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Innovative valorization of malt bagasse: transforming brewing by-product into nutrient-rich whole bread

Valorização inovadora do bagaço de malte: transformando subproduto da cerveja em pão integral rico em nutrientes

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This study aimed to valorize malt bagasse, a by-product of Pilsen type craft beer processing, by obtaining malt bagasse flour and using it in the formulation of whole bread (loaf type). The experimental bread formulations were created in an industrial unit, partially replacing whole wheat flour with varying concentrations of malt bagasse flour (10, 20, 30, and 40%). These formulations were then characterized both nutritionally and in terms of their technological properties. The results revealed that incorporating malt bagasse flour (particle size ranging from 0.15 to 1.50 mm) in whole-grain breads, with a partial replacement of up to 20% of whole wheat flour, resulted in products that exhibited excellent sensory acceptance and possessed characteristics and sensory qualities similar to bread made entirely from wheat flour. Additionally, a significant nutritional enhancement, particularly in terms of protein and potassium content, was observed. In conclusion, utilizing malt bagasse in the preparation of whole wheat flour presents an environmentally sustainable alternative that reduces waste. It also enables the development of novel products, such as bread, due to the nutritional benefits of malt bagasse. Thus, it is imperative to explore malt bagasse further, given its nutritional attributes and its abundant availability within the brewing industry.
Keywords: barley, residue, functional properties.

Este estudo teve como objetivo valorizar o bagaço de malte, subproduto do processamento de cerveja artesanal tipo Pilsen, por meio da obtenção de farinha de bagaço de malte e utilização na formulação de pães integrais (tipo pão). As formulações experimentais de pães foram criadas em uma unidade industrial, substituindo parcialmente a farinha de trigo integral por concentrações variadas de farinha de bagaço de malte (10, 20, 30 e 40%). Estas formulações foram então caracterizadas tanto nutricionalmente quanto às suas propriedades tecnológicas. Os resultados revelaram que a incorporação da farinha de bagaço de malte (granulometria variando de 0,15 a 1,50 mm) em pães integrais, com substituição parcial de até 20% da farinha de trigo integral, resultou em produtos que apresentaram excelente aceitação sensorial e possuíam características e qualidades sensoriais semelhantes às do pão feito inteiramente de farinha de trigo. Além disso, foi observado um aumento nutricional significativo, particularmente em termos de conteúdo de proteínas e potássio. Conclui-se que a utilização do bagaço de malte no preparo da farinha de trigo integral apresenta uma alternativa ambientalmente sustentável e que reduz o desperdício. Também permite o desenvolvimento de novos produtos, como o pão, devido aos benefícios nutricionais do bagaço do malte. Assim, é imprescindível explorar ainda mais o bagaço de malte, dados seus atributos nutricionais e sua abundante disponibilidade na indústria cervejeira.
Palavras-chave: cevada, resíduo, propriedades funcionais.

1. INTRODUCTION

The brewing industry, throughout its process, generates large amounts of waste. The main and most abundant is brewer’s spent grain, generated in the mashing stage, which corresponds to 85% of all waste generated. As an illustration, in the manufacture of 100 L of beer, 20 kg of bagasse (~70 wt.% moisture) is generated, equivalent of 2.82 million tons per year in Brazil, or, on average, 0.71 million tons of dry waste [1]. Most of this amount is used for animal feed (cattle, pigs, poultry, and goats) [2]. In addition, its use as a commodity for other applications has aroused interest.

The industry has focused on the development of differentiated and innovative foods to meet the consumers demand in order to improve production without harming the environment with eco-innovative, sustainable, and efficient processes. In this way, with concern for the future generations, sustainability must be considered. In this context, the main components of malt bagasse may have potential health benefits, such as dietary fiber (arabinoxylan and β-glucans) and phenolics (hydroxycinnamic acid). The protein fraction is also interesting because of its relatively high content of essential amino acids, such as lysine, compared to other cereal products [3]. Protein and fiber are concentrated after the wort process, where the starch is removed, so the hydrolyzed protein in the malt bagasse is a functional dietary ingredient [4]. The advantages for health include lowering blood lipid levels, regulating blood sugar and insulin levels, boosting energy levels, removing toxins from the body, reducing the risk of cardiovascular disease and diabetes, eliminating constipation, and better weight management.

Aiming at new alternatives for the main residue of the brewing industry, considering its chemical and nutritional composition, there is interest in its use in the elaboration of innovative products of great trend in the food sector [5]. Malt bagasse flour (MBF) has potential for application in the formulation of fiber-enriched breads [6–8]. Pan bread (also known as sliced bread or loaf bread) is a type of bread in which the dough is baked in the bread form to give it its distinctive shape. It is a source of energy, being a major part of the human daily diet of bakery products. The substitution of up to 15% of wheat flour by agro-industrial waste [9] as beer malt flour in baked products has the potential to reduce production costs.

There is still a lack in the literature on the physicochemical properties of whole wheel bread with malt bagasse flour from Pilsen type craft beer processing. Furthermore, physicochemical characteristics of malt bagasse flour must be provided for a better understanding of its use in bread formulation for a high-quality food. Thus, the objective of this work is to obtain MBF and to develop whole wheel bread with a partial substitution of MBF to whole wheat flour, evaluating its physical-chemical and sensory characteristics.

