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Development of White Bread Made from Sorghum Flour, Cassava, Arrowroot, and Red Spinach Extract as a High-Fiber Functional Food

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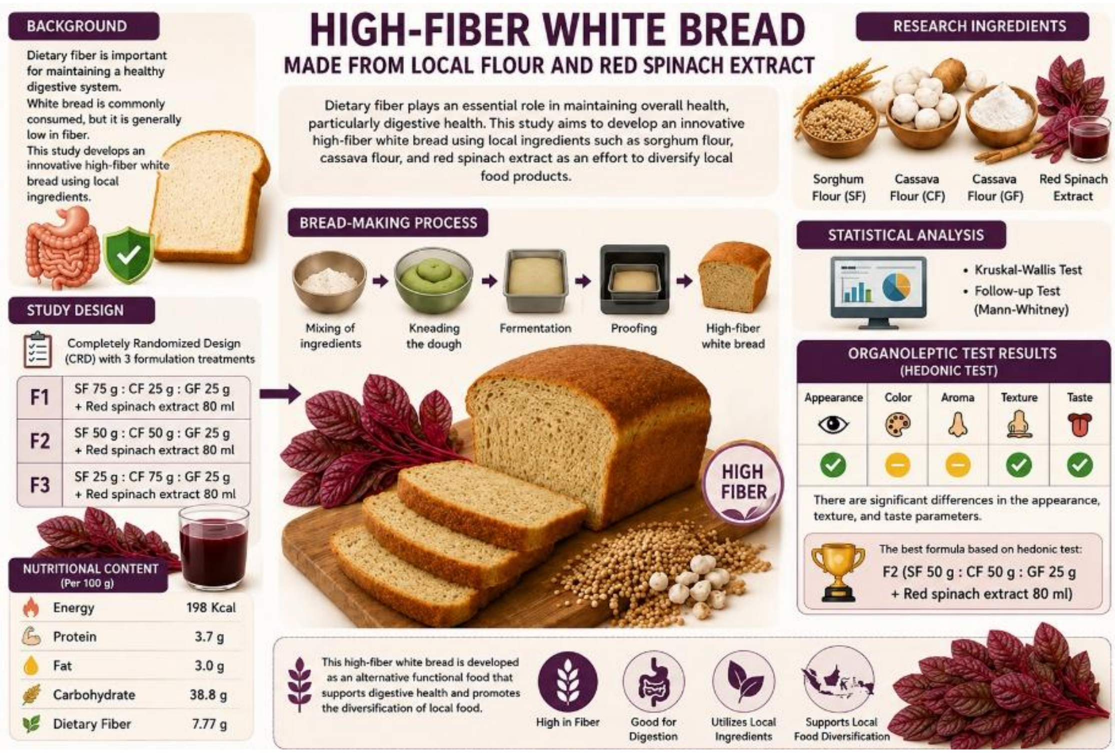
ABSTRACT

Dietary fiber is essential for digestive health, yet conventional wheat-based white bread is low in fiber and unsuitable for gluten-intolerant individuals. This study developed a high-fiber, gluten-free white bread using sorghum, cassava, and arrowroot flours combined with red spinach extract, with psyllium husk added to replicate gluten's viscoelastic properties and improve dough structure and texture. Using a Completely Randomized Design, three formulations were tested—F1 (sorghum 75 g : cassava 25 g : arrowroot 25 g), F2 (sorghum 50 g : cassava 50 g : arrowroot 25 g), and F3 (sorghum 25 g : cassava 75 g : arrowroot 25 g)—each with 80 ml red spinach extract and psyllium husk. Organoleptic testing (Kruskal-Wallis and Mann-Whitney) revealed significant differences in appearance, texture, and taste, while color and aroma were not significantly different. Formulation F2 was most preferred, containing per 100 g: 198 kcal, 3.7 g protein, 3.0 g fat, 38.8 g carbohydrates, and 7.77 g fiber. This gluten-free, high-fiber bread presents a promising healthier alternative that supports local food diversification and meets the needs of gluten-sensitive consumers.

