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## Physical and sensory characteristics of sourdough bread with local superfood leaf flour substitution

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### ABSTRACT

**Introduction:** Sourdough bread has gained popularity due to its nutritional and sensory benefits, with lactic acid bacteria fermentation improving digestibility, glycemic response, and bioactive compound availability. The incorporation of nutrient-dense superfood leaf flours such as *Moringa oleifera*, *Sauropus androgynus*, and *Centella asiatica* may further enhance its functional properties. **Methods:** Sourdough bread was formulated with wheat flour partially substituted by superfood leaf flours at 5%, 10%, and 15% levels. Physical properties were analyzed using a Texture Analyzer (hardness, cohesiveness, springiness, chewiness, stiffness, etc.), while sensory acceptability (appearance, aroma, taste, texture, and overall preference) was evaluated by 50 untrained panelists. Data were statistically analyzed using ANOVA and Duncan's Multiple Range Test ( $\alpha = 5\%$ ). **Results:** Textural analysis showed significant differences across treatments, particularly in hardness, cohesiveness, springiness, chewiness, and stiffness. Higher substitution levels of leaf flour generally increased crumb hardness and chewiness due to reduced gluten structure. Sensory analysis indicated that the control bread (100% wheat flour) received the highest overall rating. Among the modified breads, the 5% *Centella asiatica* formulation (TP1) was the most preferred, likely because moderate substitution imparted a mild herbal flavor and retained a soft crumb structure, while higher levels reduced sensory acceptability. **Conclusion:** The incorporation of superfood leaf flours significantly influenced both physical and sensory characteristics of sourdough bread. While control bread was most preferred, 5% *Centella asiatica* substitution emerged as the optimal formulation among the enriched variants, balancing improved nutritional potential with favorable consumer acceptance.

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### INTRODUCTION

In recent years, the popularity of sourdough bread has surged due to its unique flavor profile, demand for healthier food options, and the recognition of its functional health benefits. This trend can be significantly attributed to growing consumer awareness around nutrition, the artisanal bread-making movement, and a desire for traditional food practices that are perceived as healthier. According to Sanmartin et al., (2020) the use of sourdough enhances both nutritional and sensory properties of bread, contributing to its acceptance in modern diets. Furthermore, the preference for sourdough over conventional bread may stem from its lower glycemic index (GI), facilitated by lactic acid bacteria (LAB) fermentation, which reduces the sugar levels in the final product (Kwon et al., 2022; Mohd Roby et al., 2020).

The fermentation process inherent in sourdough production can significantly increase the bioavailability of nutrients, making bread not only tastier but also healthier. Research indicates that fermentation by lactic acid bacteria (LAB) and yeasts leads to the breakdown of specific compounds, promoting improved mineral absorption and higher phenolic content (Fernández-Peláez et al., 2020; Luti et al., 2021). The introduction of superfood leaf flour, which often contains high levels of vitamins, minerals, and antioxidants, could synergistically enhance these benefits, creating a bread product rich in bioactive compounds. For instance, sourdough fermented with whole grain flours has been noted to yield higher antioxidant properties, which can be expected to increase further with the addition of leaf flour, given its high nutrient profile (Alkay et al., 2024; Galli et al., 2020). Moreover, incorporating superfood leaf flour into sourdough bread could diversify its taste and texture. Sourdough's characteristic sour taste, derived from lactic acid production, can provide a unique flavor base that complements the additional earthy or herbal notes of superfood flours. This combination is likely to appeal to health-conscious consumers seeking flavorful yet nutritious options. Research indicates that consumers perceive sourdough bread as healthier and more traditional compared to yeast-leavened bread, supporting the idea that enhancing flavor can lead to better market acceptance (Pontonio et al., 2021; Sakandar et al., 2019).