2. MATERIAL AND METHODS

2.1 Malt bagasse flour

The malt bagasse was obtained from the wort filtration, after the mashing stage of the artisanal Pilsen beer production in the Pilot Plant. Subsequently, 3.520 kg of malt bagasse was dried in an oven (Marconi®-MA037, Brazil) with air circulation at 60°C for approximately 24 h. The samples were periodically collected to determine the moisture and obtain the drying curve. The moisture content was determined on an infrared scale (ID200 Marconi, Brazil) at 105ºC.

The dehydrated malt bagasse was subjected to disintegration in a multiprocessor (Walitta®, Brazil), followed by sieving 40.02 g of sample through Tyler series sieves with meshes of different openings (9 to 115 mesh). The fractions retained on each sieve were quantified by weighing. Next, the granulometry was evaluated by average Sauter diameter [10] of the MBF.

The MBF was characterized in terms of granulometric distribution, mean Sauter diameter, moisture on a dry basis, water activity, protein, lipids, total fiber, total minerals, mineral components (K, Ca, Na, Mn, and Zn) and color indices (L*, a*, b*, chroma C*).

2.2 Whole-grain breads formulations – loaf type

The raw materials used in the preparation of whole-grain bread were sourced from a local supermarket. The ingredients included wheat flour (Specht, Brazil), whole-wheat flour (Sohne, Brazil), malt cake flour, flour improver (Mauri, Brazil), brown sugar (Machado, Brazil), salt (Ivory, Brazil), biological yeast (Mauri, Brazil), hemicellulase, alpha-amylase enzymes (Patospan IS Mix Soft and IS Mix, Brazil), and filtrate water. Table 1 lists the ingredients used in the whole-grain bread formulations. Four formulations with the addition of MBF and a standard formulation (control) were prepared.

Table 1: Formulations of whole-grain breads – loaf type.

Ingredients	SF[1]	F10MBF[2]	F20MBF[3]	F30MBF[4]	F40MBF[5]
Wheat flour (g)	164	164	164	164	164
MBF (g)	0	50	100	150	200
Whole wheat flour (g)	500	450	400	350	300
Brown sugar (g)	50	50	50	50	50
Salt (g)	8	8	8	8	8
Flour improver (g)	14	14	14	14	14
Biological yeast (g)	25	25	25	25	25
Water (mL)	425	425	425	425	425
Enzyme IS Mix Maciez (g)	5	5	5	5	5
Enzyme IS Mix H (g)	5	5	5	5	5

[1] SF standard formulation – 100 % whole wheat flour; [2]F10MBF - 10% MBF and 90% whole wheat flour; [3]F20MBF - 20% MBF and 80% whole wheat flour; [4]F30MBF - 30% MBF and 70% whole wheat flour; [5]F40MBF - 40% MBF and 60% whole wheat flour.

The formulations were prepared in an industrial facility in Erechim, Rio Grande do Sul, Brazil, following typical agro-industrial procedures. Initially, the ingredients were individually weighed and then combined in a 25 kg suction mixer from Gpaniz® (Brazil) for mixing and kneading the dough. The dough was mixed for approximately 10 min at 125 rpm and an additional 5 min at 250 rpm. Following mixing, the dough was rolled to a thickness of 1 cm (Venâncio cylinder, Brazil). It was then manually divided into portions of 400 g each and rounded into shape. Subsequently, the dough was allowed to rest for approximately 20 min before being shaped and left to ferment for about 2 h at 22°C. The oven was preheated to 170°C with steam for 5 min, after which the bread was baked at 160°C for 20 min. Once baked, the breads were allowed to cool, take off mould, and sliced for further analysis.

2.3 Physical-Chemical Characterization

One unit from each formulation, randomly selected, was first sliced, and then physically disintegrated using Mastermix (Arno®, Brazil), followed by manual quartering, dividing it into a laboratory sample for physical-chemical analysis. The formulations were characterized in terms of moisture content, water activity, total minerals, fibers, mineral components (K, Na, Ca, Mn, and Zn), total fiber, lipids, protein, and color indices (L*, a*, b*, chroma *C).

The moisture was determined in an air recirculating oven at 105°C for 4 h, according to the method nº 925.10 [11]. The water activity measurements were carried out in water activity equipment (Novasina®, AG - CH-8853 Lachen, Switzerland). The total nitrogen was obtained by Kjeldahl method nº 981.10 [11] and multiplied by a factor of 6.25 to obtain the protein. The lipid content was performed by Soxhlet method nº 991.36 [11]. The total fiber content was determined according to method nº 985.29 [11]. Total minerals were obtained by a gravimetric method nº 942.05, after calcination at 550°C for 6 h [11]. Carbohydrates were quantified by the indirect method [12], by difference in constituents. The caloric value of the formulations was calculated by multiplying the values in grams of protein by 4 Kcal/g, lipids by 9 Kcal/g and carbohydrates by 4 Kcal/g [12].

The mineral components (Ca, Mn, and Zn) were determined by flame atomic absorption spectrometry - FAAS (Varian® Spectra AA-55, Mulgrave, Australia), Na and K (with a concentration standard of 100 mg/mL) in a microprocessor digital flame photometer (Analyser, Model 910, England) according to the methodology described by AOAC according to the method of nº 990.08 [11].

