

INDIGENOUS CROP-BASED BREAD AS A STRATEGY FOR REDUCING MALNUTRITION AND IMPROVING PUBLIC HEALTH

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Abstract

This study assessed the potential of soy okara, an underutilized by-product of soybean processing, as a functional and nutritional enhancer in wheat bread formulation for affordable and health-oriented consumption. Four bread formulations were developed: WSB1 (100 % wheat flour), WSB2 (90 % wheat:10 % soy okara), WSB3 (80 % wheat:20 % soy okara), and WSB4 (70 % wheat:30 % soy okara). The samples were evaluated for proximate composition, functional properties of the flour blends, physical bread characteristics, and sensory attributes. Statistical analysis was performed using ANOVA and Duncan's Multiple Range Test at $p < 0.05$ and the experimental design employed for the study was a Completely Randomized Design. Results showed a progressive increase in protein (from 9.38 % in WSB1 to 13.76 % in WSB4), fat (3.81 % to 7.21 %), and fibre content (3.0 % to 4.60 %) with increasing okara inclusion, while carbohydrate content decreased and Moisture content also increased. Functional properties of composite flours such as bulk density, swelling index, water and oil absorption capacities improved in WSB2 and WSB3 but dropped significantly at 30% substitution (WSB4). Physical properties showed that loaf volume and specific volume were highest in WSB2 (327 mL, 1.52 mL/g). Sensory evaluation revealed that WSB1 and WSB2 were most preferred in terms of appearance, taste, texture, and overall acceptability, with WSB2 achieving the highest general acceptance among the composite samples. Incorporating soy okara at 10 % – 20 % improved the nutritional and functional properties of bread without adversely affecting sensory and physical quality. WSB2 (90 % wheat, 10 % okara) emerged as the most preferred formulation, balancing enhanced nutrition with consumer acceptability. This study supports the use of soy okara as a cost-effective, functional ingredient for developing nutrient-enriched bread suited to low-income, health-conscious populations and addressing malnutrition.

Keywords: Indigenous Crops, Bread and Wheat Flours, Sensory evaluation, Physical properties, Proximate properties, Functional properties, Soy okara.

Introduction

Public health in Nigeria is still weighed down by malnutrition, most notably among economically disadvantaged populations (Obada et al., 2021). Stunting and wasting are currently afflicting more than 17 million children under the age of five in Nigeria, one of the worst malnutrition burdens in the world (World Health Organization and United Nations Children's Fund, 2020). Great reliance on refined wheat flour to prepare common foods such as bread plays into this issue and usually leads to a low intake of essential nutrients (Noort et al., 2022). This dependence is one of the major causes of problems with nutrient imbalances as well as non-communicable health problems. In an attempt to correct this, the Nigerian government adopted "National Multi-Sectoral Plan of Action for Food and Nutrition (NMPFAN) 2021–2025" with an aim of reducing malnutrition to 50 percent and stunting in under-five children to 18 percent by 2025. However, projections show that more than 31 million Nigerians are now at risk of an acute food shortage, mainly affected by phenomena, such as insecurity, climate change, and economic disparity; leading to the shift to the production of bread from local crops to combat malnutrition and safeguard public health in low-income communities (Olunusi et al., 2024).

Bread is a common meal in today's world because it is cost effective, easy to prepare and it contains many nutrients. Bread is a principal component in the everyday food of millions of people, especially in developing countries (Collar, 2015). Traditionally bread was prepared using mostly wheat flour as an ingredient which is processed and rich in carbohydrate and gluten-forming proteins essential for dough cohesion and elasticity (Suchintita et al., 2023). As consumers continue to demand healthier and more sustainable food, composite flours have come into the spotlight: mixtures of wheat flour with non-wheat flours derived from legumes, cereals, tubers and agro-industrial waste products. Soy okara is one by-product. Nigeria has many indigenous agricultural resources that are very underexploited. Soy okara is another useful product that is not appraised, a fibrous by-product of soy milk production. Paradoxically, soy okara has shown promise for promoting glucose tolerance, and lipid levels owing to its high content of dietary fibre, protein and micronutrients, thus contributing to the prevention of metabolic disorder efforts. Its potential notwithstanding, soy okara incorporation into food formulations has been given little attention that has seen a large volume of waste and hindered efforts towards improved nutrition. (Li B et al., 2012).

Despite its high levels of dietary fibre, proteins, lipids, and bioactive compounds, okara is more commonly discarded rather than used, and used only as animal feed (Asghar et al., 2023). Disposal of okara has environmental and economic challenges to manage. However, recent discoveries show that okara has a lot of nutritional benefits and could be a vital ingredient used to create composite flours for such uses as bread (Erenstein et al., 2022). Wheat flour has been the preferred product for bread making over the years due to its favorable baking characteristics. Gluten in wheat creates a network during fermentation that traps gas that adds to both the appearance and size of bread (Meybodi et al., 2019). However, this dependence on imported wheat in most developing countries makes bread production vulnerable to foreign exchange rate and global market enumeration (Ebi et al., 2021). Besides, the amino acid, lysine and other essential nutrients, dietary fibre, and certain vitamins and minerals are typically deficient in wheat-based bread, which has led to the use of enriched bread or adding nutrient-dense content (Schmidt et al., 2023).

