al*., 2023; Pimenta *et al*., 2023), the preparation and use of these flours can contribute to sustainability, such as the full use of the vegetable, and by promoting family farming, by adding value to these fruits and enhancing regional cultures.

The purpose of this replacement is to develop new food products that cater to increasingly demanding consumers, enhance nutritional value, and meet the physiological needs of individuals with celiac disease, which are key demands in the food market. Furthermore, socioeconomic circumstances combined with globalization have also stimulated the search for alternative sources of food, as well as new technological processes. These issues aim to reduce product costs and have a positive impact on meeting the nutritional demands, including the prevention of food intolerances and/or sensitivities, such as those already reported regarding gluten consumption (Czaja-Bulsa, 2015).

Gluten-free products are the main option for consumers suffering from celiac disease, which is associated with the consumption of products containing wheat gluten, which has been considered an emerging issue. Gluten has difficulty being metabolized by the human body of celiac patients, causing several reactions, especially in the intestine (Kulushtayeva *et al*., 2023; Niland; Cash, 2018). Therefore, it is important to invest in science in the development of gluten-free flours and food products that benefit the celiac population.

Furthermore, the increase in demand for gluten-free products is also due to the increase in individuals who choose to exclude gluten from their diet as a lifestyle (Gao *et al*., 2018). In this context, the expectation is that the gluten-free food market is expected to grow in the coming years, especially products conventionally made with wheat, such as bakery products.

In technological terms, wheat flour remains the best choice for baking due to the ability of its protein fractions (glutenin and gliadin) to form gluten when hydrated (Arinola; Akingbala, 2022), making food products with more acceptable sensory characteristics. However, countries that do not have sufficient wheat production are forced to import it, which increases the cost of bread. Based on this context, there is a tendency to seek flour alternatives to partially or completely replace wheat. Rice flour (*Oryza sativa*) and corn starch (*Zea mays*) have been the main gluten-free substitutes for wheat flour due to their global availability, cost-effectiveness and low allergenicity proteins (GAO *et al*., 2018). In the food industry, the production of vegetable flours has great applicability, mainly in bakery products such as breads, dietary products, baby foods, as it is a rich source of starch and minerals (Anyasi; Jideani, 2022), in addition to contributing to the supply of protein, fiber and bioactive compounds (Silva *et al*., 2022).

These food products are popular and widely accepted and consumed by people of all ages due to their practicality and good acceptance (Okpala; Okoli, 2013) and also have the advantages of an affordable cost, great versatility in terms of ingredients and being a ready-made product for consumption (Garcia-Armenta *et al*., 2017). Furthermore, this practicality can be combined with the development of functional and nutraceutical foods, with the incorporation of nutritious flours in formulations (Ajay; Pradyuman, 2018), for example, the flour of *Artocarpus altilis* L.

A. altilis L., known as breadfruit, belongs to the Moraceae family and has more than 50 species. Breadfruit is an underutilized crop, but considered highly nutritious, being a good source of essential amino acids (leucine, isoleucine and valine) and carbohydrates, and low in fat (Oladunjoye *et al*., 2010). Its potential as a global contribution to food security has been gaining popularity (Liu *et al*., 2015; Ragone, 2016). Depending on the variety, breadfruit has also been reported as a rich source of vitamins and minerals such as copper, magnesium, phosphorus, potassium, calcium, iron and manganese and several bioactive compounds such as tannin, ascorbic acid, carotenoids, among others (Azevedo-Meleiro; Rodriguez-Amaya, 2004; Clerici; Carvalho-Silva, 2011; Oladunjoye *et al*., 2010). Thus, breadfruit co-products, such as its flour, have the potential to be added to gluten-free bread formulations.

However, the absence of gluten affects the acceptability and texture of bakery products, which are the main challenges for the applications of gluten-free flours in these foods. Therefore, this article aimed to develop a flour from breadfruit, develop gluten-free breads, as well as evaluate their physical-chemical, technological and sensorial characteristics, taking advantage of the widespread cultivation of breadfruit, its high nutritional qualities, as well as the low-fat content and high levels of vitamins and minerals of the fruit.

2. MATERIAL AND METHODS

2.1 Sample preparation

The breadfruit (*A. altilis*) samples (Figure 1) were collected from a family farming site in the Quilombola Community called Gravatá de Baixo in Muritiba, Bahia, Brazil (12°31'11.7"S 38°40'58.3"W).

