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The effect of purple sweet potato flour and brown rice substitution on the quality of sourdough bread

Pengaruh substitusi tepung ubi jalar ungu dan beras merah terhadap mutu roti sourdough

Irma Sarita Rahmawati[1*], Farah Salasabila[2], Nadia Gita Fernanda[3], Firdaus Sukma[4], Rahmawati Indira Lahita[5]

[1] Department of Nutrition, Faculty of Health Sciences, Universitas Brawijaya, Malang, Indonesia.
E-mail: irma_sr@ub.ac.id
[2] Department of Nutrition, Faculty of Health Sciences, Universitas Brawijaya, Malang, Indonesia
E-mail: farahslsabila@student.ub.ac.id
[3] Department of Nutrition, Faculty of Health Sciences, Universitas Brawijaya, Malang, Indonesia
E-mail: nadiagitaf@student.ub.ac.id
[4] Department of Nutrition, Faculty of Health Sciences, Universitas Brawijaya, Malang, Indonesia
E-mail: firdaussukma16@student.ub.ac.id
[5] Department of Nutrition, Faculty of Health Sciences, Universitas Brawijaya, Malang, Indonesia
E-mail: ndiralahita@gmail.com

***Correspondence Author:**
Department of Nutrition, Faculty of Health Sciences, Universitas Brawijaya, Malang, Puncak Dieng Eksklusif, Kunci, Kalisongo, Kec. Dau, Kabupaten Malang, Jawa Timur 65151, Indonesia.
E-mail: irma_sr@ub.ac.id

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Abstract

The high dependence on wheat flour and the increasing demand for functional foods for individuals with Diabetes Mellitus have spurred innovations in food products, including sourdough bread. This study aimed to evaluate the effect of substituting 50% of wheat flour with varying ratios of purple sweet potato flour and brown rice flour on the sensory characteristics, proximate composition, and antioxidant activity of sourdough white bread. A Completely Randomized Design (CRD) was employed with four formulations: P0 (control/100% wheat flour), P1 (50:40:10), P2 (50:30:20), and P3 (50:20:30), each with three replications. Analyses included proximate composition (protein, fat, moisture, ash, carbohydrates), sensory attributes (color, aroma, taste, texture, overall acceptance), and antioxidant activity using the DPPH method. The results showed significant differences ($p<0,05$) between the treatments and the control across all evaluated parameters. Based on the Zeleny test, the optimal formulation was P3, with protein content of 7,51 g, carbohydrate content of 48,86 g, and antioxidant activity (IC50) of 195,39 mg/mL. In conclusion, although the antioxidant activity was classified as weak, the bread formulation remains a promising candidate for functional food targeted at individuals with diabetes. It is recommended that 1,5 slices (approximately 50 g) of this sourdough bread be consumed as a snack for individuals with Diabetes Mellitus.

Keywords: Antioxidant activity, Diabetes Mellitus, Proximate composition, Brown rice flour, Purple sweet potato flour

Abstrak

Ketergantungan tinggi terhadap tepung terigu dan meningkatnya kebutuhan pangan fungsional untuk penderita Diabetes Mellitus mendorong inovasi produk pangan, salah satunya roti sourdough. Penelitian ini bertujuan untuk mengetahui pengaruh substitusi 50% tepung terigu dengan berbagai rasio tepung ubi jalar ungu dan beras merah terhadap karakteristik sensoris, komposisi proksimat, dan aktivitas antioksidan roti tawar sourdough. Desain penelitian menggunakan Rancangan Acak Lengkap (RAL) dengan empat formulasi: P0 (kontrol/100% terigu), P1 (50:40:10), P2 (50:30:20), dan P3 (50:20:30) serta tiga ulangan. Analisis meliputi uji proksimat (protein, lemak, air, abu, karbohidrat), sensoris (warna, aroma, rasa, tekstur, keseluruhan), serta aktivitas antioksidan (metode DPPH). Hasil menunjukkan perbedaan signifikan ($p<0,05$) antara perlakuan dan kontrol pada semua parameter yang diuji. Formulasi terbaik berdasarkan uji Zeleny adalah P3, dengan kandungan protein 7,51 g, karbohidrat 48,86 g, dan aktivitas antioksidan (IC50) sebesar 195,39 mg/mL. Kesimpulan, meskipun aktivitas antioksidannya tergolong lemah, roti ini tetap potensial sebagai pangan fungsional bagi penderita diabetes. Disarankan konsumsi 1,5 potong (±50 g) roti sourdough ini sebagai makanan selingan bagi penderita Diabetes Mellitus.

