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Sourdough bread innovation with green banana flour seen from its physical and sensory characteristics

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ABSTRACT

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Keywords

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Introduction: Green banana flour (GBF), rich in resistant starch and dietary fiber, has gained attention as a functional ingredient for improving gut health and metabolic regulation. While GBF has been applied in conventional bread, its effect on sourdough bread remains underexplored. This study aimed to evaluate the physical and sensory properties of sourdough bread incorporated with GBF. **Methods:** Sourdough bread was prepared using wheat flour (control, TC) and GBF substitution at 10% (TP1), 20% (TP2), and 30% (TP3), with identical hydration and processing conditions. Texture profile analysis was performed using a texture analyzer, while sensory evaluation was conducted with 50 untrained panellists using a 5-point hedonic scale. Data were analyzed by ANOVA followed by Duncan's test ($\alpha = 5\%$). **Results:** Texture analysis revealed that increasing GBF substitution significantly elevated hardness, springiness, and stiffness, while reducing fracture force compared to TC. Sensory results indicated that TC scored the highest in all parameters, especially taste (4.20 ± 0.67) and overall acceptability (4.26 ± 0.76). TP1 remained acceptable, showing comparable scores to TC in aroma (3.68 ± 0.74) and texture (3.84 ± 0.57). However, TP2 and TP3 demonstrated lower consumer acceptance, with TP3 recording the lowest scores in taste (3.14 ± 0.78) and overall acceptability (3.36 ± 0.88). **Conclusion:** GBF incorporation modifies sourdough bread texture by increasing firmness and structural density, while sensory acceptance declines at higher substitution levels. Up to 10% GBF can be added without compromising consumer preference, offering potential for developing nutritionally enhanced sourdough bread.

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INTRODUCTION

In Indonesia, green bananas hold significant potential for agricultural production and economic development, yet they remain underutilized. With a production volume of over 8 million tons annually, bananas are one of the country's key horticultural products and are integral to local diets and economic activities, especially in regions like Bali, which is known for its rich diversity of local banana cultivars totaling 43 varieties (Wulandari *et al.*, 2023). The characteristics of green bananas, particularly their high starch and fiber content, make them important functional food sources with several health benefits (Falcomer *et al.*, 2019).

Despite this potential, green bananas are frequently underutilized due to consumer preferences leaning towards the ripe fruit (Baek *et al.*, 2023). Many consumers often equate bananas primarily with their sweet, ripe form, neglecting the nutritional and functional advantages offered by their green counterparts. Research indicates that while fresh green bananas contain resistant starches and prebiotic compounds beneficial for gut health, a significant portion of this crop is wasted (Baek *et al.*, 2023).

The production of green banana flour (GBF) has gained significant attention in recent years due to its numerous health benefits and potential applications in bakery products. One of the primary health benefits associated with green banana flour is its high content of resistant starch (RS). This type of starch is known for promoting digestive health by acting as a prebiotic, fostering the growth of beneficial gut bacteria, and improving insulin sensitivity (Bashmil *et al.*, 2025; Bezerra *et al.*, 2013). Studies have indicated that the inclusion of RS in the diet contributes to lower blood glucose levels and improved metabolic health, making GBF beneficial for individuals with diabetes (Khoozani *et al.*, 2020). Furthermore, the increased fiber content in GBF has been shown to aid in weight management by enhancing satiety and reducing overall calorie intake (Sunday *et al.*, 2023).

The trend of consuming bread as a staple food is deeply rooted in various cultures worldwide. Bread, particularly sourdough bread, has gained prominence due to its perceived health benefits and digestibility compared to

conventional yeast-leavened bread. Sourdough fermentation, which occurs through the action of naturally occurring lactic acid bacteria (LAB) and yeasts, significantly enhances the nutritional profile of bread, improving not only its flavor but also its texture and shelf life (Alkay *et al.*, 2024; Pontonio *et al.*, 2021).