The objective color was evaluated in a colorimeter (Minolta® Chromameter, CR-400, Japan), in the CIE L*a*b* space, the luminosity (L*), red color intensity (a*), and yellow color intensity (b*), with an illuminant D65, observer angle of 2°, aperture size of 8.0 mm with a closed cone. The chroma C* indices were calculated using the values obtained from $(a^{*2} + b^{*2})^{1/2}$.

2.4 Sensory evaluation of breath

The study was approved by the Research Ethics Committee (URI-Erechim), registered at Brazil Plataform under number nº41005620.6.0000.5351, in compliance with the terms of Res. CNS 466/12.

The sensory evaluation was performed by 50 untrained judges, of both sexes, with an age group of 20 to 50 years old. Each taster received 5 samples of the sliced breads, containing approximately 30 g, with balanced distribution, recipients coded with three-digit random numbers and accompanied by a glass of mineral water at room temperature, to be used by the taster before and between sample evaluations.

The sensory evaluation of the formulations was performed using a consumer acceptance test - structured hedonic scale with 9 points (9 - I liked it a lot and 1 - I unliked it a lot). In the purchase intent test, the reference categories were recorded in 5 points: 5. Definitely would buy; 4. Probably would buy; 3. I doubt if I would buy it; 2. Probably wouldn't buy. 1. Certainly would not buy [13].

For the check all that apply (CATA) test, evaluators select words or phrases that they think describe a product from a list of attributes. These terms can be derived from previous focus group sessions, standardized lists or assigned by the researcher [14] with a combination of the last two being the methodology that was used. In this work, a selection of terms was previously made for each attribute evaluated by the project team. During the analysis, each evaluator was asked to point out the characteristics that best describe the evaluated products, in relation to appearance/color (dark skin color, light skin color, dry skin appearance, crumb with grains, crumb color light, core color dark); aroma (fermented, burnt, pleasant, sweet, whole wheat, unpleasant); taste/flavor (fermented, bitter, pleasant, sweet, whole meal bread, salty) and texture (moist, dry, sticky, rubbery, soft, fibrous).

2.5 Statistical analysis

The results (n=3) were statistically treated by analysis of variance (ANOVA), followed by the Tukey test, with a 95% confidence level using Statistic software (Statsoft Inc, USA). The results of the CATA test were evaluated by principal component analysis (PCA), using the XLSTAT program.

3. RESULTS AND DISCUSSION

3.1 Physicochemical characteristics of malt bagasse

The raw malt bagasse sample had a moisture content of 64.49% and a water activity of 0.978. This high value associated with their composition, makes them susceptible to rapid deterioration. In addition to hampering its transport, thus justifying the need for drying, which favors a longer shelf life and greater ease of storage. Figure 1 shows the drying curve of malt bagasse at 60ºC, in an oven with air circulation, where a moisture content of 10% was obtained in 8.5 h (510 min). This value is considered safe against deterioration, facilitating transport and storage. After 15 h of drying, a moisture content of 0.79% and a water activity of 0.223 were obtained for the malt bagasse.

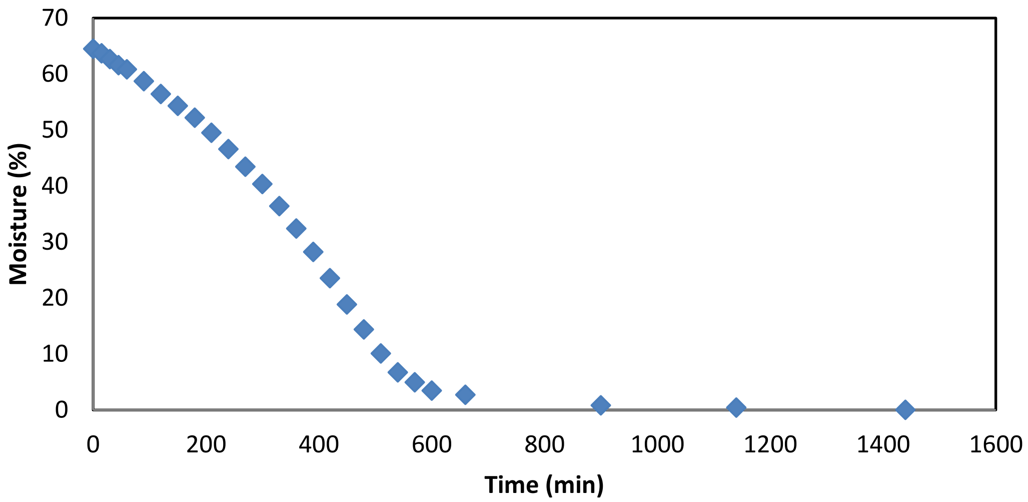

Figure 1: Curve of drying in an oven with air circulation (60 ºC) of the malt bagasse.

3.2 Physicochemical characteristics of malt bagasse flour

The MBF showed variation in the size of its particles, most being retained in the 16, 32, 35 and 60 mesh sieves, which correspond to the sizes of 0.93; 0.46; 0.39 and 0.22 mm, respectively (Figure 2a), and 50% of the particles are retained in the 32 mesh sieve (Figure 2b). The MBF particles had a mean Sauter diameter of 0.375 mm. The MBF had a moisture content of 0.78 g/100g (Table 2). This value was lower than that analyzed by Gurak and Glüger (2020) [15] of 4.19 g/100g in MBF. The latter also point out that the technical regulation on the identity and quality of wheat flour established by Normative Instruction No. 8 [16] establishes a maximum moisture content of 15 g/100g, in that this value should not be followed as a parameter for the MBF.