Key Messages:

- This study presents a novel gluten-free white bread formulated from a combination of sorghum, cassava, and arrowroot flour with red spinach extract, using psyllium husk to replace gluten functionality. The selected formulation met regulatory criteria for a high-fiber claim (7.77 g/100 g), offering a practical alternative to support wheat import substitution and address Indonesia's persistent dietary fiber gap.
- Formulation F2 (50 g sorghum : 50 g cassava : 25 g arrowroot) was selected as the best formulation due to its soft, uniform texture and highest hedonic scores for appearance, texture, and taste. The balanced sorghum, cassava, and arrowroot ratio, combined with psyllium husk as a gluten substitute, improved dough elasticity and crumb structure, while the bread retained a high dietary fiber content of 7.77g per 100g.

GRAPHICAL ABSTRACT



INTRODUCTION

Dietary fiber is a complex carbohydrate found in plant cell walls that is resistant to enzymatic breakdown and absorption in the human digestive system, yet it plays a vital role in maintaining health, preventing disease, and supporting a balanced diet (1). Based on water solubility, dietary fiber is categorized into two types: insoluble fiber, which does not dissolve in water and cannot form a gel, and soluble fiber, which dissolves in water and is capable of forming a gel within the digestive tract (2).

Dietary fiber intake among the Indonesian population remains relatively low, averaging only 10–14 grams per day according to the 2018 Basic Health Research/Riskesdas (Indonesian Ministry of Health), a finding consistent with (1), who reported that intake falls below the WHO's minimum recommendation of 10.5 grams per day, despite the WHO's ideal target of 25–30 grams per day. This insufficient fiber consumption is considered a contributing factor to various diseases, including diabetes mellitus (3), as fiber plays a key role in regulating glucose absorption into the bloodstream, supporting digestive health, and promoting satiety that helps control appetite and reduce diabetes risk (4).

A shift in public awareness has redefined eating as not merely a means of satisfying hunger but also a way to support physical health, thereby increasing demand for food products offering additional physiological benefits (5). One widely recognized category of such products is baked goods, which are flour-based and prepared through baking (6), with white bread emerging as a particularly popular choice among Indonesians, evidenced by a per capita consumption of 18.4 kg in 2022 (7), largely owing to its practicality as a breakfast staple and snack option. White bread itself is typically produced from wheat flour through a yeast fermentation process (8).

White bread is typically made from wheat-based flour without added flavorings (9); however, since wheat cannot be cultivated in Indonesia's tropical climate, the country relies heavily on imports to meet its wheat demand (10), having become the world's largest wheat importer during 2020–2022 with a total volume of 12.9 million metric tons (7). To reduce this import dependence, various food innovations have explored local raw material diversification, including sorghum and cassava flour as wheat flour alternatives, a strategy further supported by the still-low consumption of local foods such as legumes, tubers, and vegetables/fruits—averaging only 25 g, 41.4 g, and 231.8 g per capita per day, respectively, well below the recommended 38 g, 108 g, and 269 g per capita per day (11).

Sorghum flour (*Sorghum bicolor L. Moench*) holds significant potential as a wheat flour substitute in

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plain bread production, being gluten-free and high in fiber, which makes it suitable for various processed foods such as noodles, bread, and pastries (12). Its dietary fiber content reaches 8.12%, relatively high compared to other cereals like rice and wheat (8), with every 100 grams of sorghum flour containing 74.6 grams of carbohydrates, 6.3% crude fiber, 11.3 grams of protein, and 3.5 grams of fat (13). Sorghum flour was selected as the primary base of this formulation precisely because of its naturally gluten-free character combined with its comparatively high fiber content, making it an ideal foundation for developing a functional, high-fiber bread without relying on wheat.