A noteworthy approach to augmenting the nutritional value of sourdough bread is the incorporation of GBF, which known for its resistant starch and dietary fiber, ingredients known to promote gut health and assist in managing chronic diseases such as obesity and diabetes by lowering blood glucose levels (Bashmil *et al.*, 2025). Additionally, using green banana flour in sourdough bread can effectively enhance the functional properties of the product, creating a more nutrient-dense option for consumers (Khoozani *et al.*, 2020). Previous research has investigated the addition of green banana flour in conventional bread formulations, but its incorporation into sourdough bread remains unexplored. This absence of evidence not only limits understanding of how such substitution may affect fermentation kinetics and dough development but also raises broader questions about the interplay between structural modifications and consumer sensory acceptance in naturally leavened bakery products. Therefore, this study aims to analyze the physical and sensory characteristics of sourdough bread incorporated with green banana flour.

METHODS

Research conducted in Food Processing Laboratory, Faculty of Medicine and Health Science Salatiga. The method in this research is divided into several steps, namely making green banana flour (GBF), making sourdough bread, texture analysis, sensory analysis, then data analysis.

Green banana flour (GBF) making

The preparation of green banana flour using the procedure refers to Reis *et al.*, (2019) with modification. The sample used was a completely unripe banana (green skin). The skins were peeled, then the pulps were washed thoroughly then sliced (2-3mm). To avoid browning due to enzyme activity, banana slices can be soaked briefly (5-10 minutes) in a mixed of water and acid solution (0.2% citric acid). Banana slices are then laid out on a baking sheet and dried in an oven at 50-60°C for 6-8 hours. Once completely dry (crunchy and not mushy), banana pulps were grinded using a blender to a fine powder then sieved with sifter (60-80mesh).

Sourdough bread making

The white bread recipe using recipe from Forkish, (2022) while the sourdough bread formulations are presented in Table 1. The control formulation (TC) used 100% wheat flour, whereas TP1, TP2, and TP3 contained 10%, 20%, and 30% green banana flour (GBF) substitution, respectively. Importantly, no adjustments were made to hydration level, autolyse time, or folding technique, as the purpose of this study was to examine how the direct substitution of wheat flour with GBF under identical processing conditions affects the textural and sensory characteristics of sourdough bread.

Table 1. Sourdough bread formulation

Ingredients	TC	TP1	TP2	TP3
Wheat flour (g)	300	270	240	210
Green banana flour (g)	-	30	60	90
Water (g)		100		
Salt (g)		3		
Butter (g)		15		
Sourdough starter (g)		50		

The dry and wet ingredients were separately weighed and placed in large plastic containers before being combined. The dough was then kneaded until it passed the windowpane test, after which it was subjected to bulk fermentation for 2.5–3 hours at 28 ± 1 °C. Following bulk fermentation, the dough was divided according to pan size, shaped, and proofed at 30 ± 1 °C until it reached approximately 1,5 cm under the rim of the pan. The proofed dough was baked in a deck oven at 180 °C for 25–30 minutes, or until the internal temperature of the bread reached $82-90 \pm 1$ °C. After baking, the loaves were cooled at room temperature (25 ± 1 °C) for 1 hour before further analysis.

Physical analysis

Physical analysis included texture analysis performed using a Texture Analyzer (Lloyd TA Plus) in accordance with the procedure performed by Kulthe *et al.*, (2014) where the resulting analysis results were hardness, cohesiveness, springiness, gumminess, chewiness, fracture force, adhesive force, adhesiveness and stiffness. Each sample was analyzed three times.

Sensory analysis

Sensory analysis was carried out using the acceptance test of preference rating (Meilgaard *et al.*, 2016) of five parameters namely appearance, aroma, taste, texture, and overall acceptance. The rating used is a rating with 5 scales (scale 1 is the least preferred scale to scale 5 is the most preferred scale). The panellists used for the sensory test were 50 untrained panellists.