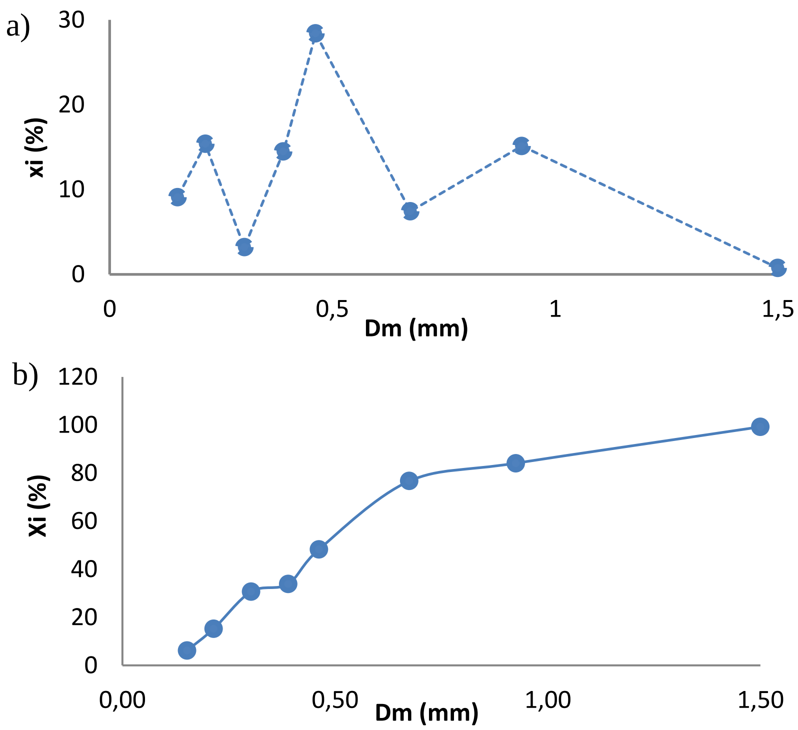

Figure 2: Particle size distribution (a) and cumulative frequency of particles (b).

The quantity of water used in dough preparation significantly influences the microstructure of the dough, particularly when incorporating MBF. The interaction between water and MBF content plays a crucial role in shaping the dough's internal structure, affecting its texture, porosity, and overall quality. Optimal water levels are essential to achieve the desired dough consistency and ensure proper hydration of MBF particles, thereby facilitating gluten development and gas retention during fermentation [17]. The water activity of MBF (0.44), as indicated in Table 2, surpassed the value reported by Silva et al. (2022) [5] (0.28), signifying a comparatively higher water content in MBF. This observation underscores that MBF possesses a low water content, a characteristic deemed favorable for mitigating the risk of microbial proliferation. This attribute is promising for maintaining the technological properties of the flour, thereby supporting its potential utilization in bakery product formulations.

Table 2. Physicochemical characteristics of MBF.

Parameters	**MBF***
Moisture (g/100g)	0.78 ± 0.09
Water activity	0.44 ± 0.01
Protein (g/100g)	13.64 ± 0.60
Lipids (g/100g)	1.29 ± 0.23
Total fiber (g/100g)	32.81 ± 0.81
Total minerals (g/100g)	2.35 ± 0.09
K (mg/100g)	179.02 ± 7.22
Ca (mg/100g)	11.76 ± 0.41
Na (mg/100g)	26.72 ± 2.30
Mn (mg/100g)	2.79 ± 0.18
Zn (mg/100g)	6.16 ± 0.30
L*	46.64 ± 0.03
a*	5.07 ± 0.04
b*	15.72 ± 0.01
Chroma C*	16.52

* Mean (n = 3) ± standard deviation.

A proposed water activity guideline for flour and farina is suggested to fall within the range of 0.62–0.68. This study reveals that this specified water activity range aligns with optimal moisture content for both hard and soft wheat flours. Furthermore, maintaining water activity within this range would prevent mold growth and help mitigate the onset of rancidity [18].

The protein value found in the MBF samples (Table 2) was similar to Nocente et al. [19] who obtained 14.5 g/100g in their work, and lower than that found by Niemi et al. [20] and Meneses et al. [21] who found values above 20 g/100g. Meneses et al. [21] studied bagasse from a beer made with malt and adjuncts (other non-malted cereals), which may explain this difference in values, since in this research the object of study was bagasse derived from a pure malt beverage.

The protein and lipid content of MBF are similar to wheat flour, 12.8 g/100g and 1.5 g/100g [22]. This higher value of lipids must be considered when developing new product formulations with the replacement or addition of flour, so that there are no undesirable changes in the structure of the dough, as well as in its nutritional value [18].

The total minerals had a value similar to that found by Nocente et al. [19] who reported 2.7 g/100g in dry malt bagasse, justifying this high value due to the presence of the outermost layers of the barley grain in the flour. Costa et al. [23] found 2.97 g/100g in malt flours from Saison beer, and lower than that found by Gurak and Glüger [15] of 3.04 g/100g.