The incorporation of functional ingredients known as superfood leaf such as *Moringa oleifera*, *Sauropus androgynus* and *Centella asiatica* (commonly referred to as Gotu Kola) in sourdough bread formulation represents a significant advancement in improving the nutritional profile of baked products. Various studies have explored the benefits of these superfoods, highlighting their potential to enhance the health benefits of sourdough bread. Research indicates that *Moringa oleifera*, known for its rich nutrient profile, can greatly enhance the nutritional quality of bread. Its leaves, seeds, bark, and pods contain a diverse array of bioactive compounds including flavonoids, phenolic compounds, alkaloids, tannins, and glucosinolates (Al-Ghanayem et al., 2022; Susanto et al., 2023). Furthermore, the presence of chemoprotective compounds such as isothiocyanates and glucosinolates is implicated in anti-carcinogenic and cytoprotective mechanisms, with additional work indicating potential benefits in chronic conditions such as diabetes and non-alcoholic liver disease (Fahey et al., 2018; Milla et al., 2021). Peñalver et al., (2023) developed gluten-free sourdough bread enriched with *Moringa oleifera*, demonstrating that the incorporation of this plant improved the protein, vitamins, and mineral contents of the bread, addressing nutritional imbalances often found in gluten-free diets. Similarly, Mishra et al., (2021) evaluated bread made from *Moringa* leaves and fenugreek, reporting an increase in essential micronutrients and fiber, indicating that such enhancements can contribute to overall health. Furthermore, Fatima et al., (2024) supported these findings by noting that adding *Moringa* leaves increases the nutrient density of various edible products, including bread, thereby promoting health.

The inclusion of *Sauropus androgynus* in bread holds promise, although specific publications directly addressing its incorporation into sourdough bread are limited. Its known benefits as a nutrient-rich leaf (including vitamins and proteins) suggest it may provide complementary health benefits similar to those of *Moringa*. This aligns with the growing trend towards functional foods, where ingredients are not only used for flavor and texture but also for their nutritional properties. *Centella asiatica* is another superfood with therapeutic potential, its health benefits include promoting cognitive function and skin health. Its active compounds are primarily triterpenoids such as asiaticoside, madecassoside, asiatic acid, and madecassic acid (Anilkumar, 2020; Wang et al., 2024). In addition, *Centella* extracts have demonstrated potent antioxidant properties by enhancing endogenous antioxidant enzyme activities—including superoxide dismutase, catalase, and glutathione peroxidase—which contribute to protection against oxidative liver injury (Choi et al., 2016; Rohmaha et al., 2022). While direct publications on its use in sourdough bread are scarce, its incorporation in other food products has been shown to increase antioxidant activity, suggesting likely health benefits for sourdough bread (Peñalver et al., 2023). Therefore, this study aims to find the optimum sourdough bread formulations with local superfood leaf flour substitutions of *Moringa oleifera*, *Sauropus androgynus* and *Centella asiatica* seen from its physical and sensory characteristics.

## METHODS

Research conducted in Food Processing Laboratory, Faculty of Medicine and Health Science Salatiga. This research method consists of the making of sourdough bread, physical analysis (texture), sensory analysis, and statistical analysis.

### Sourdough bread making

The preparation of sourdough bread followed the steps from Rahardjo & Sihombing (2023) with modifications in the incorporation of superfood leaf flours. The sourdough bread formulation in this study can be seen in Table 1. TK was formulation for sourdough bread control, TM was formulation for sourdough bread with *Moringa oleifera* flour, TA was formulation for sourdough bread with *Sauropus androgynus* flour, and TP was formulation for sourdough bread with *Centella asiatica* flour.

Table 1. Sourdough bread formulation

| Ingredients              | TK  | TM1 | TM2 | TM3 | TA1 | TA2 | TA3 | TP1 | TP2 | TP3 |
|--------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Wheat Flour (g)          | 200 | 190 | 180 | 170 | 190 | 180 | 170 | 190 | 180 | 170 |
| Superfood leaf flour (g) | 10  | 10  | 20  | 30  | 10  | 20  | 30  | 10  | 20  | 30  |
| Sugar (g)                | 30  | 30  | 30  | 30  | 30  | 30  | 30  | 30  | 30  | 30  |
| Salt (g)                 | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   |
| Butter (g)               | 30  | 30  | 30  | 30  | 30  | 30  | 30  | 30  | 30  | 30  |
| Sourdough starter        | 50  | 50  | 50  | 50  | 50  | 50  | 50  | 50  | 50  | 50  |
| Water (g)                | 80  | 80  | 80  | 80  | 80  | 80  | 80  | 80  | 80  | 80  |