Cassava flour (*Manihot esculenta Crantz*), a local ingredient made from dried and ground cassava, is characterized by its brownish-white color and distinctive cassava aroma, making it suitable for use in plain bread production (14), with every 100 grams containing 345 calories, 2.4 grams of protein, 0.4 grams of fat, 83.1 grams of carbohydrates, and 6.7 grams of dietary fiber (15). Cassava flour was incorporated into the formulation for its high carbohydrate content and mild cassava flavor, which contributes positively to the texture and volume of the resulting bread. To further enhance the fiber content of the bread developed in this study, spinach extract was incorporated as an additional ingredient, serving both as a fiber source and a natural colorant for food products such as bread, noodles, and cookies, given that every 100 grams of fresh red spinach contains 6.3 grams of carbohydrates, 2.2 grams of protein, and 2.2 grams of dietary fiber (15). Beyond its nutritional contribution, spinach extract also imparts a pale green hue that visually distinguishes the product while enhancing its overall nutritional profile.

Arrowroot flour (*Maranta arundinacea L*.), derived from processed garut tubers (16), is a local food ingredient with relatively high carbohydrate content, offering potential as a wheat flour alternative (17), with every 100 grams containing 355 calories, 0.7 grams of protein, 0.2 grams of fat, 85.2 grams of carbohydrates, and 0.4 grams of dietary fiber (15). Arrowroot flour was added in a relatively small proportion to improve the smoothness and elasticity of the dough, owing to its high starch content and fine particle structure, which help bind the other flours into a more cohesive matrix.

Since sorghum, cassava, and arrowroot flours are naturally gluten-free, the resulting dough lacks the viscoelastic network needed for gas retention and structural integrity. Psyllium husk was therefore added, as its gel-forming properties upon hydration mimic gluten's elastic network, improving dough workability, gas retention, and crumb structure. The interaction between the starch granules of these flours and the psyllium husk gel is expected to produce a more stable dough matrix, resulting in bread with better texture, softness, and volume despite the absence of gluten. Accordingly, this study on developing gluten-free, high-fiber white bread from sorghum, cassava, and arrowroot flour combined with red spinach extract is important, as it supports wheat import reduction, local food diversification, and the growing trend toward functional and healthy foods in Indonesia.

METHODS

This study used an experimental method with a completely randomized design (CRD) to test three white bread formulations based on sorghum flour, gaplek flour, and garut flour in different ratios (F1 = 75:25:25, F2 = 50:50:25, F3 = 25:75:25), each of which had 80 ml of red spinach extract and 5 g of psyllium husk added per formulation. The study was conducted from January to April 2026 at three locations: the Dietetics Laboratory and the IPB Vocational School Building (production process and organoleptic testing) and the PT Saraswanti Indo Genetech Laboratory (proximate analysis and dietary fiber analysis). The study sample consisted of 40 semi-trained panelists from the Food Service Industry Management and Nutrition Study Program at the IPB Vocational School, selected through purposive sampling based on specific criteria (healthy, not colour-blind, having taken or currently taking a sensory evaluation course, and having no allergies to the study ingredients). This number of panellists complies with the provisions of SNI 01-2346-2006 and previous studies.

Data collection was conducted through hedonic and hedonic quality testing using a 7-point Likert scale for five organoleptic parameters (appearance, colour, texture, aroma, and taste), along with proximate and dietary fiber analysis of the selected formulation. Data were analyzed using Microsoft Excel 2021 and SPSS 27, starting with the Shapiro-Wilk normality test; since data were not normally distributed, analysis proceeded with the Kruskal-Wallis test, followed by the Mann-Whitney post-hoc test and descriptive percentage analysis of panellists' preferences.

The research stages comprised: (1) preparation of cassava flour, (2) preparation of sorghum flour, (3) preparation of red spinach extract using 66 g of stemless red spinach blended with 240 ml of water at 40°C

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(sufficient for all three formulations), and (4) preparation of plain bread through mixing, fermentation, shaping, and baking at 180°C for 50 minutes, with 5 g of psyllium husk added per formulation as a gluten substitute to support dough elasticity and structural stability.

CODE OF HEALTH ETHICS

This study has received ethical approval from the IPB University Health Research Ethics Committee under number 2343/IT3.KEP-IPB/SK/2026. Each participating panellist provided written informed consent before taking part in the organoleptic testing.