Of the mineral components analyzed in the MBF there was a high content of 179 mg/100g K and 26.7 mg/100g Na. The levels were higher than malt bagasse bran for Na (8.24 mg/100g mg/100g) and K (90.90 mg/100g) [24].

Regarding the MBF color, Costa et al. [23] found 50.71 of L*, 7.3 of a* and 20.31 of b*. Gurak and Glüger (2020) [15] found for the L* parameter a value closest to the dark field of 67.03 and for the a* index (5.14) and for the b* (15.35) values closer to the red color fields and yellow. In this study, the values were lower for the L* parameter (46.64), which indicates a tendency towards the dark field, since the lower the L*, the lower the brightness/luminosity. a* (5.07) and b* (15.72) indices were similar to those of Gurak and Glüger (2020) [15], indicating a trend towards red and yellow color fields, which is also verified by the C* chroma.

3.3 Physicochemical characteristics of the formulations of whole wheel bread

Table 3 shows the physicochemical characteristics of the whole wheel bread formulations with whole wheat flour and with partial replacement of whole wheat flour by MBF. It is observed that the moisture (8 g/100g) and water activity (0.89) did not show differences between the formulations. Moisture analysis is one of the most important factors linked to stability and conservation in the case of the growth of microorganisms. In a study carried out by Rigo et al. [25] shows that adding 10, 20, and 30% MBF in cookie formulations promoted a decrease in moisture when compared to the standard cookie, and the authors attributed this to the water holding capacity of MBF. Capelezzo et al. [26] found a moisture content of 34.1 g/100g in breads added with Pilsen-type malt bagasse. When comparing the formulations of the present study, the values obtained in the formulations were lower than those reported by the authors.

Regarding proteins, is observed in the Table 3 a significant difference ($p < 0.05$) between samples F10MBF (7.57 g/100g) and F20MBF (8.54 g/100g). According to the Resolution nº 75, 2020 from the Ministry of Health [27], it is possible to use the term "protein source" for food that contains at least 10% of the recommended daily value of proteins, that is, whole wheel bread added with MBF can be considered a source of protein.

The lipid contents, as shown in Table 3, differed significantly among the formulations ($p < 0.05$), where F40MBF displaying the highest value (4.73 g/100g). This suggests a direct correlation between the concentration of FMB and the increase in lipid content. A higher value of lipid content was observed in the study by Farago et al. [28] which ranged from 10.8 to 15.2 g/100g and also found a significant influence of the addition of malt bagasse. The values obtained in the present study were similar to those obtained by Kuiavski et al. [6] in the elaboration of bread with the addition of 20% malt bagasse. In addition, the malt bagasse flour has lipid profile composed mostly of unsaturated fatty acids, and bioactive compounds such as flavonoids and phenolic acid [15], thus having antioxidant activity that can be incorporated into the whole wheel bread.

The F10MBF presented fiber content greater than 10% of the recommended daily value (RDV). Therefore, this formulation can be classified as a food source of fiber. The formulations with 20, 30 and 40% of MBF showed fiber content greater than 20% of the RDV of dietary fibers, classified as a food with high fiber content [29]. In this way, this product can be considered beneficial for health maintenance and disease prevention due to the high amounts of dietary fiber. Studies demonstrate that regular fiber intake helps the consumer prevent some diseases such as obesity, type 2 diabetes, metabolic syndrome, and constipation. Also can promoting regular bowel movements, aiding in weight management, and reducing the risk of chronic diseases such as heart disease [30].

The main macronutrient provided by bread is carbohydrates. All formulations presented a significant difference between samples of this constituent. The malt bagasse flour has some polysaccharides such as xylose, glucose and arabinose, as well as traces of rhamnose and galactose that comprise almost 45% of the total dry weight [31], that can be incorporate into the bread's formulation, increasing the nutritional value.

All formulations are calorie-rich, but whole wheat bread offers a valuable means to increase fiber intake. It is a highly nutritious product containing proteins, carbohydrates, and lipids rich in essential fatty acids, as well as essential micronutrients. In Brazil, the recommended daily intake of dietary fiber is 25 g based on a 2000 kcal diet [28]. Considering that a slice of F20MBF bread contains 50 g, it provides approximately 6.05 g of fiber, which accounts for around 25% of the recommended daily intake of dietary fiber.

Regarding the total mineral content (Table 3), no significant differences were observed among the analyzed formulations. However, it was noted that the increase in MBF in the bread led to decreased levels of K, Mn, and Zn. Malt bagasse contains various minerals, including K, Mg, Ca, P, Fe, and Zn. When incorporated into bread, these minerals contribute to the overall mineral content of the final product. In general, this enrichment enhances the nutritional value of the bread, providing essential minerals that are important for various physiological functions in the body. Particularly, the amount of K increase until 20 % of MBF, that can contribute to a diet that supports cardiovascular health and may help lower blood pressure [32].

In the analysis of both crumb and crust color of the bread (Table 4), differences were observed among the formulations. L* values signify luminosity, ranging from 0 (black) to 100 (white). The only exceptions were samples F30MBF and F40MBF, which yielded lower L* values. The incorporation of MBF and its increased concentration reduced the L* values, resulting in a darker color compared to the control formulation, both in the crumb and crust of the bread.