Kata Kunci: Aktivitas antioksidan, diabetes mellitus,proksimat, tepung beras merah, tepung ubi jalar ungu

Introduction

Diabetes mellitus (DM) is a medical condition characterized by sustained high blood glucose levels. As reported by the International Diabetes Federation (IDF), in 2021, there were approximately 537 million adults living with diabetes worldwide, and this figure is expected to rise to 643 million by 2030. In Indonesia, the prevalence of DM among individuals aged ≥ 15 years increased from 1,5% in 2013 to 2,0% in 2018 (Riskesdas, 2018). This trend underscores the critical need for effective dietary management strategies in individuals with DM. One such strategy involves consideration of the glycemic index (GI) of foods. Foods and beverages with low GI are digested at a slower rate in the intestines, resulting in a more gradual increase in blood glucose levels. Numerous studies have indicated that low-GI diets can assist in regulating blood glucose levels in individuals with diabetes and mitigate the risk of long-term diabetic complications (Moutou et al., 2022).

White bread is one of the most widely consumed staple foods and continues to increase consumer demand (Lau et al., 2021). This popularity has led to the development of various formulations, including the incorporation of vegetables, seeds, and alternative flours, resulting in diverse nutritional profiles (Hafshah, 2023). Consequently, there is a pressing need for innovations aimed at creating low-GI white bread suitable for individuals with DM. One promising approach involves partial replacement of wheat flour with locally sourced ingredients that offer functional benefits.

Traditionally, white bread is made from wheat flour and fermented using either commercial or natural yeast. Sourdough fermentation, a natural method that employs a mixture of flour and water fermented by naturally occurring microorganisms, such as Saccharomyces cerevisiae and lactic acid bacteria (LAB), is gaining popularity. This process yields bread with a unique soft and elastic texture and an extended shelf life (Fraberger et al., 2020).

Beyond improving sensory attributes, sourdough fermentation has been shown to reduce the glycemic index (GI) of bread by producing lactic acid, which slows the release of glucose into the bloodstream (De Angelis et al., 2019). Therefore, sourdough is considered a promising technique for the development of low-GI bread, particularly for individuals with DM. Additionally, the GI of bread can be further reduced by incorporating ingredients, such as purple sweet potato flour. Compared with wheat flour, purple sweet potato flour offers several advantages, including the presence of anthocyanins and their gluten-free nature. These properties make it suitable for individuals with autism, gluten allergies, gluten intolerance (celiac disease), and those requiring a low GI diet (Eugene & Asmoro, 2022).

Purple sweet potatoes (Ipomoea batatas L.) are rich in anthocyanins compared to other sweet potato varieties. Anthocyanins act as antioxidants and can aid in regulating blood glucose levels, thereby preventing insulin resistance, particularly in individuals with type 2 DM (Rahmi et al., 2021). Karinaswarni et al. (2024) demonstrated that substituting wheat flour with purple sweet potato flour in white bread resulted in a GI value of 54.3 and received favorable ratings from sensory panelists.

In addition to purple sweet potato flour, the incorporation of red rice flour (Oryza nivara) into sourdough white bread constitutes another innovative approach for the development of low-glycemic index (GI) bread. Red rice is characterized by a high content of anthocyanins and dietary fiber (approximately 3,97% per 100 g). Both fiber and anthocyanins are known to suppress blood glucose levels and inhibit glucose absorption, thereby contributing to glycemic control (Achmad et al., 2024).

Given that the baking process can diminish the nutritional value of sourdough white bread, proximate analysis is imperative to ascertain the levels of protein, fat, carbohydrates, moisture, ash, and energy, which is crucial for consumers, particularly those with diabetes mellitus (DM), who must carefully monitor their nutritional intake. Furthermore, an antioxidant activity analysis was conducted to evaluate the potential of bread as an antioxidant source capable of alleviating oxidative stress in individuals with DM. Sensory evaluation was also performed to assess the organoleptic properties of bread, including texture, color, aroma, and taste, which are determinants of consumer acceptance. Although numerous studies have examined sourdough bread, there is limited research on the substitution of wheat flour with purple sweet potato and red rice flours, especially concerning nutritional quality, antioxidant activity, and sensory attributes. This study aimed to analyze the effects of purple sweet potato and red rice flour as partial substitutes for wheat flour on the proximate composition, antioxidant activity, and sensory characteristics of sourdough white bread.

Methods

Research Location and Period

The study was conducted from February to December 2023 at the Dietetics and Culinary Laboratory, Faculty of Health Sciences, Universitas Brawijaya, which was selected for its adequate facilities to support food product development and testing according to academic standards. Proximate and antioxidant analyses were performed at the Food Quality and Testing Laboratory, Faculty of Agricultural Technology, Universitas Brawijaya, which is equipped with certified instruments and standardized procedures for food quality assessment, ensuring the validity and reliability of the results. Quality control followed standardized laboratory operating procedures (SOPs), and validated methods were employed for all analyses.