RESULTS

The white bread products developed in this study are made from sorghum flour, cassava flour, arrowroot flour, and red spinach extract, with the aim of producing a high-fiber, gluten-free product (Figure 1). Three formulations were tested in this study with varying proportions of sorghum flour and cassava flour: F1 (sorghum 75 g : cassava 25 g : arrowroot 25 g), F2 (sorghum 50 g : cassava 50 g : arrowroot 25 g), and F3 (sorghum 25 g : cassava 75 g : arrowroot 25 g), as shown in Figure 1.

Figure 1. Formulation of white bread made with sorghum flour, cassava, arrowroot, and red spinach extract

The hedonic test involved 40 semi-trained panellists who rated five parameters (appearance, colour, texture, aroma, and taste) using a 7-point Likert scale. The average results of the hedonic test are presented in Table 1.

Table 1. Results of the hedonic test

Parameters	Mean Value of the Hedonic Test			
	F1	F2	F3	*P-value*
Appearance	5.15 ± 1.40^{ab}	5.65 ± 1.18^{a}	4.72 ± 1.35^{b}	0.009*
Color	4.85 ± 1.36^{a}	5.23 ± 1.33^{a}	4.68 ± 1.30^{a}	0.165
Texture	4.15 ± 1.40^{b}	4.93 ± 1.30^{a}	4.87 ± 1.62^{a}	0.034*
Aromatic	3.83 ± 1.48^{a}	4.30 ± 1.47^{a}	4.28 ± 1.61^{a}	0.250
Taste	3.75 ± 1.49^{b}	4.65 ± 1.67^{a}	5.13 ± 1.36^{a}	<0.001*
Average total	4.34	4.95	4.73	-

Notes:
*p<0.05 based on the Kruskal-Wallis test
1 = strongly dislike; 2 = dislike; 3 = somewhat dislike; 4 = neutral; 5 = somewhat like; 6 = like; 7 = strongly like
a.b = identical letter codes indicate no significant difference at the 5% significance level of the Kruskal-Wallis test

Based on Table 1, the results of the Kruskal-Wallis test showed significant differences in the parameters of appearance, texture, and taste among the formulations, while colour and aroma did not show significant differences.

The results of the panellists' preference percentage intervals for each parameter are shown in order in Figure 2 (appearance, range 67.5%–80.7%), Figure 3 (colour, range 66.8%–74.6%), Figure 4 (texture, range 59.0%–70.4%), Figure 5 (aromatic, range 54.6%–61.4%), and Figure 6 (taste, range 53.6%–73.2%). A follow-up Mann-Whitney test showed that for the appearance parameter, F2 differed significantly from F3; for the texture parameter, F1 differed significantly from F2 and F3; and for the taste parameter, F1 differed significantly from F2 and F3.

The results of the hedonic quality test, which assessed the product's specific sensory characteristics, are presented in Table 2.

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Table 2. Results of the hedonic quality test

Parameters	Mean Value of the Hedonic Quality Test			
	F1	F2	F3	*P-value*
Appearance	5.25 ± 1.19[a]	5.53 ± 1.10[a]	4.68 ± 1.26[b]	0.008*
Color	3.55 ± 1.15[a]	4.50 ± 0.93[b]	5.70 ± 1.04[c]	<0.001*
Texture	3.90 ± 1.23[a]	4.23 ± 1.20[a]	4.53 ± 1.69[a]	0.087
Aromatic	3.68 ± 1.36[a]	3.98 ± 1.27[a]	4.22 ± 1.42[a]	0.161
Taste	4.15 ± 1.21[a]	4.68 ± 1.07[b]	5.35 ± 0.94[c]	<0.001*
Average total	4.10	4.58	4.89	-

Notes:
*p<0.05 from the Kruskal-Wallis test
a.b.c = identical letter codes indicate no significant difference at the 5% level according to the Kruskal-Wallis test

Based on Table 2, the mean values of the hedonic quality test for each treatment (F1, F2, F3) differed. The results of the Kruskal-Wallis test showed significant differences in the parameters of appearance, color, and taste among the three formulations.