In the a* parameter (Table 4), it's evident that increasing the MBF concentration in the bread led to higher crumb values, indicating a stronger presence of red color. The a* coordinate, indicating the shift toward red (+5.3 to +6.73), is particularly significant for studying browning because the brown color, resulting from sugar degradation or enzymatic reactions, is a blend of green and red. A more pronounced darkening corresponds to a redder tone, hence a higher a* value. Formulations F10MBF and F20MBF showed no significant difference between them ($p > 0.05$). Conversely, in the b* parameter, values decreased as MBF was added, and the samples tended to exhibit a yellowish hue. The b* coordinate represents the shift toward yellow.

For the colorimetric analysis of the crust (Table 4), it was observed that increasing the MBF concentration resulted in lower a* and b* values. F30MBF and F40MBF did not differ significantly from each other regarding a*, suggesting a prevailing red color among these samples. As for the b* parameter, the samples tended to display a yellowish color. Notably, the F10MBF and F20MBF formulations did not differ from each other. These observations align with the visual characteristics of the bread formulations (Figure 3).

All the samples exhibited positive values in the chromaticity parameter (Table 4), falling within the red and yellow regions. The positive combination of a* and b* values contributes to the characteristic brown color observed in whole-grain breads, especially since brown sugar was included in the bread formulations.

When malt bagasse flour is incorporated into the bread formulation, it introduces additional phenolic compounds into the dough. These compounds, along with those present in other ingredients such as wheat flour, can undergo oxidation more readily during the baking process. The increased availability of phenolic compounds from MBF may lead to a more pronounced browning effect, resulting in the variation in color. This can be associated with the caramelization or Maillard reaction that involves the breakdown of sugars, amino acids at high temperatures. While it occurs concurrently with the Maillard reaction, it predominantly contributes to the development of brown colors and can influence the L* and b* values of bread crusts [33]. Also, can occur protein denaturation that contributes to the development of brown coloration in the crust and can affect the a* value, indicating changes in redness/greenness [32].

Table 3: Physicochemical characterization of the formulations of whole wheel bread - type loaf.

Parameters	SF	F10MBF	F20MBF	F30MBF	F40MBF
Moisture (g/100g)	7.65[a] ± 0.696	8.00[a] ± 0.280	8.26[a] ± 0.320	8.31[a] ± 0.343	7.90[a] ± 0.104
Water activity	0.884[a] ± 0.001	0.897[a] ± 0.001	0.897[a] ± 0.001	0.896[a] ± 0.001	0.892[a] ± 0.001
Protein (g/100g)	8.04[ab] ± 0.230	7.57[b] ± 0.366	8.54[a] ± 0.104	8.12[ab] ± 0.016	7.97[ab] ± 0.340
Lipids (g/100g)	2.87[c] ± 0.001	3.04[bc] ± 0.250	2.99[bc] ± 0.186	3.48[b] ± 0.333	4.73[a] ± 0.063
Total fiber (g/100g)	4.07[d] ±0.204	5.09[c] ± 0.254	6.11[b] ± 0.306	7.13[a] ± 0.356	7.47[a] ± 0.373
Total minerals (g/100g)	1.84[a] ± 0.135	1.96[a] ± 0.076	1.68[a] ± 0.104	1.77[a] ± 0.148	1.70[a] ± 0.001
Carbohydrates (g/100g)	75.50[a] ± 0.181	74.34[b] ± 0.221	72.42[c] ± 0.110	71.19[d] ± 0.176	70.23[e] ± 0.102
K (mg/100g)	177.46[a] ± 5.13	178.99[a] ± 5.120	179.44[a] ± 2.670	121.36[c] ± 0.001	121.15[c] ± 0.440
Ca (mg/100g)	9.57[a] ± 1.120	9.24[a] ± 0.58	9.08[a] ± 1.230	9.26[a] ± 0.286	9.27[a] ± 0.801
Na (mg/100g)	41.23[a] ± 0.250	40.29[a] ± 3.24	41.02[a] ± 4.08	41.34[a] ± 0.001	43.89[a] ± 1.730
Mn (mg/100g)	6.53[a] ± 0.421	5.51[b] ± 0.121	5.20[bc] ± 0.448	4.62[c] ± 0.163	4.59[c] ± 0.090
Zn (mg/100g)	3.59[a] ± 0.295	2.75[b] ± 0.101	2.80[b] ± 0.237	2.20[c] ± 0.278	2.09[c] ± 0.170
Caloric value (Kcal/100g)	359.99[a] ± 0.821	355.00[b] ±1.023	350.75[c] ± 1.232	348.56[c] ± 1.345	355.37[b] ± 1.076

Different letters in the same line indicate statistical difference ($p < 0.05$) between the results by the Tukey test.

Table 4: Shell and crumb color parameters of the formulations of whole wheel bread - type loaf.

