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# Effect of sweet potato flour substitution on the sensory characteristics of mini bun bread using principal component analysis

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**Abstract.** Indonesia's growing dependence on imported wheat flour highlights the need to incorporate local carbohydrate sources into bakery products. This study evaluated mini bun bread in which wheat flour was partially substituted with orange-fleshed sweet potato flour (0–30%) and examined the resulting sensory characteristics using both univariate and multivariate approaches. Mini buns were produced using a completely randomized design and assessed by 25 semi-trained panelists for colour, aroma, taste, and texture on a five-point hedonic scale. ANOVA and Tukey's test were applied, followed by principal component analysis (PCA) of mean sensory scores. Substitution levels of 10–20% yielded hedonic scores for all attributes comparable to the control, with 20% substitution providing the most desirable colour and aroma, and 10% the highest scores for taste and texture. At 30%, texture decreased significantly. PCA showed that two principal components explained 100% of the variance, with colour and aroma closely associated with 20% substitution and texture negatively associated with 30%. Overall, 10–20% sweet potato flour is recommended as an optimal range, whereas higher levels would require technological improvements to maintain texture.

## 1 Introduction

Bakery products, particularly bread, are among the most widely consumed processed foods in Indonesia, and their demand continues to increase. This growth has been accompanied by a strong dependence on imported wheat flour, as wheat is not cultivated commercially in the country. Recent national statistics indicate that wheat and meslin imports exceeded 10 million tons in 2023 and are approaching 11 million tons, exposing the food system to international price volatility and geopolitical disruptions [1]. In this context, incorporating locally available carbohydrate sources into bakery formulations is a strategic option to support food diversification and enhance food security.

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Sweet potato (*Ipomoea batatas L.*) is an important root crop in Indonesia and is widely grown, including on marginal lands less suitable for cereals. Although its harvested area and total production have slightly declined in recent years, sweet potato remains a significant component of local agriculture [2]. Beyond its agronomic adaptability, sweet potato is rich in complex carbohydrates, dietary fibre, provitamin A carotenoids (especially in orange-fleshed varieties), antioxidants, and other bioactive compounds [3]–[5]. When incorporated into staple foods, these components can contribute to improved diet quality, making sweet potato flour a promising partial substitute for wheat flour in bakery products with potential nutritional and socio-economic benefits.

However, the technological constraints associated with using sweet potato flour in bread and buns are well documented. Sweet potato flour is essentially gluten-free and differs from wheat flour in starch morphology, fibre content, and water-binding behaviour. Partial replacement of wheat flour dilutes the gluten network, alters water distribution between gluten and non-gluten components, and reduces gas retention during proofing [6]–[8]. These changes typically result in decreased loaf volume, firmer crumb, and reduced elasticity at higher substitution levels. Studies on breads, steamed breads, and noodles produced from wheat–sweet potato composite flours consistently report a trade-off: moderate substitution levels can improve colour, antioxidant capacity, and nutritional value, whereas excessive substitution often leads to harder texture and lower overall acceptability. This pattern suggests the existence of an optimal substitution range that maintains acceptable sensory quality while delivering functional benefits, but the specific range appears to be product- and formulation-dependent.

Most previous research on sweet potato–based bakery products have focused on physicochemical and nutritional properties combined with univariate sensory analysis. Sensory attributes such as colour, aroma, taste, and texture are frequently evaluated separately using analysis of variance and mean comparisons, and conclusions are drawn attribute by attribute relative to wheat controls [9]–[14]. This approach does not fully account for the fact that sensory variables are often correlated; for example, changes in crumb softness may co-occur with changes in moistness and overall liking. As a result, the overall sensory profile associated with different substitution levels, and the joint contribution of attributes to consumer acceptance, remain insufficiently characterised, particularly for mini bun bread formulated with sweet potato flour.

Multivariate techniques such as principal component analysis (PCA) offer a powerful way to address these limitations [15]. PCA can reduce complex, correlated sensory datasets into a small number of independent components that capture most of the variation, thereby revealing patterns among samples and visualising relationships between products and sensory descriptors in a single map. In bakery research, PCA has been used to combine instrumental texture data with descriptive or hedonic sensory scores, to identify the attributes that most strongly influence perceived quality, and to distinguish clusters of formulations with similar sensory characteristics [16], [17]. When applied to hedonic data, PCA can show how overall liking aligns with specific attributes such as aroma, texture, or taste and thus provide more informative guidance for product optimisation than univariate analyses alone. Despite these advantages, the integration of hedonic sensory testing with PCA in the context of sweet potato flour substitution in mini bun bread has received limited attention.