F2 was selected as the best formulation because it received a higher average likability score (hedonic test) than F3, indicating that F2 was generally more acceptable to the panellists. The hedonic test served as the primary basis for selection because it directly reflects consumer preferences and acceptance, whereas the hedonic quality test only indicates the intensity of a sensory attribute without guaranteeing its alignment with the panellists' tastes.

DISCUSSION

Appearance

Based on the evaluations by 40 semi-trained panellists of the appearance parameters of white bread made from sorghum flour, cassava, arrowroot, and spinach extract, the range of panellists' preference percentages was 67.5%–80.7%. The results of the hedonic test for appearance parameters are shown in Figure 2.

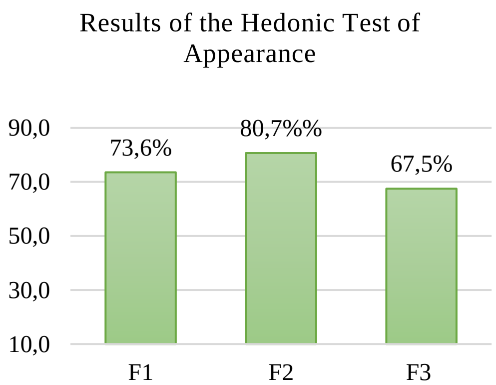

Figure 2. Results of the Hedonic Test of Appearance

The results of the hedonic test showed that the panellists' level of preference for the appearance of white bread fell into the neutral to somewhat favorable category, with scores ranging from 4.72 to 5.65. Based on the order of preference scores, F2 received the highest score (5.65 ± 1.18), followed by F1 (5.15 ± 1.40), and F3 received the lowest (4.72 ± 1.35). The Kruskal-Wallis test indicated a significant difference among the formulations ($p < 0.05$), and the subsequent Mann-Whitney test confirmed that F2 differed significantly from F3, while F1 did not differ significantly from either of them.

The panellists' preference for the bread's appearance was likely influenced by the balance between the starch content of cassava flour—which plays a role in dough structure formation and expansion—and the fiber content of sorghum flour, which affects crumb characteristics. (18) noted that using high amounts of sorghum flour can reduce expansion volume due to the absence of gluten, which helps retain gas during fermentation. Conversely, (19) explain that an excessively high proportion of cassava flour can also reduce rising ability due to its limited capacity to form a viscoelastic network, resulting in a less stable bread structure.

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In F1, the high proportion of sorghum flour (±75 g) resulted in unappealing bread appearance due to the dough's low gas-retention capacity caused by the absence of gluten, leading to low expansion volume and a dense bread structure—consistent with the findings of (20) that the use of sorghum flour results in relatively low expansion volume and requires additional treatment to improve its characteristics. Conversely, in F3, the high proportion of cassava flour (±75 g)—despite contributing a high starch content—actually resulted in an unstable dough structure due to the absence of a viscoelastic network like gluten, leading to non-uniform bread pores and suboptimal shape, consistent with the statement by (8) that the substitution of non-wheat ingredients such as sorghum or other starch sources can affect the structure and physical characteristics of bread. Additionally, (21) noted that the use of sorghum flour can reduce color brightness and affect the visual appearance of bread.

Colour

Based on the evaluations by 40 semi-trained panellists of the colour parameters of white bread products made from sorghum flour, cassava, arrowroot, and spinach extract, the range of panellists' preference percentages was 66.8%–74.6%. The results of the hedonic test for colour parameters are shown in Figure 3.