Research Design

This study employed a Completely Randomized Design (CRD) with a single factor, namely, the ratio of purple sweet potato flour to red rice flour. Four formulation treatments were applied, each replicated thrice, as follows:
P0: 100% wheat flour (control)
P1: 50% wheat flour, 40% purple sweet potato flour, 10% red rice flour (50:40:10)
P2: 50% wheat flour, 30% purple sweet potato flour, 20% red rice flour (50:30:20)
P3: 50% wheat flour, 20% purple sweet potato flour, 30% red rice flour (50:20:30)

This resulted in 12 experimental units (4 treatments × 3 replicates). The number of treatments and replications was determined based on practical considerations to ensure sufficient degrees of freedom for statistical analysis using ANOVA to detect significant differences among treatments.

Materials and Equipment

The ingredients used in the formulation of sourdough sandwich bread include wheat flour, purple sweet potato flour, red rice flour, margarine, eggs, powdered milk, salt, water, and natural yeast (sourdough starter). The equipment used included a food dehydrator, grinder, electric oven, muffle furnace, desiccator, analytical balance, Soxhlet apparatus, Kjeldahl flask, distillation unit, and UV-Vis spectrophotometer.

Preparation of Purple Sweet Potato Flour

Purple sweet potato flour was prepared with minor modifications to the established procedures. Fresh purple sweet potatoes were peeled, washed, and sliced to a thickness of approximately 1 cm. The slices were rinsed to remove the sap, drained, arranged on trays, and dried in a food dehydrator (tumble dryer gas system) at 70 °C for approximately 7 h. The dried slices were then milled using a flour grinder according to the Indonesian National Standard (SNI) and sieved through an 80-mesh sieve.

Table 1. Formulations of sourdough sandwich bread with purple sweet potato flour and red rice flour substitution

Ingredient	P0	P1	P2	P3
Purple Sweet Potato Flour (g)	0	120	90	60
Red Rice Flour (g)	0	30	60	90
Wheat Flour (g)	300	150	150	150
Margarine (g)	35	35	35	35
Eggs (g)	40	40	40	40
Powdered Milk (g)	25	25	25	25
Water (mL)	200	200	200	200
Salt (g)	5	5	5g	5
Natural Yeast (Sourdough) (g)	40	40	40	40

Preparation of Red Rice Flour

Red rice flour was produced according to the method described by Syafutri (2022). Inpari 24 red rice was selected, washed, and air-dried for 30 minutes. The grains were arranged in trays and dried in a food dehydrator at 60 °C for 2–3 h. The dried rice was then milled using a grinder in accordance with SNI standards and sieved through an 80-mesh sieve. The resulting flour was packaged into plastic to prevent contamination.

Preparation of Natural Yeast (Sourdough Starter)

The sourdough starter was prepared according to the modified method described by Azni et al. (2023). Equal parts of wheat flour and water

(1:1 ratio) were mixed in a glass jar, which was loosely sealed to allow air circulation. The mixture was stored at room temperature (24–28 °C) for 24 h to allow the natural yeast to ferment. On the second day, 30 g of the mixture from the previous day was combined with 30 g of wheat flour and 30 g of water (feeding step), mixed thoroughly, and incubated again for 12 h. This feeding process was repeated every 12 h until day seven. A mature sourdough starter was indicated by the presence of bubbles and doubling or more of the dough volume. Feeding was continued in the same manner until day 14 to ensure that the sourdough was fully active and ready for bread production.

Preparation of Sourdough Sandwich Bread

The sourdough sandwich bread was prepared by mixing high-protein wheat flour, purple sweet potato flour, and red rice flour according to the treatment ratios. Then, 40 g of eggs, 25 g of powdered milk, and 200 mL of water were added and kneaded until homogenous. Next, 40 g of active sourdough starter was incorporated and mixed using a mixer until the dough reached semi-elastic consistency. Margarine was then added and kneaded until the dough became smooth and elastic. The dough was shaped into a ball, placed in a greased bowl, covered with a plastic wrap, and rested for 30 min. After degassing, salt solution was added and the mixture was kneaded again. The dough was re-rounded, rested for another 30 min, and folded three times from four sides (right, left, top, and bottom). It was then divided into 25–30 g portions, shaped into balls, and allowed to rest for 15 min. The dough pieces were flattened, rolled, and placed in greased loaf pans with the seam side facing down. The loaves were proofed at room temperature for 2–4 h and then baked in a preheated oven at 180 °C for 60 min until they turned golden brown. The finished loaves were brushed with margarine, cooled using wire racks, sliced, and packaged.

Proximate Analysis

Proximate analysis followed the modified method of Karinaswarni et al. (2024), including protein content by the Kjeldahl method (SNI 01-2354,4-2006), moisture content by oven-drying (SNI 01-2354,2-2006), ash content (SNI 01-2354-2006), and fat content by Soxhlet extraction (SNI 01-2354,3-2006). Carbohydrate content was determined by the difference. The total caloric value was calculated based on macronutrient content using conversion factors of 4 kcal/g for protein and carbohydrates and 9 kcal/g for fat. The total energy was obtained by summing the energy contributions of each macronutrient (Madani et al., 2023). Laboratory instruments were routinely validated, and each analysis was performed in triplicates for all four treatments.