Color indices	SF	F10MBF	F20MBF	F30MBF	F40MBF
Shell					
L*	67.68[a] ± 0.187	66.47[b] ± 0.006	61.61[c] ± 0.486	59.81[d] ± 0.025	58.92[d] ± 0.624
a*	5.31[d] ± 0.025	5.64[c] ± 0.060	5.88[c] ± 0.087	6.41[b] ± 0.045	6.73[a] ± 0.205
b*	21.30[a] ± 0.250	21.20[a] ± 0.012	20.30[c] ± 0.012	19.62[d] ± 0.015	20.70[b] ± 0.040
C*	21.95	21.94	21.13	20.64	21.77
Crumb					
L*	57.62[a] ± 0.030	55.55[b] ± 0.217	53.17[c] ± 0.125	51.30[d] ± 0.010	51.65[d] ± 0.170
a*	15.51[a] ± 0.025	15.51[a] ± 0.069	15.31[b] ± 0.010	12.18[c] ± 0.044	8.52[d] ± 0.129
b*	35.27[a] ± 0.038	31.25[b] ± 0.021	31.19[b] ± 0.081	29.19[c] ± 0.086	25.91[d] ± 0.225
C*	38.53	34.88	34.74	31.63	27.27

Different letters in the same line indicate statistical difference ($p < 0.05$) between the results by the Tukey test.

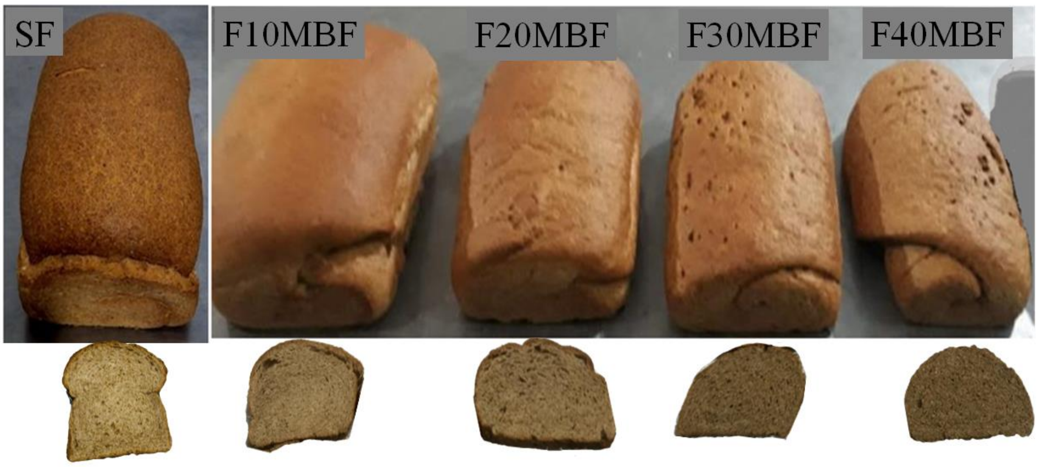

Figure 3: Visual aspect of whole wheel bread – type form shell and core.

3.4 Sensory characteristics of formulations

The sensory analysis involved predominantly female evaluators (60%), primarily in the young age group of 18 to 25 years (44%), as indicated in Table 5. Table 6 presents the average scores obtained from the statistical analysis of sensory data, encompassing general acceptance and purchase intention for the different formulations of whole wheat bread.

Table 5: Profile of evaluators who participated in the sensory analysis.

Demographic characteristics		Distribution* (%)
Sex	Female	60
	Male	40
Age group (years)	18 to 25	44
	26 to 35	28
	36 to 45	16
	Over 46	12

*n = 30 untrained judges.

In the general acceptance scores (Table 6), it's evident that there was no significant difference ($p > 0.05$) among the standard formulation, F10MBF, and F20MBF samples. However, F30MBF and F40MBF differed significantly ($p < 0.05$) from the others. Acceptance ratings ranged from "I liked it slightly" (score 6) to "I liked it a lot" (score 8) on the hedonic scale. Samples with 10% MBF replacement didn't differ significantly ($p > 0.05$) from the standard formulation. Additionally, F20MBF also didn't differ from F10MBF ($p > 0.05$), suggesting that it's possible to incorporate up to 20% MBF into whole wheat bread while maintaining acceptance rates above 81.78%.

Table 6: Average scores for the attribute general acceptance, purchase intention and acceptance index of whole wheel bread – type loaf formulations.

Formulations	General acceptance*1	Purchase intention (%)	Purchase intention score*2
SF	8.04[a]	89.33	4.32[a]
F10MBF	7.60[ab]	84.44	4.20[a]
F20MBF	7.36[b]	81.78	3.32[ab]
F30MBF	6.00[c]	66.67	2.56[b]
F40MBF	5.40[c]	60.00	2.16[b]

*Different letters in the same column indicate statistical difference ($p < 0.05$) between the results by the Tukey test.

Purchase intention scores from the evaluators (Table 6) showed statistically significant differences ($p < 0.05$) between the standard (SF) and F10MBF in comparison to F30MBF and F40MBF. However, there was no significant difference ($p > 0.05$) between F20MBF and the other samples. These scores were associated with categories 2 ("probably would not buy"), 3 ("maybe would buy"), and 4 ("probably would buy").

The PCA results for bread formulations were projected onto an external preference map (Figure 4) using acceptance data and terms assessed in the CATA methodology. Sensory attributes were represented as vectors, with longer vectors indicating a more significant contribution to attribute variability. The first (CP1) and second (CP2) dimensions collectively explained 75.65% of the total variance. Notably, discrimination was observed between whole wheat bread formulations, particularly F30MBF and F40MBF, compared to the standard, F10MBF, and F20MBF formulations.