The fruits were initially selected, cleaned and sanitized with sodium hypochlorite (200ppm/15 min) followed by washing in running water. After cleaning, the fruits were peeled and the pulp was cut into cubes (±0.5 cm^3) and subjected to dehydration in a forced air oven (TE 400/D) at 55oC for 30 h. They were then crushed in a hammer mill (TE-650) to obtain flour (Figure 1).

Figure 1. A. Photographic record of breadfruit (*Artocarpus altilis* L.). **B.** Photographic record of Breadfruit pulp flour.
Source: own authorship.

2.2 Preparation of breads made from breadfruit flour (BFF)

To prepare the gluten-free breads, some preliminary tests were carried out regarding the proportion of flour. Once the composition of the base flour (BF) composed of corn starch (36%), cassava starch (14%) and rice flour (50%) (m/m) was defined, three bread formulations were developed: control bread formulation (CB) containing only BF, and the others with partial replacement of BF by 15 and 25% of breadfruit flour (BFF), respectively for the preparation of BFFB15 and BFFB25 (Table 1). The other ingredients used in the preparation of the breads (corn starch, rice flour, sweet corn, yeast, eggs, sugar and margarine) were purchased at the local market.

Table 1. Gluten-free bread formulations with breadfruit flour (*A. altilis*).

Ingredientes	**CB**	**BFFB15**	**BFFB25**
BF (%)	37.8	32.1	28.3
BFF (%)	-	5.7	9.5
Egg (%)	10.0	10.0	10.0
Margarine (%)	8.0	8.0	8.0
Sugar (%)	2.0	2.0	2.0
Biological yeast (%)	1.6	1.6	1.6
Xanthan gum (%)	0.4	0.4	0.4
Salt (%)	0.4	0.4	0.4
Water (45ºC)	40	40	40

BF: base flour composed of corn starch (36%), cassava starch (14%) and rice flour (50%) (m/m). **CB:** control bread; **BFFB15:** Bread with 15% breadfruit flour; **BFFB20:** Bread with 20% breadfruit flour.

Initially, all ingredients were mixed until a homogeneous dough was formed, then placed in an oil mold greased with oil - and BF-greased mold, left to rest for 60 minutes, and subsequently baked at 180ºC for 20 minutes (Figure 2). After cooling to room temperature, the bread was divided (5 x 7 cm) and distributed for sensory analysis.

Figure 2. Photographic record of bread with 15% of breadfruit flour (*A. altilis*). **A.** Bottom base of the bread. **B.** Top base of the bread. **C.** Internal structure of the bread.
Taken from: Own authorship.

2.3 Physicochemical analysis

2.3.1 Proximate composition of BFF and prepared breads (CB, BFFB15 and BFFB25)

Proximate composition analyzes of BFF and bread (BC, BFFB15 and BFFB25) were carried out in triplicate, according to methods from the Association of Official Analytical Chemists (AOAC, 2019). Carbohydrates were calculated by percentage difference. The statistical analysis was performed using the software SPSS®.

2.3.2 Particle size and BFF absorption and solubility indexes

Regarding the BFF technological analyses, the water solubility index (WSI) and water absorption index (WAI) were determined, in quadruplicate, according to the methodology described by Gimenez et al. (2012), with modifications. Initially, 2.5g of flour was homogenized with 30mL of distilled water. Next, this mixture was subjected to a water bath at different temperatures (30ºC, 50ºC and 95ºC) for 15 minutes. After this step, the samples were centrifuged at 3000 rpm for 15 min. After centrifugation, the supernatant was separated from the gel and transferred to a previously dried capsule at 100°C/1h to determine the soluble solids present in the supernatant. The tubes containing the gel were inverted at 45º for 2 min to drain and subjected to 50ºC until the remaining water dried. The results were expressed in % (WSI) and g/g (WAI).

The granulometric analysis of the BFF was determined according to Kelte-Filho *et al*. (2017) with adaptations, using a set of sieves with metallic meshes (500/32, 300/48, 250/60, 212/85 and 150/100 µm/mesh) coupled to an electromagnetic sieve shaker. The sieves were weighed empty and overlapped according to the opening of their meshes, in descending order. Subsequently, 100g of BFF was weighed and placed on the largest sieve, followed by stirring at 5000 rpm/10 min. After this period, the sieves are weighed again with their respective residues. The results were expressed as % of passing mass.