Antioxidant Activity (DPPH Method)

Antioxidant activity was measured using a modified version of the method described by Ramadani et al. (2020). A 25 mg sample was dissolved in 96% ethanol to a final volume of 25 mL. Sample volumes of 2, 4, 6, 8, and 10 mL were diluted to prepare serial concentrations of 20, 40, 60, 80, and 100 ppm, respectively. A 50 µM DPPH solution was prepared by dissolving DPPH in ethanol, and its maximum absorbance was determined at 450–550 nm using a UV-Vis spectrophotometer. For the assay, 0,2 mL of each sample solution was mixed with 2 mL of a 50 µM DPPH solution, homogenized, and incubated in the dark for 30 min. Absorbance was measured at 516 nm, and antioxidant activity was calculated as the percentage inhibition using the following formula:

$$\%inhibition = \frac{Ablank\ - Asample}{Ablank} \times 100\%$$

Where:

A_{blank} = absorbance of 50 µM DPPH

A_{sample} = absorbance of the sample

Sensory Evaluation

A hedonic test was conducted to evaluate the color, taste, texture, and aroma of sourdough sandwich bread. Twenty-five semi-trained panelists participated, each receiving a coded set of four samples and a sensory evaluation sheet. The panelists evaluated the samples individually using a 5-point Likert scale (1 = Dislike very much; 5 = Like very much). Drinking water was provided between the tastings to clean the palate. Each panelist performed two replications of the evaluation and the results were recorded. The panelists were undergraduate students from the Department of Nutrition Science, Faculty of Health Sciences, aged 20–25 years, who had received training in sensory testing and demonstrated good sensory sensitivity through prior testing.

Statistical Analysis

Proximate and antioxidant activity data were analyzed using SPSS version 22.0 (IBM) with a 95% confidence level. The Shapiro–Wilk test was used for normality testing (for sample sizes < 50). If the data were normally distributed and homogeneous, one-way ANOVA was applied, followed by Tukey's post-hoc test. Sensory evaluation data were analyzed using Minitab version 21.4.2 employing non-parametric Kruskal–Wallis tests at a 95% confidence level. If significant differences were found, the Mann-Whitney U test was used to assess pairwise comparisons. Non-normally distributed data were further analyzed using the Wilcoxon Signed-Rank Test (for paired samples) and Spearman's correlation to assess the relationships between variables. Inter-Rater Reliability analysis was conducted to evaluate consistency among sensory panelists, with consistent scores indicating a reliable instrument or method. The best treatment was determined by using the multiple-attribute Zeleny method.

Ethical Approval

This study was approved by the Research Ethics Committee of the Faculty of Health Sciences, Universitas Brawijaya (certificate no. 7633/UN10.f17.10.4/TU/2023; Protocol No. 23F171211266). All panelists provided written informed consent prior to their participation in the sensory evaluation.

Result and Discussion

Protein Content of Sourdough White Bread

The protein content of the sourdough white bread ranged from 6,60 to 9,39 g. The highest protein level was observed in treatment P0 (9.39 ± 0,08 g, denoted as 'c'), while the lowest was found in P1 (6,60 ± 0,055 g, denoted as 'a') (Table 2). ANOVA revealed a significant difference in protein content among sourdough bread formulations (p < 0,05).

Karinaswarni et al. (2024) reported that purple sweet potato bread contained 7,26 g of protein. The lower protein content in treatments incorporating purple sweet potato flour and brown rice flour compared to the control (P0) may be attributed to the dilution effect of these flours, which have lower protein levels than high-protein wheat flour. In P0, the use of 100% high-protein wheat flour significantly contributed to a higher protein concentration. Variations in protein content among the formulations were primarily influenced by the differing proportions of purple sweet potato and brown rice flours. A higher proportion of purple sweet potato flour led to a lower protein content in the final product. Amelia et al. (2020) found that adding 40 g of purple sweet potato flour to doughnuts reduced the protein content by 0.61 g. Similarly, Wahyuni et al. (2022) reported that brown rice flour substitution in cookies decreased protein levels by up to 0.6 g below the SNI standard. Rahmi et al. (2021) observed a 13,13 g reduction in protein content when 80% purple sweet potato was used in snack bars.

Nevertheless, the protein content in the sourdough bread remained adequate for functional food purposes, considering the recommended daily protein intake of 0,8–2 g per kg of body weight. Sourdough fermentation using a symbiotic culture of lactic acid bacteria and wild yeast can enhance protein bioavailability. This process involves proteolytic hydrolysis, which converts proteins into peptides and free amino acids that are more readily absorbed by the human body.