Data analysis

All data obtained will be analyzed using analysis of variance (ANOVA) at $\alpha = 5\%$ or t test to determine the real effect on each test parameter. Significant results from ANOVA calculations are then continued with Duncan's Multiple Range Test at $\alpha = 5\%$ to determine the treatment level that provides a real difference. All statistical tests were assisted by using IBM SPSS Statistics 29 software.

RESULTS AND DISCUSSION

Physical analysis

Bread texture encompasses a variety of factors such as bread crumb consistency, gas bubble size distribution, and others. Bread texture is intimately related to its composition and processing method; for example, high-volume bread has a soft texture and high porosity, whereas high-density bread has a denser and firmer texture (Yamsaengsung *et al.*, 2010). Bread texture is assessed by assessing criteria such as crumb chewiness, stiffness, and relative elasticity using standardised methodologies. In this study, sourdough bread texture was evaluated using the parameters of hardness, cohesiveness, springiness, gumminess, chewiness, fracture force, adhesive force, adhesiveness, and stiffness. However, after statistical analysis using ANOVA (Analysis of Variance) on these parameters, there were parameters that did not have significant differences, namely the cohesiveness, gumminess, chewiness, adhesive force, and adhesiveness parameter, whereas the parameters that had significant differences were hardness, springiness, springiness index, fracture force, and stiffness. Table 2 summarizes the texture profile analysis of sourdough bread with different levels of green banana flour (GBF) substitution.

Table 2. Physical analysis results

Parameter	TC	TP1	TP2	TP3
Hardness (gf)	234.85 ± 52.451	318.91 ± 39.691	395.90 ± 10.382	419.84 ± 16.812
Cohesiveness	0.30 ± 0.061	0.05 ± 0.041	0.05 ± 0.041	0.08 ± 0.011
Springiness (mm)	7.24 ± 1.021.2	6.02 ± 0.701.2	7.19 ± 1.481.2	9.65 ± 1.922
Springiness Index	0.35 ± 0.041	0.34 ± 0.051	0.44 ± 0.021	0.96 ± 0.052
Gumminess (gf)	65.70 ± 0.341	7.29 ± 0.411	4.25 ± 0.651	16.67 ± 0.491
Chewiness (Nmm)	0.40 ± 0.041	0.40 ± 0.061	0.23 ± 0.021	1.59 ± 0.091
Fracture Force (kgf)	0.03 ± 0.003	0.01 ± 0.001	0.01 ± 0.001	0.02 ± 0.002
Adhesive Force (kgf)	0.05 ± 0.011	0.01 ± 0.001	0.01 ± 0.001	0.02 ± 0.011
Adhesiveness (kgf.mm)	0.31 ± 0.041	0.01 ± 0.001	0.01 ± 0.001	0.01 ± 0.011
Stiffness (kgf/mm)	0.03 ± 0.012.3	0.02 ± 0.001.2	0.02 ± 0.001	0.04 ± 0.013

Notes: Different superscript numbers in the same row indicate significant differences ($\alpha = 5\%$).

Bread hardness, defined as the peak force required to compress the crumb during texture profile analysis (TPA), is a critical parameter influencing the sensory attributes, perceived freshness, and overall consumer acceptance of bread. Hardness is affected by multiple factors, including flour composition, starch–protein interactions, fiber content, hydration level, and fermentation conditions. As shown in Table 2, the control (TC) and the 10% GBF substitution (TP1) did not differ significantly ($p > 0.05$), with hardness values of 234.85 gf and 318.91 gf, respectively. However, higher substitution levels led to a progressive increase in hardness, reaching 395.90 gf in TP2 (20% GBF) and 419.84 gf in TP3 (30% GBF). This trend suggests that increasing amounts of dietary fiber and resistant starch from GBF reduced dough gas retention and crumb porosity, thereby producing a denser and firmer bread structure.