The dry and wet ingredients were first mixed, except for salt and butter. Mixing was performed using a MITO mixer at speed 2 (medium speed) until all ingredients were homogeneous and the sugar was dissolved for 4 minutes. Salt and butter were then added, followed by mixing at speed 3 (high speed) for approximately 6 minutes until the dough reached a smooth consistency. The dough was placed in a basin and allowed to undergo bulk fermentation for 3 hours at room temperature (25-27 °C). After bulk fermentation, the dough was shaped, placed on a silicon mat, and subjected to final proofing for 6 hours under the same conditions until its volume doubled. The proofed dough was then baked in

an oven at 180 °C for approximately 30 minutes, or until the internal temperature reached 80-90 °C and the surface was golden brown. The resulting sourdough bread was then ready for further analysis.

### Physical analysis

Physical analysis included texture analysis performed using a Texture Analyzer (Lloyd TA Plus) in accordance with the procedure performed by Li et al., (2013) with specific instrumental parameters applied in this study. Measurements were carried out using a cylindrical aluminum probe (diameter 36 mm) with a 25 kg load cell. The samples were compressed to 40% of their original height at a test speed of 1.0 mm/s, with a trigger force of 5 g. Each bread sample was cut into 25 mm thick slices from the central portion of the loaf and equilibrated at room temperature ( $28 \pm 1$  °C) prior to measurement. The resulting parameters obtained included hardness, cohesiveness, springiness, gumminess, chewiness, fracture force, adhesive force, adhesiveness, and stiffness.

### Sensory analysis

Sensory analysis was carried out using the acceptance test of preference rating (Meilgaard et al., 2016) of five parameters namely appearance, color, 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 panelists used for the sensory test were 50 untrained panelists.

### Statistical 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

Physical analysis done for quantifying the textural parameters of food products, serving as a bridge between sensory characteristics and instrumental measurements. The methodology operates by imitating the mechanical action of mastication, providing objective measurements that are otherwise difficult to evaluate through sensory analysis alone (Almeida et al., 2024). In this study, sourdough bread and sourdough bread incorporated with superfood leaf flour texture was tested with the parameters 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 fracture force, gumminess, adhesiveness and adhesive force parameter, meanwhile the parameters that had significant differences were hardness, cohesiveness, springiness, springiness index, chewiness, and stiffness. The results of texture analysis for sourdough bread and sourdough bread incorporated with superfood leaf flour can be seen in Table 2.

Hardness is a critical parameter affecting the textural quality of bread, which significantly influences consumer acceptance. The hardness of bread crumb is measured by the maximum force required to compress a sample during a texture profile analysis (TPA) (Adamczyk et al., 2021). This parameter serves as an indicator of the bread's freshness and overall quality, with higher values typically signifying staler bread (Zolfaghari et al., 2015). In the context of sourdough bread made with additives such as superfood leaf flours from *Moringa oleifera*, *Sauropus androgynus*, and *Centella asiatica*, it showed that these additions can alter the texture compared to bread made with wheat flour alone. An increase in hardness may indicate a staling process, where the starch retrogradation leads to firmer bread, typically resulting from the loss of moisture and gas cells (Sahin et al., 2024). Conversely, a decrease in hardness suggests improved freshness and softness, often desired in consumer preferences, which can come from the right balance of fermentation duration and ingredient mixture promoting optimal gas retention and moisture balance (Bieniek & Buksa, 2024).

For instance, the incorporation of various non-wheat flours like pulse flours is known to affect hardness and other textural properties by impacting gluten formation and moisture retention (Nkurikiye et al., 2023). Table 2 showed that the incorporation of superfood leaf flours such as *Moringa oleifera*, *Sauropus androgynus*, and *Centella asiatica* into sourdough bread formulations has been shown to significantly affect the bread's textural properties, notably increasing its hardness along with its increasing of percentage in sourdough bread formulation. One of the primary reasons for the increased hardness is the limited gluten content in doughs formulated with these non-wheat flours. Gluten plays a crucial role in the structural integrity and elasticity of bread dough, with reduced gluten availability when substituting wheat flour with leafy flour, the dough's ability to trap air and rise effectively is compromised. This may lead to a denser crumb structure, thereby increasing hardness. Yaver (2022) reported that substituting wheat flour for chickpea flour negatively impacted the dough's gluten network, leading to increased hardness and gumminess in bread.