The yield (%) of the product (post-cooking) was calculated from the ratio between the average mass weights after and pre-cooking multiplied by 100 (Araújo; Guerra, 1992). Each unit of bread was considered as an experimental replication.

2.3.3 Sensory analysis of gluten-free breads with BFF

Sensory analysis was carried out in the DCVII-UNEB Sensory Analysis Laboratory in individual booths, through affective tests in which 60 untrained tasters, from the university community, were recruited. They received samples of each product prepared and were instructed to give its acceptance score in relation to the attributes appearance, color, aroma, flavor, texture and overall quality using a structured hedonic scale of nine points (Meilgaard *et al.*, 2007). To calculate the product's Acceptability Index (AI), the expression was adopted: AI (%) = A x 100/B, where A = average score obtained for the product, and B = maximum score given to the product (Dutcosky, 1996; Stone; Sidel, 1985). This study was approved by the UNEB Ethics Committee (CAAE: 44307415.0.0000.0057).

3. RESULTS AND DISCUSSION

The Table 2 presents data on the proximate composition of breadfruit flour (BFF) and gluten-free breads made with breadfruit flour (BFFB).

Table 2. Proximate composition (g%) of breadfruit flour (*A. altilis*) and gluten-free breads added with this flour

	Moisture (g%)	Protein (g%)	Lipids (g%)	Ashes (g%)	CHO (g%)
BFF					
	3,97±0,20	2,89±0,08	0,81±0,10	1,15±0,12	91,33±0,25
Breads with BFF					
CB	47,24±0,21[a]	5,31±0,28[a]	4,97±0,07[a]	0,87±0,06[a]	42,21±0,07[a]
BFFB15	48,71±0,13[b]	5,29± 0,10[a]	5,40±0,47[b]	0,94±0,08[a]	40,00±0,47[b]
BFFB25	51,88±0,21[c]	5,39±0,11[a]	5,36±0,10[b]	1,29±0,06[b]	35,91±0,10[c]

CB: control bread; **BFF:** breadfruit flour (*A. altilis*); **BFFB15:** bread with 15% from BFF; **BFFB20:** bread with 20% from BFF; **CHO:** carbohydrates.

The data in Table 2 show that BFF has an average moisture content of 3.97 g/100g, a low lipid content (0.81±0.10 g%), and protein content of 2.89±0.08 g%. However, it is rich in carbohydrates (91.33±0.25g%) and mineral content, which is attributed to the ash content (1.15±0.12g%). Despite the low lipid content, breadfruit has been reported to be a rich source of omega-3 and omega-6 according to Tukura and Obliva (2015). The high carbohydrate content implies that BFF is also a source of dietary fiber (soluble and insoluble) (Kehinde *et al.*, 2022) and starch (Huang *et al.*, 2019). Several studies have shown that there are significant variations in the composition nutritional status between breadfruit cultivars (Table 3).

Table 3. Variations in the composition nutritional status between breadfruit cultivars.

Study	Protein (g%)	Lipids (g%)	Ashes (g%)	CHO (g%)
Soifoini *et al*. (2018)	4.44	0.77	---	---
Nochera; Ragone (2019)	2.32	8.33	4.48	---
Ayodele; Aladesanmi (2013)	6.35	1.1	3.28	81.75
Mehta *et al.* (2023)	5.16	2.85	2.85	77.09
Mbah *et al.* (2022)	2.86	1.87	---	65.29
Appiah *et al.* (2016)	10 to 17	---	---	57 to 75

These data show that some of the macronutrients analyzed (Table 2) presented higher concentrations, others lower or similar. There are several factors that can influence the data on the physical-chemical characteristics of the fruits, such as the stage of maturation, variety, climatic conditions, processing and storage of samples before analysis, methodologies, and dehydration technique, when it comes to flours. (Daley *et al*., 2020). Kehinde *et al*. (2022) cite a particularly underutilized cultivar (Yuley) that is rich in starch and soluble and insoluble dietary fiber, performed significantly better in nutritional properties than the more popular cultivated commercial cultivar Ma'afala.

In Brazil, the ANVISA Resolution nº. 711/2022 establishes that the moisture content of flour must be less than 15% (Brazil, 2022). Therefore, the preparation of breadfruit flour, with a moisture content of 3.97g% (Table 2), allows greater stability and shelf life for the product, which favors access to this product even in non-seasonal fruit periods. Moreover, flours, in general, present greater conservation and concentration of the dry extract (nutrients) due to the dehydration process, mainly when made at low temperatures, which promotes a greater nutritional value in the flour, compared to the fruit *in nature*.