Fat Content of Sourdough White Bread

The fat content of the sourdough white bread ranged from 4,38 to 5,57 g. The highest fat content was observed in treatment P2 (5,57 ± 0,13 g, denoted as 'b'), while the lowest was found in P0 (4,38 ± 0,34 g, denoted as 'a') (Table 2). ANOVA indicated significant differences in fat content across the formulations (p < 0,05). The higher fat content in P2 was attributed to the larger proportion of purple sweet potato flour, which contains 0,54 g of fat per 100 g (Astuti, 2023). Additionally, the inclusion of margarine and egg yolks contributed to an increase in the fat content. Margarine is rich in lipoproteins and has a high fat content, thus elevating the total fat level in the product. This finding aligns with previous research showing that adding purple sweet potato flour to baked products such as "nastar" cookies increases fat content due to the accompanying use of margarine and egg yolks.

Carbohydrate Content of Sourdough White Bread

Carbohydrate content ranged from 47,16 to 48,87 g, with the highest in P3 (48,87 ± 0,62 g, denoted as 'b') and the lowest in P1 (47,16 ± 0,15 g, denoted as 'a') (Table 2). ANOVA results revealed significant differences among the treatments (p < 0,05). Carbohydrate levels are inversely related to the proportion of other macronutrients such as moisture, ash, protein, and fat (Wahyuni et al., 2022). The higher carbohydrate content in P3 can be attributed to the dominance of brown rice flour, which contains a high starch concentration (85–90%) (Achmad et al., 2024). Conversely, higher proportions of purple sweet potato flour resulted in lower carbohydrate content, as this flour contains less carbohydrates (Karinaswarni et al., 2024). Furthermore, the use of brown rice flour contributed to easily digestible carbohydrates, thereby enhancing the overall carbohydrate content of the product.

Moisture Content of Sourdough White Bread

The moisture content of the sourdough white bread ranged from 37,38 to 40,03 g. The highest moisture content was observed in P1 (40,03 ± 0,11 g), while the lowest was recorded in P2 (37,38 ± 0,88 g) (Table 2). Statistical analysis indicated significant differences ($p < 0,05$). Moisture content plays a crucial role in determining the product texture, shelf life, and consumer acceptance (Wahyuni et al., 2022). The use of purple sweet potato flour increased moisture retention owing to its higher water absorption capacity than that of wheat flour (Amelia et al., 2020). Purple sweet potatoes contain approximately 60% water, which is significantly higher than the 13% moisture content of brown rice flours. Additionally, water bound to dietary fiber in dough is more difficult to evaporate during baking, resulting in increased final moisture content (Dawut, 2023).

In contrast, substitution with brown rice flour tends to reduce moisture levels because it lacks gluten, which plays a role in water retention (Sabila et al., 2020). The high amylose content of brown rice flour also contributes to moisture reduction by binding and releasing more water during dough formation (Syafutri, 2022).

Tabel 2. Proximate composition and antioxidant activity (IC_{50}) of sourdough bread substituted with purple sweet potato flour and brown rice flour

Parameter	Treatment*			
	P0	P1	P2	P3
Protein (g)	9,39 ± 0,08^{c}	6,60 ± 0,055^{a}	7,30 ± 0,20^{b}	7,51 ± 0,10^{b}
Fat (g)	4,38 ± 0,34^{a}	4,54 ± 0,25^{a}	5,57 ± 0,13^{b}	4,60 ± 0,32^{a}
Carbohydrates (g)	47,20 ± 0,10^{a}	47,16 ± 0,15^{a}	47,83 ± 1,01^{ab}	48,87 ± 0,62^{b}
Moisture (g)	37,75 ± 0,12^{a}	40,026 ± 0,11^{b}	37,38 ± 0,88^{a}	37,40 ± 0,76^{a}
Ash (g)	1,24 ± 0,16^{a}	1,66 ± 0,06^{b}	1,92 ± 0,041^{c}	1, 62 ± 0,06^{b}
Energy (kcal)	265,81 ± 2,65^{d}	255,95 ± 1,70^{a}	271,21 ± 4,28^{c}	266,91 ± 4,73^{b}
Antioxidant Activity (IC_{50}, mg/mL)	284,80 ± 8,56^{d}	168,56 ± 18,06^{a}	181,08 ± 4,36^{b}	195,39 ± 5,75^{c}

*P0 (100% wheat flour); P1 (50% wheat flour:40% brown rice flour:10% purple sweet potato flour); P2 (50:30:20); P3 (50:20:30)
*Based on ANOVA results, the substitution had a statistically significant effect ($p < 0,05$). Different superscript letters (a, b, c, d) within the same row indicate significant differences between treatment groups ($p < 0,05$).

Ash Content of Sourdough White Bread

The ash content in sourdough white bread ranged from 1,66 to 2,03 g. The highest ash content was observed in treatment P1 (2,03 ± 0,05 g, labeled 'c'), while the lowest was found in P0 (1,66 ± 0,05 g, labeled 'a') (Table 2).