Table 2. Physical analysis results

| Parameter | Hardness (gf)   | Cohesiveness | Springiness (mm) | Springiness Index | Chewiness (Nmm) | Stiffness (kgf.mm) | Fracture Force | Gumminess  | Adhesiveness | Adhesive Force |
|-----------|-----------------|--------------|------------------|-------------------|-----------------|--------------------|----------------|------------|--------------|----------------|
| TK        | 129,19±12,251   | 0,05±0,021   | 12,29±0,292      | 1,55±0,122        | 0,83±0,271      | 0,02±0,001,2       | 0,01±0,001     | 6,92±2,361 | 0,01±0,001   | 0,01±0,001     |
| TM1       | 153,30±48,811,2 | 0,05±0,031   | 6,34±3,471,2     | 0,74±0,511        | 0,45±0,281      | 0,03±0,011,2,3     | 0,01±0,001     | 7,24±2,831 | 0,01±0,001   | 0,01±0,011     |
| TM2       | 213,42±29,132,3 | 0,05±0,031   | 4,19±2,351       | 0,36±0,221        | 0,54±0,501      | 0,05±0,023         | 0,02±0,001     | 8,33±1,651 | 0,02±0,001   | 0,02±0,001     |
| TM3       | 252,04±16,401,2 | 0,06±0,021,2 | 4,71±1,061       | 0,34±0,081        | 0,48±0,321      | 0,03±0,001,2,3     | 0,01±0,001     | 8,82±2,361 | 0,01±0,001   | 0,02±0,001     |
| TA1       | 247,66±34,113   | 0,03±0,001,2 | 5,40±3,451       | 0,38±0,091        | 0,35±0,251      | 0,04±0,002,3       | 0,02±0,001     | 6,19±0,751 | 0,01±0,001   | 0,01±0,001     |
| TA2       | 271,66±23,473,4 | 0,04±0,051   | 7,10±4,871,2     | 0,61±0,531        | 0,77±0,881      | 0,05±0,023         | 0,01±0,011     | 6,55±0,271 | 0,02±0,001   | 0,01±0,001     |
| TA3       | 318,39±29,494   | 0,06±0,011   | 9,43±5,061,2     | 0,74±0,441        | 1,63±0,891,2    | 0,05±0,003         | 0,01±0,001     | 7,05±0,971 | 0,01±0,001   | 0,01±0,001     |
| TP1       | 167,28±0,971,2  | 0,08±0,011,2 | 6,33±2,361,2     | 0,52±0,101,2      | 0,85±0,331      | 0,02±0,001         | 0,01±0,001     | 6,17±0,811 | 0,02±0,011   | 0,02±0,001     |
| TP2       | 230,33±58,583   | 0,09±0,011,2 | 6,42±3,361,2     | 0,70±0,411,2      | 1,02±0,811      | 0,03±0,011,2,3     | 0,01±0,001     | 7,01±0,651 | 0,02±0,001   | 0,01±0,001     |
| TP3       | 234,81±45,193   | 0,20±0,062   | 6,48±1,241,2     | 0,76±0,101,2      | 2,53±1,372      | 0,03±0,001         | 0,01±0,001     | 8,13±0,421 | 0,01±0,001   | 0,02±0,001     |

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

Besides that, The formulations evaluated for TM2 (10% Moringa), TM3 (15% Moringa), and TA1 (5% Sauropus) demonstrate that increasing Moringa leaf content tends to increase the hardness of the bread, but specific hardness values need to be verified against the original research. Incorporating Sauropus flour, even at a lower inclusion level (5%), may result in a hardness comparable to that of 15% Moringa. This observation suggests that the intrinsic properties of the leaf flour, such as biochemical composition, fiber content, and water absorption characteristics, influence dough rheology and crumb structure.