The difference in hardness level maybe caused by the fundamental differences in starch composition and structure between wheat flour and GBF. Studies indicate that GBF contains a higher gelatinization temperature and transition enthalpy compared to wheat flour, which can result in a denser bread structure when baked, leading to increased hardness (Tribess *et al.*, 2009). This finding is substantiated by observations from Thakaeng *et al.*, (2021) who reported that the inclusion of unripe green banana flour caused a significant increase in the density and hardness of the bread. The physico-chemical properties of GBF also contribute to the changes in bread texture. For instance, the presence of resistant starch (RS), which is abundant in GBF, affects the retrogradation of starch during cooling, leading to a firmer crumb structure (Sarawong *et al.*, 2014). This aligns with findings reported by Khalil *et al.*, (2017) which indicate that as the level of unripe banana flour increases in the blend, the hardness of the flatbreads increases.

Springiness and springiness index are critical attributes in assessing the texture and overall quality of bread. Springiness represents the ability of bread to recover its original shape after being compressed, essentially indicating how well the bread maintains its structure and elasticity post-deformation (Puerta *et al.*, 2020). A high springiness value correlates with a fresh, elastic product, whereas low values suggest brittleness and a tendency to crumble, indicating inferior quality (Puerta *et al.*, 2020). The differentiation between springiness and springiness index is nuanced yet significant. Springiness is a qualitative measure of the bread's texture, while the springiness index is a quantifiable metric derived from mechanical tests. In texture profile analysis (TPA), the springiness index can be mathematically expressed as the ratio of the height after release to the height during compression; thus, it provides a more objective measure of how a bread's texture responds to force (Puerta *et al.*, 2020).

For this research, incorporation of green banana flour (GBF) into bread formulations results in notable increases in both springiness and springiness index compared to bread made solely from wheat flour. This phenomenon can primarily be attributed to the unique physicochemical properties of green banana flour, which enhance the textural characteristics of the bread. Green banana flour, derived from unripe bananas, is rich in resistant starch and dietary fiber, both of which contribute to improved textural attributes. The increasing value of both springiness and springiness index in sourdough bread incorporated with green banana flour in this research aligns with findings reported by Thakaeng *et al.*, (2021) that addition of GBF in moderate amounts, up to around 25%, has been shown to significantly enhance loaf volume compared to gluten-based bread, attributed to the flour's capacity to increase gas retention during baking.

Fracture force in bread texture is a critical measurement that reflects the mechanical properties and overall quality of the product. This parameter indicates the force required to compress or fracture the bread crumb, providing insight into its firmness, chewiness, and textural attributes. The results for this research showed that sourdough bread made with green banana flour tends to exhibit a lower fracture force compared to sourdough bread with wheat flour. This is caused maybe due to the inherent properties of banana flour, including its fiber content and the type of starch present. Green banana flour, contains resistant starch and dietary fibers that can modify the dough structure and the final texture of the bread (Kowalski *et al.*, 2024).

Also, incorporating green banana flour results in significant changes to moisture retention and gas retention within the dough, essential for texture (Esfanjani & Mohebbi, 2023). The porous structure created by the combination of starch and fiber in banana flour differs from that of wheat flour, making the final product less dense and thus requiring less force to break apart. The non-uniform gas cell formation due to the addition of banana flour contributes to a softer crumb texture, reducing the maximum force needed to compress the bread (Kowalski *et al.*, 2024). Furthermore, bread made with a higher proportion of dietary fiber has been shown to correlate with softer textural properties, which aligns with the observations of reduced fracture force in banana flour-enriched breads (Kowalski *et al.*, 2024). This research showed that sourdough bread that incorporated with 10-20% green banana flour in its formulation had the lowest value of fracture force.