Therefore, the present study was designed with two main objectives. First, it evaluates the effect of substituting wheat flour with orange-fleshed sweet potato flour at different levels on the organoleptic characteristics of mini bun bread, focusing on consumer hedonic scores for colour, aroma, taste, and texture. Second, it applies PCA to the sensory data to explore interrelationships among attributes, identify the dominant sensory dimensions associated with higher acceptance, and determine substitution levels that balance technological feasibility with consumer preference. The findings are expected to contribute to the understanding of composite flour technology in soft bakery products and to provide practical recommendations for bakeries interested in incorporating sweet potato flour into mini bun formulations.

# 2 Materials and Methods

## 2.1. Materials and equipment

The main materials used in this study were medium-protein wheat flour as the control and sweet potato flour prepared from fresh orange-fleshed sweet potatoes with uniform tuber size (approximately 150–250 g) and free from defects. The roots were peeled, sliced, dried, and milled into fine flour. Additional ingredients included instant yeast, granulated sugar, milk powder, margarine, salt, and water. The main equipment consisted of a bread mixer for dough preparation, an electric oven for baking, a digital balance for weighing, and standard laboratory glassware. Statistical analyses were performed using SPSS for analysis of variance (ANOVA) and XLSTAT/Minitab for principal component analysis. Radar charts (spider diagrams) were created using Microsoft Excel to visualize sensory profiles.

## 2.2. Experimental design

The experiment employed a Completely Randomized Design (CRD) with one factor, namely the substitution level of sweet potato flour for wheat flour. Three treatments were applied: P1 (10% substitution), P2 (20% substitution), and P3 (30% substitution). Each treatment was replicated three times, resulting in a total of 15 experimental units. This design was selected to minimize experimental bias and ensure that variations observed were attributable to the treatments.

## 2.3. Preparation of mini bun bread

The bread-making process began with preparing the ingredients according to the formulation. Wheat flour, sugar, milk powder, salt, and yeast were mixed together, after which water was gradually added until the dough became elastic. Margarine was incorporated once the dough reached a half-elastic stage, followed by further kneading until fully developed. The dough was subjected to a first fermentation at room temperature for approximately 45 minutes until it doubled in volume. The dough was then divided into smaller portions, shaped into mini buns, and allowed to undergo a second fermentation for about 30 minutes. Baking was carried out at ±180°C for 15 minutes, after which the bread was cooled at room temperature before sensory evaluation, following the straight-dough method adapted from [18].

## 2.4. Sensory evaluation

Sensory evaluation involved 25 semi-trained panelists, comprising students and lecturers in the field of food technology. A five-point hedonic scale was used, where 1 = "dislike very much" and 5 = "like very much." The sensory attributes assessed were color, aroma, taste, and texture. Samples from each treatment were presented to the panelists in a randomized order to minimize bias in evaluation. The procedure for sample presentation, panelist instruction, and use of the hedonic scale followed the Indonesian National Standard SNI 2346:2015, which provides general guidelines for sensory testing of food products, with minor adjustments for bakery items.

### 2.5. Data analysis

The sensory data were analyzed using analysis of variance to determine the effect of sweet potato flour substitution levels on each sensory attribute, following standard procedures for sensory and consumer tests. When significant differences were detected, Tukey's honestly significant difference test at a 5% significance level was applied to identify treatments that differed significantly [19]. In addition, principal component analysis was performed on the matrix of mean sensory scores for each treatment to summarize correlations among color, aroma, taste, and texture and to identify the main sensory dimensions that discriminate the substitution levels. The choice and implementation of principal component analysis followed recommendations for multivariate analysis of sensory data in Statistics for Sensory and Consumer Science. The sensory profiles of the mini bun breads were further visualized using radar charts with four axes (color, aroma, taste, and texture), which enabled straightforward comparison of the overall sensory patterns between the control and breads containing different levels of sweet potato flour [20], [21].

## 3 Results and Discussion

### 3.1 Sensory evaluation results

The hedonic test results for the four sensory attributes (color, aroma, taste, and texture) indicated that the substitution of sweet potato flour significantly influenced several parameters. ANOVA revealed significant effects on color ($p = 0.00024$), aroma ($p = 0.0078$), and texture ($p = 3.96 \times 10^{-8}$), while taste did not differ significantly ($p = 0.121$). The descriptive statistics (mean ± SD) and the Tukey's HSD grouping for each attribute are summarized in Table 1, which provides a clear comparison of sensory performance across substitution levels.