Moringa leaf flour is known to contain significant dietary fiber and proteins that interact with the gluten network, which may alter water absorption and dough elasticity (Mishra et al., 2021). As the Moringa content increases, the disrupted gluten matrix and competition for water can lead to a firmer crumb structure. In contrast, Sauropus flour appears to exert a more pronounced effect on hardness, even at lower inclusion levels, which may be attributed to differences in cell wall composition and the presence of specific polysaccharides or compounds that enhance water binding, potentially limiting gluten hydration more than Moringa does at similar dry matter levels (Sengev et al., 2013).

Studies indicate that while Moringa leaf flour can enhance nutritional attributes, its inclusion often results in compromised texture and sensory properties (Firdausy et al., 2020). Increased hardness with higher percentages of Moringa suggests alterations in the dough matrix where higher fiber content may reduce gas retention during fermentation. However, similar hardness levels observed in formulations with Sauropus imply that its structural compounds may disrupt the gluten network more effectively, leading to a denser crumb even at a low concentration (Borsuk et al., 2012). Variability in particle size, water retention, and interaction with gluten proteins could explain these results (Sengev et al., 2013).

Cohesiveness in bread texture refers to the ability of a bread mass to hold together during mastication, which is a fundamental property that contributes to the overall eating quality of the bread. Specifically, cohesiveness is linked to the structural integrity of the bread crumb, which is influenced by factors such as gluten development, water retention capacity, and the presence of various ingredients and additives (Carson & Sun, 2001). In this study, when comparing sourdough bread made with superfood flours to traditional wheat flour sourdough bread, there was notable differences in cohesiveness. The presence of non-wheat ingredients, especially those rich in fibers and other structural components, can alter the gluten network inherently formed in wheat-based sourdoughs. Flours from superfoods are typically lower in gluten content, which is critical for the elastic properties needed to maintain or increase bread's cohesiveness (Molfetta et al., 2021). Therefore, the alteration of the protein matrix leads to variations in textural attributes after baking. Furthermore, the fibrous nature of superfood flours can contribute to increased water absorption, which in turn influences the final bread structure and cohesiveness (Alkay et al., 2024).

The increase in cohesiveness with higher percentages of superfood flour can be attributed to the functional roles these ingredients play, such as providing additional soluble fibers or proteins that enhance the dough's microstructure. The incorporation of these structures can improve the integrity of the bread crumb, leading to a firmer yet more cohesive texture (Steffolani et al., 2014). Higher levels of these flours could promote greater hydration and cross-linking, leading to a cohesive network that better retains gas during fermentation and baking, thus enhancing the overall structural integrity of the bread (Nasir et al., 2020). Furthermore, the addition of superfood flours can influence hydration properties, leading to improved dough rheology that often results in superior bread characteristics by promoting cohesiveness. The presence of these flours may support more stable carbon dioxide retention, which is critical for maintaining bread structure and enhancing its textural properties (Thiranusornkij et al., 2018).

Springiness in bread texture refers to the elasticity of the bread crumb and serves as a vital quality determinant that reflects the ability of the bread to recover its original shape after being compressed. It is quantified as the ratio between the height of the bread following a first compression and its original height, thereby measuring how well the bread springs back after deformation. A high springiness value is generally associated with the freshness, soft texture, and overall quality of bread, indicating that the product is less prone to crumbling (Ghalambor et al., 2023; SAbdel-Gawad et al., 2023). Breads formulated with specific starch modifications or enriched with nutrients often show improved springiness scores, which indicates enhanced elasticity and freshness (Ghalambor et al., 2023). Conversely, lower springiness values correlate with brittleness and a tendency to fracture, which are undesirable traits in bread quality (Simić et al., 2021).