Stiffness in bread texture is a critical characteristic that reflects the structural integrity and mouthfeel of the bread. It relates to the resistance of the bread to deformation, typically measured through parameters such as hardness, chewiness, and elasticity. For this research, it showed that the incorporation of 10-20% green banana flour into wheat bread may result in only slight variations in stiffness compared to bread made exclusively from wheat flour. This suggests that at moderate levels of incorporation, the functional properties of wheat flour are complemented by the banana flour without significantly altering mechanical resistance (Thakaeng *et al.*, 2021). However, at higher incorporation levels of 30%, the stiffness may increase, indicating changes in structural integrity due to the increased presence of resistant starch and fibers that enhance moisture retention and create a denser bread structure (Thakaeng *et al.*, 2021).

An increase in stiffness at higher percentages, potentially evident from increased hardness values, could contribute to reduced volume and density, as correlations exist between flour composition, water binding, and mechanical properties of the dough (Abu-Alruz, 2023; Škrobot *et al.*, 2022). Bread stiffness is not only a reflection of texture but also a crucial factor in consumer acceptability and the sensory experience of the product. Decreased stiffness typically results in softer bread, which is often preferred (Abedfar & Sadeghi, 2019; Rizzello *et al.*, 2019). In contrast, increased stiffness can indicate greater chewiness and a denser crumb, which may be less desirable in certain bread types.

Sensory analysis

Sensory evaluation provides critical insight into consumer perception, as it directly measures acceptance through human senses such as sight, aroma, taste, and texture. In this study, 50 untrained panellists aged 20–30 years participated in the sensory acceptance test of sourdough bread formulations, and the results are presented in Table 3. The control sample (TC) consistently received the highest scores across most attributes, particularly in taste (4.2 ± 0.67) and overall acceptability (4.26 ± 0.76). Substitution with 10% GBF (TP1) was still well-accepted, showing no significant

decline in aroma (3.68 ± 0.74) and texture (3.84 ± 0.57) compared to TC. However, higher substitution levels (TP2 and TP3) resulted in a progressive reduction in panel scores, with TP3 (30% GBF) recording the lowest ratings for taste (3.14 ± 0.78), texture (3.56 ± 0.88), and overall acceptability (3.36 ± 0.88). This trend indicates that while low levels of GBF can be incorporated without compromising consumer acceptance, higher levels negatively impact sensory qualities, especially taste and texture, leading to reduced overall liking.

Table 3. Sensory analysis results

	Appearance	Aroma	Taste	Texture	Overall
TC	4.22 ± 0.62^2	3.88 ± 0.75^3	4.20 ± 0.67^3	4.10 ± 0.63^2	4.26 ± 0.76^3
TP1	3.58 ± 0.73^1	$3.68 \pm 0.74^{2,3}$	$3.92 \pm 0.72^{2,3}$	$3.84 \pm 0.57^{1,2}$	3.96 ± 0.63^2
TP2	3.52 ± 0.81^1	$3.48 \pm 0.79^{1,2}$	3.62 ± 0.95^2	$3.82 \pm 0.76^{1,2}$	3.80 ± 0.57^2
TP3	3.32 ± 0.98^1	3.30 ± 0.76^1	3.14 ± 0.78^1	3.56 ± 0.88^1	3.36 ± 0.88^1

Notes: Different superscript numbers in the same column indicate significant differences ($\alpha = 5\%$).

Green banana flour contributes significantly to the appearance of sourdough bread, typically resulting in a darker coloration due to the Maillard reaction and the higher levels of resistant starch that can influence crust formation (Bashmil *et al.*, 2025). The initial color of the dough and its final baked product often reflect the flour's composition, with GBF leading to a more pronounced color contrast in comparison to flour solely from wheat (Bashmil *et al.*, 2025). This visual effect directly affects consumer perception, often leading to a preference for products with appealing aesthetic properties).

In terms of aroma, studies have shown mixed findings regarding the influence of GBF on bread aroma. While some findings indicate that the addition of banana flour can impart a pleasant aroma that enhances consumer appeal, others note no significant differences compared to wheat-only bread (Dawodu *et al.*, 2019; Thakaeng *et al.*, 2021). The aroma's acceptability can be attributed to the natural sugars and compounds released during the fermentation and baking processes, which are distinct in GBF compared to wheat (Dawodu *et al.*, 2019).