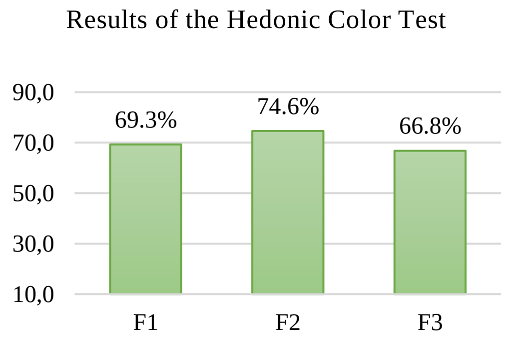

Figure 3. Results of the Hedonic Color Test

The differences in bread colour observed in this study were influenced by variations in the composition of the sorghum flour used in each formulation. Treatment F1, which used the highest amount of sorghum flour (75 g), produced brown-coloured bread. This finding is consistent (21) assertion that increasing the proportion of sorghum flour can reduce the brightness of the product's colour. This brown colour is believed to be related to the presence of a natural pigment in sorghum, namely 3-deoxyanthocyanidin, as well as the intensity of the browning reaction that occurs during the baking process. This browning reaction is formed through the Maillard reaction between reducing sugars and amino acids, which plays an important role in the formation of brown colour in bread (22).

Conversely, the use of non-wheat flours such as cassava flour in higher proportions—as in treatment F3 (75 g)—resulted in a lighter bread colour compared to F1. This is consistent with the findings of (23), who noted that substituting alternative flours at certain levels can produce a lighter bread colour that is more preferred by panellists than high-level substitutions. Therefore, the higher proportion of cassava flour in F3 compared to sorghum flour resulted in a light brown colour in the product. Additionally, the addition of arrowroot flour also helped improve the bread's colour due to its bright white characteristics. This aligns with (24) finding that the use of arrowroot flour in bread and baked goods can enhance sensory characteristics and produce a better product colour that is more acceptable to panellists.

Texture

Based on the evaluations of 40 semi-trained panellists regarding the texture parameters of plain bread made from sorghum flour, cassava, arrowroot, and spinach extract, the range of panellists' preference percentages was 59%–70%. The results of the hedonic test for texture parameters are shown in Figure 4.

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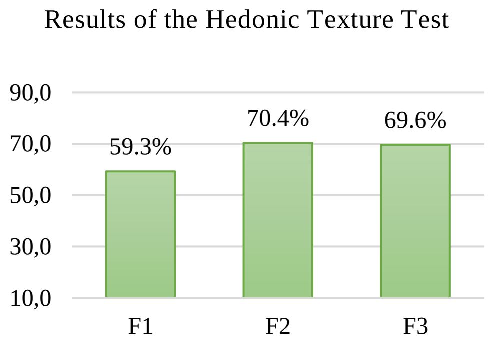

Figure 4. Results of the Hedonic Texture Test

This result was influenced by the high proportion of cassava flour in treatment F3 (75 g), where the starch content played a role in the gelatinization process, which contributed to the softness of the bread's texture. This is consistent with the findings of (25), who noted that cassava starch possesses good functional properties, particularly in the gelatinization process, which plays a crucial role in determining the texture of food products. Conversely, the use of sorghum flour in excessively high proportions tends to result in a dense bread texture, due to its high fiber content and the absence of gluten, which is responsible for forming an elastic network in the dough. This is consistent with the findings of (18), who noted that high levels of sorghum flour can reduce volume expansion due to the absence of gluten capable of retaining gas during fermentation, resulting in a denser texture. Therefore, the panellists tended to prefer the plain bread made with sorghum flour, cassava, and red spinach extract in treatment F3 over the other formulations. Additionally, the addition of arrowroot flour was also reported to improve the bread's textural characteristics, as its gelatinizing properties can mimic the function of gluten in maintaining the bread's structure (12).

Aromatic

Based on the evaluations by 40 semi-trained panellists of the aroma parameters of plain bread products made from sorghum flour, cassava, arrowroot, and spinach extract, the range of panellists' preference percentages was 54.6%–61.4%. The results of the hedonic test for aroma parameters are shown in Figure 5.