According to Liu *et al*. (2015), breadfruit is a source of high-quality protein and is composed of a complete protein, specifically rich in valine, isoleucine, phenylalanine and leucine. However, certain breadfruit cultivars have higher protein and essential amino acid content. Jones *et al*. (2011) reported that the Ma'afala cultivar has the highest amount of protein and essential amino acid content among the cultivars analyzed. For Mbah *et al*. (2022), amino acids were nutritionally richer in breadfruit flour than in wheat flour used as a control. Furthermore, the digestibility of breadfruit protein is higher when compared to wheat protein in in vitro studies (Liu *et al*., 2020).

The protein content in BFF, in addition to contributing in nutritional terms when compared to isolated starches obtained from flours, may also influence the hydration rate, thus affecting starch swelling and gelatinization during cooking (Nwokocha; Williams, 2011).

With regard to carbohydrates, breadfruit has a high percentage, mainly in the form of starch and fiber (Liu *et al*., 2015). In the work of Huang *et al*. (2019) the physicochemical characteristics of flour from two breadfruit cultivars were evaluated in which the total carbohydrate content (g%) ranged from 80.13 to 83.98, and among these, starch was predominant (64 .12 to 62.68 g%). For the authors, the different starch content of the two breadfruit flours was probably caused by the type of cultivar, maturity stage and climatic/agronomic conditions. The high starch content of these flours can make them promising ingredients to improve the technological properties of food products when compared to other flour sources (Huang *et al*., 2019).

Breadfruit has been attributed a high level of dietary fiber and amylose, which potentially helps to delay the absorption of glucose in the gastrointestinal tract (Mc Rae, 2018), contributing to the fruit's low glycemic index (GI) (Widanagamage *et al*., 2009). The GI is an index used to categorize carbohydrate foods into different groups (low, medium, high) based on their ability to increase blood glucose levels (Liu *et al*., 2020).

Regarding breads made with BFF, the data in Table 2 show that the moisture (g%) of the breads was 48.71±0.13 (BFF15); 51,88±0,21 (BFF25). When BFF increased, humidity increased (Table 2), corroborating the work of Rajini *et al*. (2021). Arinola *et al*. (2022) prepared breads with mixed BFF flour and soy flour, with the control bread using wheat flour (WF). The moisture content (g%) found ranged from 27.9 to 37.30. Bread produced with 100% BFF had the highest moisture content (37.3 g/100 g), while WF had the lowest value (27.9 g/100 g). It has been suggested that this difference in moisture content may be due to a lower vaporized water content of the BFF dough during cooking as a function of the dough components. Arinola *et al*. (2022) reported that the fiber content of BFF is 4.77 g%, which was higher than 0.63 g% reported for wheat flour by Akubor and Fayashe (2018); thus, the high fiber content and type of BFF may have contributed to the flour absorbing and retaining more moisture, resulting in higher moisture content of the bread after baking (Akubor; Fayashe, 2018).

The contents (g%) of proteins and lipids were similar for the three bread formulations (CB, BFFB15 and BFFB25) ranging from 5.29 ± 0.10 to 5.39 ± 0.11 and 5.36 ± 0.10 to 5.40 ± 0.47, respectively. However, as the BFF concentration increased, the ash content increased and the carbohydrate content reduced (Table 2). These data emphasize the mineral content of BFF, which is probably higher than the base mixed flour (BF) obtained by mixing starches and rice flour, unlike the carbohydrate content, which appears to be even higher in BF. Arinola *et al*. (2022) prepared breads with mixed flour (BFF and soy flour - SF) and the macronutrient levels found varied from: protein - 3.20 to 7.60 g%, lipids -1.58 to 2.99 g%; ash – 1.98 to 2.86g%; carbohydrates – 50.50 to 54.30g%.

The replacement of wheat with other gluten-free raw materials in the preparation of flours changes their technological characteristics, such as granulometry, WSI and WAI, as well as the products derived from them, which, in the case of breads, the texture and crunchiness are the most affected. Table 2 presents the BFF granulometry data with the results expressed as mass passing (%).

Table 4. Granulometry of breadfruit flour (*A. altilis*).