Regarding taste, green banana flour is noted for having a mild, neutral flavor. Its addition can modify the overall taste profile without overpowering the sourdough characteristics typical of wheat breads. However, this can lead to variations in taste acceptance depending on the proportion of GBF used (Genitha, 2014; Silva *et al.*, 2021). Higher inclusions of GBF can sometimes lead to perceptible changes in flavor that affect consumer preferences, particularly if the balance with the fermentation profile is not maintained (Viana *et al.*, 2018). In addition, the sensory characteristics of flavor and mouthfeel of bread containing GBF may not always align with consumer expectations formed by traditional wheat bread. The distinct flavor profile imparted by GBF could potentially detract from the desirable chewy and soft texture that consumers typically associate with wheat bread (Rachman *et al.*, 2023; Reis *et al.*, 2019).

Texture is another critical parameter where the incorporation of GBF exerts significant effects. The resistant starch content inherent in GBF modifies crumb structure, generally resulting in a denser product with improved chewiness compared to traditional wheat breads (Khoozani *et al.*, 2020). The presence of dietary fibers in GBF can also influence mouthfeel, making the bread feel less airy and more substantial (Genitha, 2014). This change often correlates with consumer preferences for higher fiber content, although excessive density might deter some consumers who expect the lightness characteristic of traditional sourdoughs (Dawodu *et al.*, 2019).

For the overall acceptability of sourdough bread incorporating GBF is statistically significantly different from that of wheat-only breads, primarily due to the combined effects on all sensory parameters (Amini Khoozani *et al.*, 2020b). Statistical analysis reveals that incorporation levels until 30% GBF lead to significant changes in texture, taste, and appearance, prompting sensory consumer tests to reflect lower overall acceptance scores for higher ratios of GBF unless carefully balanced with other ingredients. Sourdough bread made with wheat flour only holds the highest rating for overall acceptability and for sourdough bread incorporated with GBF the 10% incorporation in formulation holds the highest rating compared to incorporation of 20% and 30%. The inherent differences in the starch compositions between GBF and wheat flour, particularly the higher resistant starch content in GBF, contribute to these sensory attributes, influencing digestion and consumer sensory perception (Amini Khoozani *et al.*, 2020; Cândido *et al.*, 2023). Moreover, consumer attitudes and acceptance levels play a crucial role in assessing sensory ratings. Research has suggested that while consumers may appreciate the nutritional benefits of higher fiber content, such as that found in GBF, they often report mixed responses to the resultant changes in taste and mouthfeel (Li *et al.*, 2022). Therefore, the sensory acceptability of bread that incorporates GBF might suffer in direct comparison to standard wheat bread, influenced by these multifaceted effects on appearance, texture, and flavor. For future product development, maybe the scores could be increased by carefully balanced the sourdough bread with green banana flour incorporation with other ingredients.

CONCLUSION

This study demonstrated that the incorporation of green banana flour (GBF) into sourdough bread significantly influences both physical and sensory characteristics. From a physical standpoint, increasing levels of GBF resulted in higher hardness, springiness, and stiffness, which can be attributed to the high resistant starch and dietary fiber content of GBF that reduced gas retention and altered crumb structure. Sensory evaluation revealed that the control bread made solely with wheat flour was the most preferred across all attributes. A 10% substitution (TP1) was still acceptable, showing comparable scores to the control in aroma and texture. However, higher substitution levels (20% and 30%) led to a marked decline in taste, texture, and overall acceptability. These findings suggest that GBF has potential as a functional ingredient in sourdough bread, but consumer acceptance is limited at higher substitution levels. The optimal formulation to balance nutritional enhancement and sensory quality lies at approximately 10% GBF substitution.

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