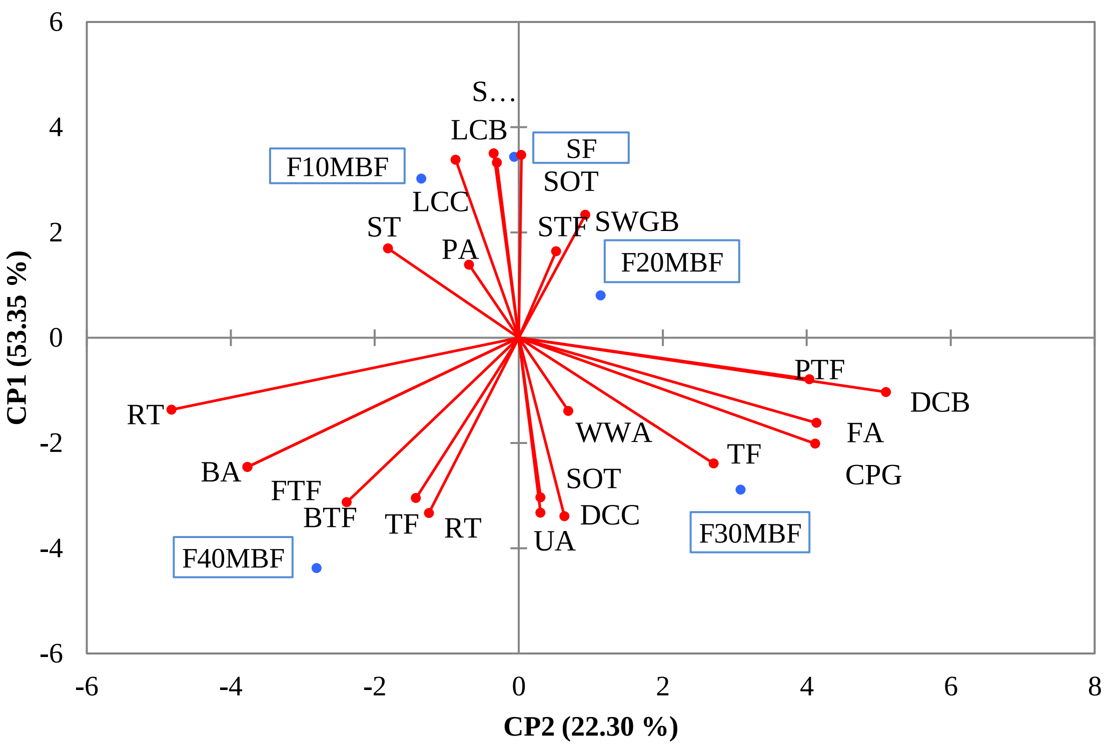

Figure 4: External preference map with distribution of sensory attributes for bread formulations. DCB - Dark colored bark, LCB - Light colored bark, DB - Dry bark, CPG - Crumb with grains, LCC - Light core color, DCC - Dark core color, FA - Fermented aroma, BA - Burnt aroma, PA- Pleasant aroma, SA- Sweet aroma, WWA - Whole wheat aroma, UA- Unpleasant aroma, FTF - Fermented taste/flavor, BTF - Bitter taste/flavor, PTF - Pleasant taste/flavor, STF - Sweet taste/flavor, SWGB - Taste/flavor of whole grain bread, SFT - Salty flavor/taste, WT - Wet texture, DT - Dry texture, ST - Sticky texture, RT - Rubbery texture, SOT - Soft texture, FT - Fibrous texture.

The standard, F10MBF, and F20MBF formulations exhibited a crumb color and light crust, a pleasant sweet aroma, soft texture, and a sweet wholegrain bread flavor. In contrast, the F30MBF had a darker crumb, visible grains, an aroma reminiscent of alcoholic fermentation and whole wheat, a pleasant flavor, and a fibrous texture. However, the F40MBF was notably characterized by its moist, sticky, and rubbery texture, a burnt and unpleasant aroma, a dark crumb color, a bitter taste, and residual alcoholic fermentation. These attributes of F30MBF and F40MBF may be linked to the observed differences in consumer acceptance, as shown in the statistical analysis of the acceptance test (Table 6).

The attributes of dark color and slightly bitter flavor may be related to the high content of free phenolic compounds, peptides, and fatty acids [22] that are characteristic of wholegrain products. Whole wheat bread is also often associated with attributes such as low bread volume, firm and sandy texture, dark and rough crust, and bitter taste [33], which may explain the results found in this work. The attributes related to the term “alcoholic fermented residue” may be associated with a higher percentage of use of MBF, as the flavor can lead the evaluator to remember the sensory characteristics of the drink, which is an alcoholic fermentation drink.

4. CONCLUSION

The incorporation of MBF in whole wheel breads in partial replacement by whole wheat flour in up to 20% generated products with good acceptance, with sensory characteristics/attributes of crumb color and light crust, pleasant aroma, soft texture, and sweet taste similar to whole-wheat flour bread. In addition to relevant nutritional gain, especially in terms of fiber, protein, and potassium.

The reuse of malt bagasse in human food represents a sustainable procedure that should be explored more and more, due to its good nutritional characteristic’s concomitant with its abundant supply. Its good acceptance in breads was confirmed until the addition of 20% of malt bagasse flour, new researches on incorporation in other foods can be explored. In addition, showed a valorization of by-product from malt grains and a transformation into high-quality bread with health-promoting properties.

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