**Table 1.** Mean ± SD of sensory attributes of mini bun bread substituted with sweet potato flour and Tukey's HSD grouping. Means within the same attribute followed by different letters are significantly different ($p < 0.05$) according to Tukey's HSD test.

| Attribute | Substitution (%) | Mean ± SD | Tukey grouping* |
|---|---|---|---|
| Color | 10% | 3.48 ± 0.59 | b |
| | 20% | 4.12 ± 0.60 | a |
| | 30% | 4.08 ± 0.57 | a |
| Aroma | 10% | 3.64 ± 0.64 | b |
| | 20% | 4.24 ± 0.72 | a |
| | 30% | 3.76 ± 0.72 | b |
| Taste | 10% | 4.28 ± 0.61 | a |
| | 20% | 3.92 ± 0.64 | a |
| | 30% | 4.04 ± 0.61 | a |
| Texture | 10% | 4.32 ± 0.56 | a |
| | 20% | 3.76 ± 0.72 | b |
| | 30% | 3.08 ± 0.70 | c |

*Different superscript letters in the same column indicate significant differences at $p < 0.05$ according to Tukey's HSD test. SD = standard deviation

The mean hedonic scores indicated that mini bun bread with 10% sweet potato flour substitution (P1) received the highest scores for taste (4.28) and texture (4.32) from the panelists. At 20% substitution (P2), improvements were observed in color (4.12) and aroma

(4.24), although the texture score declined to 3.76. By contrast, 30% substitution (P3) resulted in the lowest texture score (3.08), despite still achieving relatively good color (4.08). These findings confirm that higher substitution levels (>20%) compromise bread texture, consistent with previous studies reporting that local flour substitutions often reduce the structural quality of bakery products [22], [23].

### 3.2 Sensory profile analysis using radar charts

To provide a more comprehensive visualization of the sensory profiles across substitution levels, the mean hedonic scores were plotted in a radar chart (Figure 1). The sensory profiles were further visualized using radar charts (spider diagrams) to provide a holistic comparison of treatments. The diagram clearly demonstrated that treatments P1 (10%) and P2 (20%) shared sensory patterns closely resembling the control (P0), particularly in taste and aroma. On the other hand, P3 (30%) displayed a marked reduction in texture, shown by the narrowing of the radar plot along the texture axis. This visual evidence supports the statistical results, highlighting texture as the most affected attribute at higher substitution levels. Radar charts thus proved effective in illustrating the balance of sensory attributes and in identifying which treatments remained acceptable to panelists.

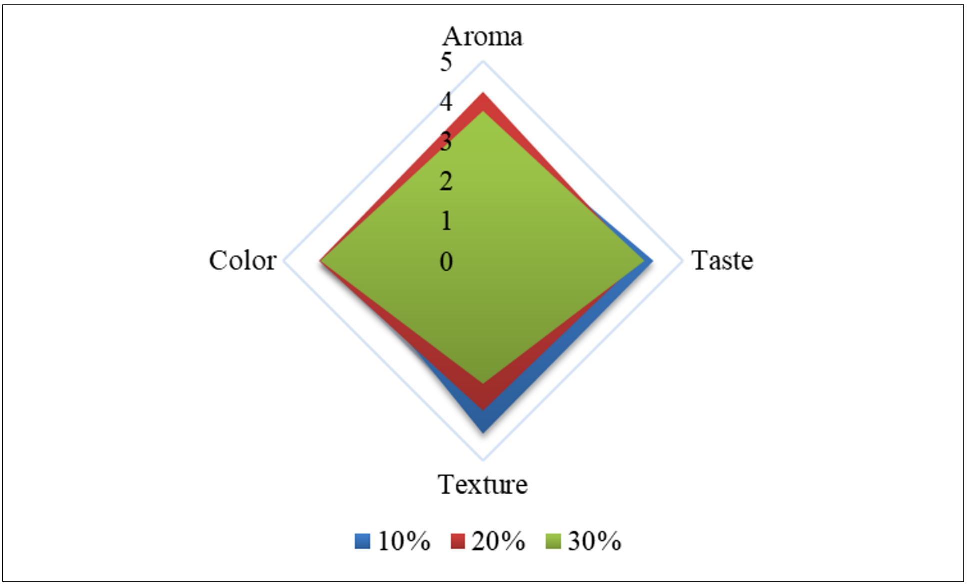


**Fig. 1**. Radar chart of sensory profiles (mean scores) of mini bun bread with different levels of sweet potato flour substitution