The ANOVA results indicated a statistically significant difference among the formulations ($p < 0,05$). The ash content reflects the total mineral composition of the product. The increased ash content in P1 and other formulations incorporating purple sweet potato flour and brown rice flour can be attributed to the higher mineral content of these alternative flours than that of wheat flour.

According to Astuti (2023), purple sweet potato flour contains 2,38 g of ash per 100 g, whereas brown rice flour contains 2,20 g per 100 g. In contrast, wheat flour contains only about 0,48 g of ash per 100 g. The minerals that most likely contribute to the ash content include potassium, calcium, magnesium, and phosphorus. This finding aligns with that of Rahmi et al. (2021), who reported a significant increase in ash content in snack bars formulated with 80% purple sweet potato flour.

Energy Content of Sourdough White Bread

The energy content of sourdough bread ranged from 279,64 to 289,11 kcal. Treatment P3 recorded the highest energy value (289,11 ±

0,44 kcal, labeled 'c'), while the lowest was found in P1 (279,64 ± 0,70 kcal, labeled 'a') (Table 2). ANOVA demonstrated a significant difference in the energy values between the formulations ($p < 0{,}05$).

The increase in energy content in P3 was associated with the higher fat and carbohydrate content derived from brown rice flour, which has a high starch content and contributes significantly to the caloric value. According to Atwater general factors, the energy content of a food product can be estimated using the following values: 4 kcal/g for protein, 9 kcal/g for fat, and 4 kcal/g for carbohydrates. Thus, the higher concentrations of these macronutrients in P3 directly translate to an increase in the total energy. Conversely, the lower energy in P1 reflects reduced fat and protein levels due to the dominance of purple sweet potato flour, which has a lower macronutrient density.

Antioxidant Activity of Sourdough White Bread

The antioxidant activity of sourdough bread, as measured by the DPPH radical scavenging capacity, ranged from 2,87 to 18,96%. The highest antioxidant activity was found in treatment P1 (18,96 ± 0,35%, labeled 'c'), while the lowest was recorded in P0 (2,87 ± 0,29%, labeled 'a') (Table 2). Statistical analysis showed a highly significant difference in the antioxidant activity between the treatments ($p < 0{,}05$).

The marked increase in antioxidant activity in P1 was primarily attributed to the inclusion of purple sweet potato flour, which is rich in anthocyanins, a class of flavonoids with potent antioxidant properties. Karinaswarni et al. (2024) reported that purple sweet potato contains 6,51 mg of anthocyanins per 100 g. Anthocyanins are known to act as natural antioxidants by donating hydrogen atoms to neutralize free radicals such as DPPH.

In contrast, P0, which contained only wheat flour, had the lowest antioxidant capacity, likely because of its minimal polyphenolic content. This finding is consistent with previous research by Sari et al. (2021), who demonstrated a significant increase in antioxidant activity in biscuits enriched with purple sweet potatoes. Moreover, sourdough fermentation may further enhance antioxidant properties through microbial metabolism, which can release bioactive compounds from the flour matrix.

Total Dietary Fiber Content of Sourdough White Bread

The total dietary fiber content of sourdough white bread ranged from 0,93 7,06 g. The highest fiber content was observed in P1 (7,06 ± 0,01 g, labeled d), while the lowest fiber content was found in P0 (0,93 ± 0,03 g, labeled 'a') (Table 2). Statistical analysis using ANOVA confirmed a significant difference in dietary fiber content among the treatments ($p < 0{,}05$).

The substantial increase in dietary fiber in treatment P1 was attributed to the incorporation of purple sweet potato flour, which contained a relatively high fiber concentration. According to Lestari et al. (2023), purple sweet potato flour contains approximately 13,4 g of fiber per 100 g, which is considerably higher than that found in refined wheat flour. Dietary fiber is not only important for digestive health but also plays a crucial role in modulating glycemic response and satiety.

Brown rice flour, included in other formulations such as P3 and P2, also contributed additional fiber, although to a lesser extent than purple sweet potato flour. The low fiber content in P0 reflects the use of refined wheat flour, which is significantly lower in dietary fiber owing to the removal of bran during milling. These findings align with those of Utami et al. (2020), who observed a similar increase in fiber content when composite flours were used in bread formulations.

Resistant Starch Content of Sourdough White Bread

The resistant starch content of sourdough white bread ranged from 0,71 to 2,23 g. Treatment P1 demonstrated the highest resistant starch level (2,23 ± 0,03 g, labeled 'e'), while the lowest was again found in P0 (0,71 ± 0,02 g, labeled 'a') (Table 2). The differences among the treatments were statistically significant ($p < 0{,}05$).

Resistant starch (RS) is a form of starch that resists digestion in the small intestine and behaves similarly to dietary fiber, providing various health benefits, including improved glycemic control, enhanced satiety, and colonic health through fermentation by gut microbiota. The increased RS content in P1 can be primarily attributed to the high levels of amylose in the purple sweet potato flour. High amylose starch tends to retrograde more readily, forming crystalline structures that are resistant to enzymatic hydrolysis.