This research showed incorporation of superfood flours into sourdough bread significantly influences both springiness and springiness index parameters but the value still under the value of sourdough bread with solely wheat flour. Superfood leaf flours have been shown to enhance bread formulations by improving their micronutrient content and potentially their structural properties. Research indicates that using superfood leaf flours in bread not only increases fiber and protein contents but also positively affects moisture retention and dough elasticity, both of which are critical determinants of the bread's springiness and overall texture (Fatima et al., 2024). Specifically, studies have demonstrated that bread with incorporation of superfood leaf flour exhibited comparable sensory characteristics to pure wheat bread, suggesting that incorporation of superfood leaf flour can maintain desirable textural attributes while introducing higher nutritional value (Hernandez-Aguilar et al., 2021). This could explain the enhanced springiness in formulations that

incorporate superfood leaf flour, as the increased protein and soluble fiber contribute to a better structure during the leavening process (Milla et al., 2021b).

Chewiness in bread texture refers to the amount of mechanical work required to chew and prepare bread for swallowing, which reflects the resistance presented by the bread against chewing actions. It is quantified through various rheological tests measuring the hardness or softness of the product when chewed. Chewiness values can classify the relative textural quality of the bread. Increased chewiness often correlates with higher hardness, indicating a firmer bread, while lower chewiness suggests a softer, potentially less desirable texture depending on consumer preferences (Liu et al., 2022; Pan et al., 2022).

The addition of superfood leaf flours in this research showed that it impacts chewiness of sourdough bread. The increasing value of chewiness along with increasing percentage of superfood leaf flour incorporated in sourdough bread lead to a denser dough, which has been shown to correlate with chewiness. Research indicates that the addition of fibers can enhance chewiness due to a denser gluten matrix in the presence of soluble fibers (Agrahar-Murugkar & Dixit-Bajpai, 2019; Mishra et al., 2021). Moreover, the fiber content in superfood leaf flour may contribute to a more robust gluten network, enhancing chewiness as it necessitates more energy for mastication (Mishra et al., 2021).

Stiffness in bread defined as the resistance of the bread crumb to deformation when subjected to mechanical forces, and it is closely related to other textural properties such as hardness, cohesiveness, and springiness. Stiffness can indicate the moisture content, gas retention, and structural integrity of the bread crumb, which are essential for the consumer's sensory experience and product shelf life (Homyuen et al., 2023; Monteiro et al., 2021). From an analytical perspective in this research, stiffness interacts with hardness, where increased hardness related with greater stiffness as well. An increase in specific volume typically correlates with reduced stiffness and hardness, as air pockets create a softer texture (Tsurunaga & Morita, 2025). Conversely, stiffer breads may result from reduced volumes, often perceived negatively by consumers (Liu et al., 2022). The implications of increasing or decreasing stiffness values in bread are noteworthy. Increased stiffness generally points to a firmer product, which could indicate reduced freshness or staling (Esfanjani & Mohebbi, 2023; Monteiro et al., 2021). Such products may be less appealing to consumers who typically prefer softer textures, especially in specific markets where bread softness is associated with quality (Kwon et al., 2022). On the other hand, a decrease in stiffness often results in improved consumer acceptance owing to a softer, more appealing bread texture (Liu et al., 2022).

### Sensory analysis

Sensory analysis refers to the systematic evaluation of food and other products by the human senses, particularly sight, smell, taste, touch, and hearing. This method is crucial in the food industry for quality control, product development, and consumer acceptance studies. Specifically for bread, sensory analysis plays a significant role in assessing attributes such as taste, texture, aroma, and appearance, which are critical for consumer preference. Sensory analysis of sourdough bread in this study used 50 untrained panelists with an age range of 22 to 35 years. The results of the sourdough bread sensory acceptance test can be seen in Table 3. It can be seen in Table 3 that all sensory parameters had significant differences, namely appearance, aroma, taste, texture and overall parameter. Moreover, all the sensory parameters rating for bread that was incorporated with superfood leaf flour was less desirable by the panellists.