### 3.3 Principal component analysis

To further explore the relationships among sensory attributes and to identify the dominant factors driving differences among treatments, PCA was conducted on the mean hedonic scores. The first principal component (PC1, shown on the horizontal axis as F1) explained 77.37% of the total variance, whereas the second principal component (PC2, vertical axis F2) accounted for 22.63%, giving a cumulative variance of 100.0%. Thus, the two-dimensional biplot in Figure 2 provides an adequate summary of the sensory data.

In the biplot, blue vectors represent sensory attributes, and red points represent the substitution levels (10%, 20%, and 30% sweet potato flour). Attributes that point in a similar direction are positively correlated, while attributes located in opposite directions are negatively related. Treatments that lie close to a given attribute vector are interpreted as having higher scores for that attribute.

Color and aroma load strongly and positively on F1 and are positioned in the same quadrant as the 20% substitution, indicating that mini buns with 20% sweet potato flour are mainly characterized by more attractive color and aroma. Texture loads positively on F2 and in the opposite direction from the 30% treatment, showing that 30% substitution is associated with a marked decline in texture quality. The 10% substitution appears on the left side of the plot, near the taste vector, suggesting only a modest differentiation in taste but overall acceptable sensory performance. Taste lies close to the origin, indicating limited contribution to sample discrimination compared with color, aroma, and texture. Collectively, these patterns reinforce that texture is the critical attribute limiting consumer acceptance at higher substitution levels, whereas moderate substitution (around 20%) improves color and aroma without severely compromising overall liking.

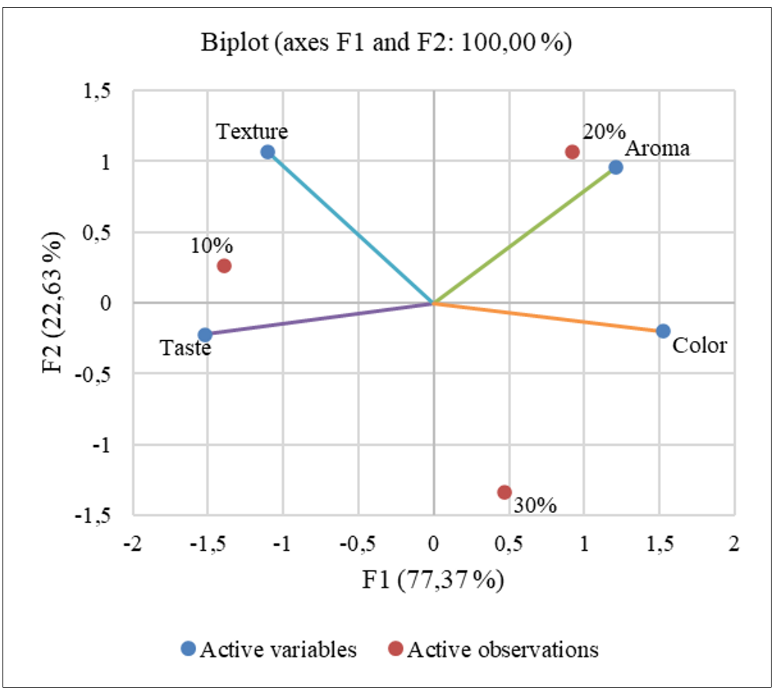


**Fig. 2**. PCA biplot of sensory attributes of mini bun bread with different levels of sweet potato flour substitution

## 4 Discussion and implications

This study provides new insights into the use of sweet potato flour as a partial substitute for wheat flour in mini bun bread, with an emphasis on sensory quality and the joint behaviour of sensory attributes. The hedonic scores indicated that mini buns containing up to 20% sweet potato flour were generally well accepted, with colour, aroma, taste, and texture scores comparable to the control. In contrast, the 30% substitution level led to a marked reduction in texture scores, despite maintaining relatively good colour and aroma. These findings are consistent with previous reports that incorporating local flours can enhance the perceived nutritional or visual appeal of bakery products but may compromise structural and textural quality when substitution levels become too high [8–12].