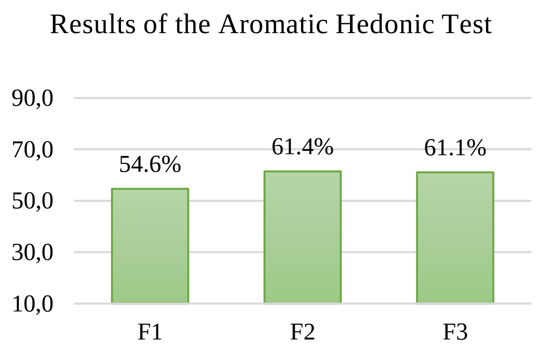

Figure 5. Results of the Aromatic Hedonic Test

The neutral aroma produced in the F3 treatment was due to the flour composition of that formulation, which predominantly used cassava flour with a low proportion of sorghum flour, thereby reducing the volatile compounds characteristic of sorghum that could potentially cause a musty aroma. This is consistent with the study by (26), which stated that the proportion of sorghum flour used in food product formulations has a significant effect on organoleptic attributes, particularly aroma, where an increase in the amount of sorghum flour can enhance its characteristic aroma. This also explains the panellists low preference for F1 and F2, given that the proportion of sorghum flour in both formulations was quite high—75 g and 50 g, respectively. Furthermore, the use of arrowroot flour in gluten-free bread products was found to improve sensory characteristics by producing a

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neutral aroma that is not overly sharp. This aligns with research indicating that the use of arrowroot flour in bakery products can increase panellists' acceptance levels regarding aroma parameters (24).

Taste

Based on the evaluations by 40 semi-trained panellists of the taste parameters of plain bread made from sorghum flour, cassava, arrowroot, and red spinach extract, the range of panellists' preference percentages was 53.6%–73.2%. The results of the hedonic test for taste parameters are shown in Figure 6.

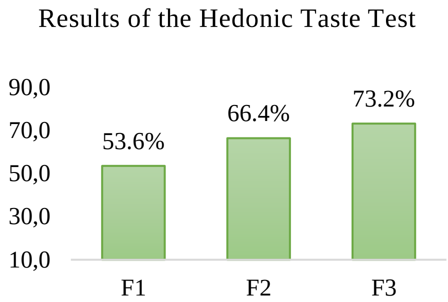

Figure 6. Results of the Hedonic Taste Test

Differences in the proportion of sorghum flour in each formulation affected the intensity of the product's flavour. In treatment F3, the lower use of sorghum flour (25 g) resulted in a non-dominant sorghum flavour, so the product's taste tended to be mild and nearly bland. Conversely, a higher proportion of sorghum flour contributes a stronger flavour, which panellists tended to perceive as neutral. This aligns with the research by (27), which states that the proportion of sorghum flour in food products affects organoleptic properties, including flavour, where differences in formulations result in varying levels of acceptance by panellists. This is supported by the findings of (28), who noted that increasing sorghum flour substitution can reduce panellists' liking for the flavour due to the increasingly pronounced characteristic sorghum flavour. On the other hand, the use of arrowroot flour was found to have no significant effect on taste parameters due to its relatively neutral nature. This is consistent with the study by (16), which stated that the addition of arrowroot flour can increase panellists' acceptance of taste parameters because of its neutral characteristics and its ease of combination with other local food ingredients.

CONCLUSION

This study successfully developed high-fiber, gluten-free white bread made from sorghum flour, cassava, arrowroot, and red spinach extract as a form of local food diversification to reduce dependence on imported wheat flour. Of the three formulations tested (F1, F2, and F3), significant differences were found in appearance, texture, and taste, while colour and aroma did not differ significantly. Formulation F2, with a balanced ratio of sorghum and cassava, was selected as the best formulation because it possessed the sensory characteristics most preferred by the panellists overall. Proximate analysis results for F2 showed an energy content of 198 kcal, 3.7 g of protein, 3.0 g of fat, 38.8 g of carbohydrates, and 7.77 g of dietary fiber per 100 grams of product, meeting the criteria for a "high-fiber" claim. These findings indicate that this white bread made from local ingredients has the potential to serve as a healthier functional alternative to conventional wheat-based white bread, while also supporting efforts to reduce wheat imports and address the fiber intake gap among the Indonesian population. Further research is recommended to examine the product's shelf life, broader market acceptance, and the development of advanced formulations to enhance its nutritional value and sensory quality. In addition, further studies are also recommended to assess the glycemic index of the product, given its high fiber content and the use of local flour sources, in order to determine its suitability as a healthier alternative for individuals requiring blood glucose control, such as those with diabetes or prediabetes.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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