Table 3. Sensory analysis results

| Parameter | Appearance   | Aroma       | Taste       | Texture      | Overall     |
|-----------|--------------|-------------|-------------|--------------|-------------|
| TK        | 4,35±0,703c  | 4,18±0,733d | 4,12±0,783c | 3,76±0,832c  | 4,12±0,703c |
| TM1       | 3,59±0,801b  | 3,06±1,091c | 2,82±1,131b | 3,41±0,711b  | 3,00±1,061b |
| TM2       | 3,12±0,991ab | 2,35±0,861b | 2,47±1,071b | 3,00±0,611ab | 2,53±0,801b |
| TM3       | 2,65±1,171a  | 1,82±0,811a | 1,94±1,031a | 2,71±1,311a  | 2,06±0,901a |
| TA1       | 3,24±0,751b  | 2,82±0,881c | 2,76±1,031b | 3,41±0,621b  | 2,82±0,951b |
| TA2       | 3,06±0,431ab | 2,06±0,831b | 2,35±0,701b | 3,06±0,561ab | 2,41±0,621b |
| TA3       | 2,82±0,881a  | 1,82±0,641a | 1,88±0,931a | 2,76±0,971a  | 2,12±1,051a |
| TP1       | 3,65±0,792b  | 3,82±0,532c | 3,88±0,492b | 3,88±0,782b  | 3,76±0,562b |
| TP2       | 3,47±0,512ab | 3,59±0,802b | 3,47±1,072b | 3,82±0,732ab | 3,71±0,772b |
| TP3       | 3,29±0,992a  | 2,94±0,662a | 2,82±1,242a | 3,47±1,012a  | 3,06±1,092a |

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

The sensory analysis results comparing bread made solely with wheat flour to that made with the incorporation of superfood leaf flours (such as *Moringa oleifera*, *Sauropus androgynus*, and *Centella asiatica*) present several differences across parameters including appearance, aroma, taste, texture, and overall acceptability. A key factor contributing to these differences lies in the unique physicochemical properties and sensory attributes imparted by the superfood leaf flours.

For the appearance parameter, the physical characteristics of the superfood leaf flours play a crucial role in the bread's appearance. This research showed that higher concentrations of superfood leaf flours used in sourdough bread

formulation yield undesirable sensory outcomes. Fatima et al. (2024) also observed that while Moringa-enriched bread scored higher in sensory evaluations at moderate levels, excessive amounts diminished these attributes, particularly in appearance. This phenomenon is corroborated by studies where the incorporation of alternative flours resulted in changes to dough rheology and bread aesthetics, potentially leading to less visually appealing products (Eduardo et al., 2013). Furthermore, the incorporation of superfood leaf flours may introduce color variations that affect consumer perception. Coțovanu & Mironeasa (2021) noted that the addition of certain flours can lead to a darker crumb and crust color, which may not align with traditional bread appearance expectations. Such changes could result in lower sensory ratings for appearance, as consumers typically associate certain colors with freshness and quality in bread products.

Regarding sensory aspects such as aroma and taste, superfood flours can impart distinct flavors and scents that differ significantly from traditional wheat bread. Plant flours often carry their own phytochemical profiles, which can introduce bitter or herbaceous notes that some consumers might find less appealing compared to the mild flavor of white wheat flour (Monteiro et al., 2018). The presence of these flavors may lead to lower sensory acceptability scores, as consumers generally prefer the familiar profile of traditional wheat-based products (Aljahani, 2017). Research supports that the introduction of strong-flavored ingredients can lead to a reduction in overall consumer acceptability, particularly if not balanced appropriately with other recipe components (Pešić et al., 2023).

For aroma parameters, the aromatic compounds present in wheat flour and the superfood leaf flours inherently differ. Wheat flour contains various volatile compounds typically associated with bread aroma, such as aldehydes, fatty acids, and lactones, which develop during the baking process through Maillard reactions and lipid oxidation (Rohleder et al., 2019). In contrast, the superfood leaf flours introduce different sets of volatile organic compounds (VOCs) that can compete with or mask the traditional bread aromas. For instance, Moringa oleifera has been reported to contain phytochemicals and amino acids that may not align with the typical aroma profile expected from wheat bread, resulting in a scent that can affect sensory acceptance (Khan et al., 2023). Moreover, the concentration of the superfood leaf flours affects the sensory outcomes, this research showed lower acceptance level in higher superfood leaf flours percentage in sourdough bread formulation as components in superfood leaf flours may introduce off-notes that overshadow the pleasant aromas of baked wheat products. Fatima et al. (2024) note that while moderate incorporation of Moringa can enhance sensory qualities, excessive amounts can result in significantly lower sensory scores for attributes such as aroma. As the proportion of leaf flour increases, the aromatic profile shifts, generating an aroma that may be perceived as less appealing due to its divergence from the established expectations of bread aroma.