The improvement in colour and aroma at 20% substitution can reasonably be linked to natural pigments and flavour precursors present in orange-fleshed sweet potato flour, which may participate in Maillard reactions and contribute to a more appealing crust and crumb appearance. Conversely, the decline in texture at higher substitution levels is in line with the expected weakening of the gluten network. As sweet potato flour replaces wheat flour, the viscoelastic gluten matrix responsible for gas retention and crumb softness is progressively diluted, resulting in denser crumbs and firmer texture [9,10]. The radar chart clearly illustrated this pattern: while the overall sensory profiles of 10% and 20% substitution treatments closely resembled the control, the 30% treatment was characterised by a pronounced narrowing along the texture axis, highlighting texture as the most sensitive attribute to excessive substitution. Interestingly, taste scores remained relatively stable across all substitution levels, suggesting that sweet potato flour does not introduce prominent off flavours that would limit consumer acceptance within the tested range.

The multivariate analysis complements and strengthens these univariate observations. PCA condensed the four sensory attributes into two principal components that together explained all of the variance in the mean hedonic scores, indicating that a two-dimensional representation was sufficient to describe the sensory differences among treatments. Colour and aroma loaded strongly and positively on the first principal component and were closely associated with the 20% substitution treatment, confirming that mini buns with 20% sweet potato flour were primarily characterised by more attractive appearance and aroma. Texture loaded mainly on the second principal component and lay opposite to the 30% substitution treatment, indicating that high substitution levels were defined by poorer texture. Taste was located near the origin of the biplot, reflecting its limited contribution to discriminating samples compared with colour, aroma, and texture. Taken together, these results show that texture is the critical attribute limiting consumer acceptance at higher substitution levels, whereas moderate substitution around 20% improves colour and aroma without severely compromising overall liking.

From an application perspective, the ability to substitute wheat flour with 10–20% sweet potato flour offers a practical strategy to reduce dependence on imported wheat while maintaining acceptable sensory quality in mini bun bread. Although this study did not quantify nutritional parameters such as β-carotene, fibre, or antioxidant capacity, the use of orange-fleshed sweet potato flour is likely to enhance the nutritional profile of the product, as suggested by previous literature on sweet potato–based foods [8,11–13]. Thus, mini buns formulated with 10–20% sweet potato flour could be positioned as products that support both dietary diversification and the utilisation of local crops. However, the clear deterioration in texture observed at 30% substitution underscores the need for technological interventions when higher levels of wheat flour replacement are targeted. Potential approaches include using hydrocolloids, enzymes such as xylanase or transglutaminase, or emulsifiers to strengthen dough viscoelasticity and preserve desirable crumb softness and elasticity [14,15].

Beyond formulation strategies, the findings also have broader implications for the development and scaling of composite-flour bakery products in Indonesia. The acceptable sensory performance of mini buns with 10–20% sweet potato flour suggests that small- and medium-scale bakeries could adopt such formulations with minimal risk of consumer rejection. Educational production units and pilot-scale facilities can serve as platforms to translate these formulations into practice, adapt them to local preferences, and evaluate their market potential. Future research could build upon the present work by combining flour substitution with dough improvers or alternative fermentation methods, such as sourdough, to further mitigate texture defects at higher substitution levels while preserving the potential nutritional and functional advantages of sweet potato flour. In addition, integrating instrumental texture measurements and compositional analyses with consumer-centered multivariate sensory modelling would provide a more comprehensive basis for optimizing sweet potato–based bakery products.

## 5 Conclusion

Based on the hedonic scores, partial substitution of wheat flour with sweet potato flour in the range of 10–20% produced mini buns with color, aroma, taste, and texture scores that were comparable to the control, indicating that these levels are acceptable to consumers. The 20% substitution level gave the highest scores for color and aroma, while taste remained relatively stable across all treatments. In contrast, the 30% substitution level significantly reduced texture scores, confirming that excessive substitution weakens crumb softness and overall mouthfeel.

Principal component analysis summarized the sensory data into two principal components that together explained almost all of the variance. Color and aroma were positively associated with the 20% substitution treatment, whereas texture was strongly and negatively associated with the 30% substitution treatment. Taste contributed little to the differentiation among samples. These multivariate results confirm that texture is the critical attribute limiting consumer acceptance at higher substitution levels, while improvements in color and aroma are mainly obtained at moderate substitution.

In practical terms, incorporating 10–20% sweet potato flour in mini bun formulations can be recommended as an optimal range that balances sensory quality with the aim of utilizing local carbohydrate sources. Higher substitution levels would require additional technological adjustments, such as the use of improvers or hydrocolloids, to compensate for texture deterioration.

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