Mesh	500µm	300µm	250µm	212µm	150µm
Mass passing (%)	55	72,31	85,10	82,50	81,82

Knowledge of particle size distribution, among other parameters, is of utmost technological importance as it guarantees the uniformity of the flour. The non-uniform distribution of flour particle sizes affects the mixing time within the baking process and is responsible for water absorption, interfering with the machinability characteristics of the dough (Posner; Hibbs, 2005).

Since there is no specific legislation for the different flours, the Brazilian legislation that deals with grain size for wheat flour, the Ordinance of the Ministry of Agriculture and Livestock of Brazil Nº 469/2022 was taken as a reference, which states that in wheat flour intended for domestic use and for industrialization, 95% of the product must pass through a sieve with a mesh opening of 250 µm (Brazil, 2022). In this sense, it can be seen in Table 4 that 85.10% of the breadfruit flour had particles smaller than 250µm, that is, it passed through a sieve with a mesh opening of 250 µm, a value that is close when compared to wheat flour, and can therefore be considered a flour with the potential to be used to partially replace other flours with similar particle sizes in food product formulations.

It is important to highlight that the BFF in the present study was prepared with fresh fruits that were not subjected to pre-treatments such as bleaching. This technique could promote partial gelatinization of the starch, which would affect the composition properties, especially moisture, agglutination during drying and, consequently, granulometry (Tribess, 2009).

Huang *et al*. (2019) compared the nutritional and functional properties of tropical flour sources (breadfruit flours var A - BFFA and var B - BFFB) and banana flour - BF). The particle size of BFFB was 220.94 µm and BF 222.89 µm, larger than those of BFFA (138.73 µm) and wheat flour 132.54. Different processing techniques, as well as the chemical composition of the flours, can affect the particle size distribution, which can interfere with the physical-chemical properties of the flours (Ahmed *et al*., 2016; Abebe *et al*., 2015).

According to Huang *et al*. (2019) the results of the study also indicated that flours with larger size and/or higher carbohydrate content may have greater water retention capacity.

The water absorption index (WAI) and the water solubility index (WSI) are other characteristics that are also important in food processing. They are desirable in most processes to improve yield and provide appropriate sensory properties that make foods unique and acceptable to consumers (Tan *et al*., 2017). Thus, the BFF WSI and WAI data are presented in Table 5.

Table 5. Water solubility index (WSI) and water absorption index (WAI) of breadfruit flour (*A. altilis*).

Analysis/Temperature	30ºC	50ºC	95ºC
WAI (g/g)	1,27	1,09	4,76
WSI (%)	16,10	19,39	8,8

According to Table 5, WAI and WSI exhibited different behaviors in response to BFF exposure to temperature, with WAI peaking at 95ºC and WSI at 50ºC. The WAI in the present study reached 4.76, a higher index than those observed in the study by Huang *et al*. (2019), in which the following WAI values were found in different flours: 2.04 g/g (breadfruit flour A); 3.32 g/g (breadfruit flour B); 3.08 g/g (banana flour) and 1.25 g/g (wheat flour). It was reported in the work of Adepeju *et al*. (2011) that the absorption capacity of Water content of breadfruit pulp flour increased with increasing temperature (60°C to 90°C), a behavior similar to that found in this work.

The WAI is based on several factors, such as: carbohydrate content in the flour, particle size, amount of damaged starch, ratio of amylose to amylopectin in the starch, and intra and inter molecular forces (Ahmed *et al*., 2016). On the other hand, the solubility index of products depends on the chemical composition of the food and the interaction between the food constituents and water depends on the amount of starch and proteins present. Thus, according to Lopes *et al*. (2012) for solubility, the water-protein interaction is much more relevant than the amylose/amyloprotein/water interaction, since flours with higher protein levels have shown greater solubility. Thus, it is suggested that the drastic reduction of WSI at 95 °C is associated with the low protein content compared to the carbohydrate content of BFF (Table 1), since according to Lopes *et al*. (2012), solubility is normally more intense the higher the protein content and the high temperature, in this case, would not favor this process. Since BFF is rich in carbohydrates (Table 1), the opposite occurs with WAI, in which the interaction of the soluble amylose/amyloprotein fractions and water are more relevant and the increase in temperature facilitates starch gelatinization and, consequently, water absorption.