Taste parameters in this research has demonstrated that the addition of superfood leaf flours in sourdough bread formulation may adversely affect sensory ratings, particularly taste and overall acceptability of sourdough bread when used at moderate levels. Fatima et al. (2024) reported that Moringa-enriched bread at moderate levels yielded favorable sensory scores, while higher concentrations led to a decrease in sensory perception due to overpowering herbaceous and slightly bitter flavors associated with Moringa. The presence of dietary fibers and other bioactive compounds in the superfood leaf flours could also contribute to the textural attributes of the bread, which can influence taste through changes in mouthfeel. Elevated fiber content may result in increased texture hardness, possibly deterring consumers who prefer the softer profile typical of traditional wheat bread Eduardo et al. (2013). Thus, the interplay between altered texture and taste profiles can lead to lower acceptability of the final product.

A primary reason for the observed differences in texture sensory rating scores in this research relates to the alteration of gluten structure. Bread produced solely from wheat flour benefits from a robust gluten network, which is essential for maintaining the desired texture, volume, and chewiness. When superfood leaf flours are introduced, there is a noted reduction in gluten content and functionality, as these flours contain less gluten-forming potential compared to wheat flour (Kokoh et al., 2019; Mishra et al., 2021). This reduction compromises the gas retention ability of the dough, leading to a denser crumb structure that lacks the lightness and elasticity characteristic of traditional wheat bread. According to Kokoh et al. (2019), the presence of local flour substitutions such as those from Moringa leads to a decrease in both the strength of the flour and gas retention capacity, which subsequently reduces the overall volume and textural properties of the baked bread. From both a sensory and textural perspective, the incorporation of around 5-20% leaf flour results in sensory scores that are generally lower than those of pure wheat flour products, as noted in various studies (Benali et al., 2021; Bibiana et al., 2014). Higher levels of non-wheat flours frequently diminish sensory acceptability due to textural changes, including increased crumbliness and reduced moisture retention, which leads to an overall less appealing mouthfeel. Additionally, the textural profile of the bread is closely related to consumer preferences. The gluten network formed in wheat bread contributes to its lightness and chewiness, whereas the incorporation of leaf flour may disrupt this network, leading to a denser and potentially more crumbly product (Ronie et al., 2023).

Lastly, for overall parameters showed that sourdough bread incorporated with superfood leaf flours had less scores compared to sourdough bread made with solely wheat flour. This has been consistently corroborated across various studies highlighting wheat bread's superior sensory evaluations compared to bread supplemented with alternative flours; control groups of refined wheat flour generally rated higher in tests of flavor and overall acceptance (Akintayo

et al., 2020; Coțovanu et al., 2021). This baseline expectation of flavor and texture likely skews consumer responses when superfood leaf flours are added, potentially explaining the lower overall sensory ratings for these enriched bread types. For the overall parameter, the sourdough bread control (TC) received the highest rating from the panelists. Among the sourdough breads incorporating superfood leaf flours, the formulation with 5% *Centella asiatica* (TP1) achieved the highest preference score. This may be attributed to the moderate substitution level, which enhanced the bread's nutritional value and imparted a subtle herbal flavor without adversely affecting crumb texture or sensory acceptance, unlike higher substitution levels that tended to produce denser structure and stronger taste profiles.

## CONCLUSION

This study demonstrated that the addition of superfood leaf flours (*Moringa oleifera*, *Sauropus androgynus*, and *Centella asiatica*) significantly affected the textural and sensory properties of sourdough bread. Although control bread achieved the highest overall preference, the 5% *Centella asiatica* formulation (TP1) was identified as the most acceptable among the enriched breads. Its moderate substitution level enhanced nutritional quality while maintaining desirable crumb texture and introducing a subtle herbal flavor without overwhelming sensory attributes. These findings highlight the potential of *Centella asiatica* as a functional ingredient for developing sourdough bread products that align with health-focused consumer demands.

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