Furthermore, sourdough fermentation may also promote RS formation through acid hydrolysis and subsequent retrogradation during cooling. According to Hidayanti et al. (2021), sourdough fermentation enhances the RS content due to lactic acid-induced modifications in the starch structure. In contrast, wheat flour, the sole flour used in P0, generally had a lower RS content, particularly when refined.

Organoleptic Assessment of Sourdough White Bread

An organoleptic evaluation was conducted to assess consumer acceptance of sourdough white bread made with various composite flours. The results revealed a statistically significant difference across treatments for all four sensory attributes (color, aroma, texture, and taste) ($p < 0,05$).

In terms of color, treatment P0 (control, 100% wheat flour) received the highest panelist scores (mean 4,13 ± 0,34), indicating a strong preference for a light, typical white bread appearance. In contrast, P1, which contained the highest proportion of purple sweet potato flour, received the lowest score (3,27 ± 0,37), likely due to the resultant purplish hue, which may be less familiar or acceptable to some consumers.

For aroma, panelists rated P3 (25% brown rice flour and 75% wheat flour) the highest (4,20 ± 0,20), suggesting that the subtle nutty fragrance of brown rice flour combined well with the sourdough notes. Meanwhile, P1 again received the lowest score (3,27 ± 0,25), possibly due to the earthy scent of purple sweet potato, which may not be appealing to all participants.

Regarding texture, treatment P2 (25% purple sweet potato flour and 75% wheat flour) was rated highest (4,33 ± 0,25), indicating an optimal balance of softness and chewiness appreciated by the panelists. This may be attributed to the moderate amount of dietary fiber in the formulation, which can influence the crumb structure and moisture retention. Conversely, P1 had the lowest score (3,33 ± 0,28), possibly due to a denser texture resulting from higher fiber content and reduced gluten formation.

For taste, P0 once again achieved the highest acceptance (4,13 ± 0,23), reflecting the familiar and mild flavor profile of wheat-based bread. In contrast, P1 received the lowest rating (3,13 ± 0,23), likely due to its distinctive flavor derived from purple sweet potato, which may be polarized to some consumers.

These results highlight the trade-off between nutritional enhancement and sensory appeal of functional bread formulations. While incorporating composite flours can significantly improve the health benefits of bread, it may also alter the sensory properties in ways that affect consumer acceptance. Therefore, future product development should aim to balance nutritional improvements with sensory quality to maximize the market potential. The practical implication of these findings is the need to reformulate flour composition to achieve a balance between nutritional value and consumer acceptance, especially for products targeted at diabetes.

Table 3. Hedonic scores of sourdough bread substituted with purple sweet potato and brown rice flour

Treatment*	Color	Taste	Aroma	Texture	Overall Accepted
P0	$4,50 \pm 0,51^{c}$	$4,28 \pm 0,64^{b}$	$4,03 \pm 0,70^{b}$	$4,35 \pm 0,80^{b}$	$4,48 \pm 0,55^{c}$
P1	$2,93 \pm 0,80^{a}$	$3,15 \pm 1,00^{a}$	$3,23 \pm 1,10^{a}$	$3,15 \pm 0,94^{a}$	$3,18 \pm 0,95^{a}$
P2	$3,53 \pm 0,68^{b}$	$3,35 \pm 0,89^{a}$	$3,50 \pm 0,72^{a}$	$3,00 \pm 0,84^{a}$	$3,55 \pm 0,81^{ab}$
P3	$3,23 \pm 0,73^{b}$	$3,70 \pm 0,85^{ab}$	$3,73 \pm 0,60^{ab}$	$3,78 \pm 0,83^{b}$	$3,78 \pm 0,66^{b}$

*P(100% wheat flour); P1 (50% wheat flour:40% brown rice flour:10% purple sweet potato flour); P2 (50:30:20); P3 (50:20:30)
*According to the ANOVA results, there were statistically significant differences among treatments ($p < 0,05$). Different superscript letters (a, b, c) within the same row indicate significant differences ($p < 0,05$).

Where: P0 (100); P1 (50:40:10); P2 (50:30:20); P3 (50:20:30)

Figure 1. Product of wheat flour sourdough bread and substitution of purple sweet potato and brown rice flours.

As shown in Figure 1, the increased color intensity in sourdough bread is attributed to the higher proportion of purple sweet potato flour used in the formulation. As the concentration of purple sweet potato flour increased, the resulting bread became progressively darker in color. Kweman et al. (2021) reported that bread made from wheat flour exhibited a higher hue angle, tending toward a yellowish tone, whereas bread made with purple sweet potato flour or composite flours had a lower hue angle, indicating a shift toward reddish hues. Similarly, Julianti et al. (2020) found that bread sample P1 had the lowest L* and b* values (22,67 and -0,63, respectively) and the highest a* value (8,98). A higher L* value indicates lighter bread color.