Considering the WSI and WAI values identified in BFF (Table 5), it is suggested that when preparing foods with BFF, consider that the added water or liquid ingredients are at temperatures close to 50ºC, as this temperature favors an improved solubility of BFF in water and this can contribute to better homogenization of the entire food matrix. Furthermore, the water absorption capacity was greater when the BFF was subjected to a temperature of 95ºC, thus, baked products that are subjected to even higher temperatures would already be favorable products for gel formation, swelling, increase in volume of the BFF and lower post-supply losses.

Regarding the weight loss of the dough during cooking, it was found that BFFB15 and BFFB25 obtained 6.44% and 6.03%, respectively, which is correlated with the lower humidity of BFFB15 and higher humidity of BFFB25 (Table 2). These data corroborate the work of Bakare et al (2016) in which the physicochemical and sensory properties of breads made with BFF (Artocarpus communis Forst) and WF were evaluated. The authors observed that the weight loss of bread reduced as BFF replaced WF in the mixtures and, according to them, the dough lost weight during the fermentation and baking stages of bread processing, and this may be due to the fermentation losses caused by amylases and the use of soluble sugar by yeast, as well as by the evaporation of moisture during cooking.

The nutritional composition, technological and physical-chemical properties of BFF demonstrated its viability in the creation of healthier food products (Appiah *et al*., 2016; Turi *et al*., 2015).

The Table 6 presents data from the sensory evaluation of BFF, based gluten-free breads.

Table 6. Acceptance Test of gluten-free breads based on breadfruit flour (*A. altilis*).

Samples	Flavor	Texture	Aroma	Aparence	Global Quality	Acceptability Index (%)
BFFB15	6,8[a]	7,0[a]	7,1[a]	7,0[a]	7,4[a]	95,40[a]
BFFB25	6,7[a]	6,7[b]	6,8[b]	7,0[a]	7,0[b]	97,71[b]

BFFB15 – bread with 15% from BFF; **BFFB25 –** bread with 25% from BFF.
Source: Own authorship.

The data in Table 6 shows that both breads presented very similar acceptance scores, with BFFB15 obtaining the highest scores, although the acceptability index was slightly lower.

The sensory analysis of breads prepared by Parinduri *et al*. (2021) with BFF indicated that the formulation with breadfruit flour, mocaf, breadfruit starch, orange sweet potato starch, orange sweet potato flour in proportions (%) of 10:20:10:10:50 it was more accepted by panel members than other breads made with mixed flour.

The type(s) of flour(s) and additives such as hydrocolloids used in bakery food formulations influence the physicochemical characteristics and, consequently, the sensorial evaluation of the products (Clark; Aramouni, 2018; Martínez *et al*., 2021).

The work of Bakare *et al*. (2016) was also based on the preparation of breads with BFF (*Artocarpus communis* Forst) and WF. Sensory properties presented average scores between 3.55 and 6.73 for appearance (crust and crumb color, contour, consistency and grain quality), which decreased significantly ($p < 0.05$) as WF was replaced by the BFF. Similar trends were observed for flavor (3.47–7.80) and texture (4.25–8.03). Interactions between gluten (specifically gliadin), starch and other components of the flour were responsible for the viscosity properties that contributed to the aeration of the dough, influencing the consistency and texture of the bread (Bakare *et al*., 2016).

Other studies have shown that bread, when replaced with 10 to 15% BFF, exhibited acceptable sensory properties (Bakare *et al*., 2016; Clark; Aramouni, 2018; Zakaria *et al*., 2018).

When 10% BFF was used, no significant difference was observed in terms of crust, aroma and shape, compared to bread with pure WF (Bakare *et al*., 2016). Zakaria *et al*. (2018) showed that up to 15% breadfruit starch replacement showed no texture differences in terms of chewiness, hardness and elasticity, but moisture and volume were slightly lower compared to a pure wheat flour loaf. Clark and Aramouni, (2018) mention that there was a good acceptance of breads made with BFF replacement of ≤20% of FT with BFF. These data are similar to this work in which BFFB15 showed better acceptance for each sensory attribute (Table 6).

3. CONCLUSION

Breadfruit flour demonstrated technical, nutritional, and sensory viability for the development of gluten-free breads, offering an additional alternative for individuals with celiac disease. Therefore, it is necessary for the food industries to innovate and incorporate fruit-bread in food applications. Further research on breadfruit is recommended, as this fruit has great potential for food security and sustainability, while also contributing to employment and income generation for small-scale farmers.

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