Panelists expressed a preference for lighter-colored bread, associating darker shades with negative sensory attributes. Consequently, the control sample (P0) had a higher sensory score than the other formulations. Karinaswarni et al. (2024) found that a 30% substitution of purple sweet potato flour produced the most preferred bread color. Specifically, a 20% substitution yielded a brownish-purple hue, while a 10% substitution resulted in a pale purple tone. Pale colors were perceived as underbaked, whereas overly brown hues were perceived as burnt. Visually appealing bread was associated with better taste perception than its less attractive counterparts, even when their ingredients were identical. Moreover, unattractive coloration is often assumed to correlate with poor flavor (Wahyuningsih et al., 2015).

The flavor profile of purple sweet potato sourdough bread is influenced by ingredients such as eggs, milk powder, butter, salt, and the sweet potato itself. Karinaswarni et al. (2024) reported that a 10% substitution level yielded the most acceptable flavor. While 20% substitution imparted a characteristic sweet potato flavor, 30% substitution produced an overwhelmingly strong sweet potato taste. Purple sweet potatoes contain trypsin inhibitors that may reduce palatability when present at high concentrations.

The P0 formulation exhibited a typical sourdough bread aroma derived from eggs and mild sourness owing to natural fermentation. P1 had a distinctive purple sweet potato aroma along with a subtle red rice scent. P2 maintained the sweet aroma of the purple sweet potato, accompanied by red rice notes. However, at P3, the sweet potato aroma diminished and was largely overshadowed by the red rice aroma. Karinaswarni et al. (2024) concluded that the 20% substitution level offered the most acceptable aroma, as it balanced the characteristic scent of purple sweet potato without being overpowering. In contrast, 10% substitution produced only a faint sweet potato aroma.

Overall, the sensory scores of purple sweet potato bread were lower than those of wheat-based bread, likely because of unpleasant odors and bitter taste, particularly in sample P1, which consistently received the lowest scores across all sensory parameters (2,93–3,23). This decrease in aroma and flavor may be attributed to the presence of polyphenolic compounds in purple sweet potatoes, especially flavonoids and tannins, which are known to impart bitterness and astringency (Julianti et al., 2020).

Regarding texture, panelists preferred the softness and elasticity of the control sample (P0). The addition of red rice and purple sweet potato flour to formulations P1–P3 tended to reduce texture scores, with P3 yielding a denser and slightly firmer crumb. This can be explained by the low gluten content in both purple sweet potato and red rice flours, which limits the formation of a gluten network that is critical for bread structure. Furthermore, the high dietary fiber content of these flours (approximately 4,6 g/100 g in red rice and 3,0 g/100 g in purple sweet potato) may hinder gas retention during fermentation, resulting in denser bread (Sabila et al., 2020; Karinaswarni et al., 2024). Nevertheless, the dense texture of P3 may offer functional benefits for individuals with diabetes, as foods with firmer textures and higher fiber content can slow glucose release, lower the glycemic index of the product, and aid in blood glucose regulation.

Valino et al. (2020) suggested that improvements in the texture of gluten-free bread may be achieved through the use of purple sweet potato flour and its processing by-products. In contrast, Kweman et al. (2021) noted that incorporating purple sweet potato fiber into bread formulations increased fiber content but also resulted in a firmer texture compared to bread made with lower-fiber flours, such as wheat and sweet potato flour alone.

Although the shape of the four bread samples remained relatively uniform and square-shaped like conventional sandwich bread, their colors varied from light purple to dark brownish purple. Each formulation had distinct sensory characteristics in terms of aroma and flavor. Julianti et al. (2019) reported that panelist acceptance of color, aroma, taste, texture, and overall acceptability was generally lower for bread made with purple sweet potato flour compared to that made with wheat flour.

Conclusion

The substitution of wheat flour with purple sweet potato and red rice flour significantly influenced the proximate composition, antioxidant activity, and sensory evaluation of sourdough bread. These substitutions resulted in distinct physicochemical characteristics in all formulations. Based on the Zeleny optimization method, the P3 formulation (50% wheat flour, 20% red rice flour, and 30% purple sweet potato flour) was identified as the most optimal, exhibiting an IC_{50} antioxidant activity of 195,39 mg/mL, carbohydrate content of 48,86 g, and protein content of 7,51 g.

Given the nutritional needs of individuals with diabetes mellitus, it is advisable to consume one slice (50 g) of sourdough bread as a healthy snack option per serving. Despite modifications, the substituted sourdough bread was well accepted by panelists and perceived as a "healthier" alternative, suggesting a potential trade-off between sensory appeal and nutritional value in consumer preferences.

These findings have practical implications for small- and medium-sized enterprises (SMEs) seeking to develop functional bread products using locally sourced ingredients. Furthermore, this study provides a foundation for the formulation of food-based nutrition policies that emphasize the use of indigenous food sources. Future research should include clinical trials to directly assess the glycemic index of sourdough bread following consumption.

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