Composite flour technology was developed in the 1950s as an important program to reduce dependence on wheat and enrich staple food content. This strategy combines wheat flour with regionally available, nutrient-rich elements including legumes (such as soybeans and cowpeas), roots and tubers (such as cassava and sweet potatoes) and by-products of cereal grains (e.g.; bran and okara) (Kunlere, 2025). Composite flours are with particular benefit in resource-poor and economically hard-pressed backgrounds as it offers nutritional insecurity and influences food access and quality (Li et al., 2012). Soy okara contains approximately 25% dietary fibre and 15% protein by dry weight and contains essential amino acids prevalent in cereals yet to be found in wheat. Furthermore, amino acid profiles of these blends have shown supremacy to individual parts in several critical points (Nwankwegu et al., 2024). Bioactive compounds in soy okara, such as isoflavones, antioxidants, occur in soy okara (Usman et al., 2024) and as such, these active compounds can share in promoting health outcomes such as lowered cholesterol, improved glycemic regulation, and improved digestive health. The application of okara to wheat bread production is in line with general sustainable development objectives, especially in regard to waste reduction and nutrition-conscious agriculture development. In order to help producers create a sustainable circular economy that minimizes environmental damage while contributing to community well-being, Haruna et al. (2017) state that transforming soy okara into a useful food element is important. This approach helps small food processors leverage regional materials in manufacturing local products, thereby creating employment opportunities and food system robustness.

The adoption of composite flour technology in Nigeria and other Sub-Saharan countries is increasing due to the government strategies of wheat importing limitations and increased food self-sufficiency (Liu et al., 2024). Through the addition of soy okara to composite flour blends, producers can develop affordable, nutrient-dense, and culturally appropriate foods appropriate for low-income communities. Now, since functional foods are being preferred for their extra health benefits attached to the mainstream nutrition, Bread enriched with soy okara can serve as a powerful dietary intervention against malnutrition, non-communicable diseases and food insecurity. Application in bread making using soy okara may present a financially attractive alternative way of enhancing the nutritional profile of a regularly used staple, addressing problem of food insecurity. The use of soy okara in bread can be used to make nutritional enhancement of a commonly consumed staple at low cost to overcome food insecurity and public health problem. It also promotes some form of climate adaptation by reducing agricultural waste and advancing environmental sustainability as reported by Sanful et al (2010). In addition, the use of soy okara as a local resource strengthens food system resilience, reduces dependence on imported wheat, and supports both food sovereignty and peacebuilding efforts by establishing regional value chains. The objective of this study is to develop and evaluate bread products enriched with soy okara flour as a means to promote nutritional well-being and food system sustainability in low-income Nigerian populations.

Materials and methods

Materials and sample preparation

Wheat flour was bought from the international market in Abakaliki, Ebonyi State, Nigeria and Fresh okara was collected immediately after soymilk extraction. All chemicals and equipment used were of analytical grade.

Sample preparation

Fresh okara flour was produced as described by Liu (2024) with slight modifications. Fresh soy okara was collected immediately after soymilk extraction to prevent microbial spoilage. Excess moisture (80 % in fresh soy okara) was removed using muslin cloth and cutting for uniform (5 mm thick) and efficient drying. It was dried in a hot air oven (70 °C for 8 hours) and ground into fine flour using hammer mill (Fritsch GmbH, Germany), sieved (500 µm), packaged (airtight containers) and stored under proper storage conditions (27 °C) for analysis as shown in figure 1.

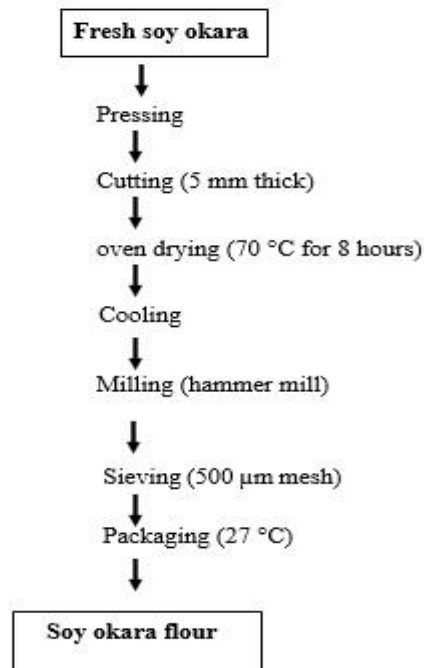


Figure 1: Production of soy okara flour

The wheat and soy okara flour were blended in various ratios as shown in Table 1.

Table 1: Formulations of wheat and soy okara flour blends

Sample Code	Wheat Flour (%)	Soy Okara Flour (%)
WSB1 (Control)	100	0
WSB2	90	10
WSB3	80	20
WSB4	70	30

Key = WSB1 (Control) = 100 % wheat flour and 0 % soy okara flour, WSB2 = 90 % wheat flour and 10 % soy okara flour, WSB3 = 80 % wheat flour and 20 % soy okara flour, WSB4 = 70 % wheat flour and 30 % soy okara flour

Bread production

Bread was produced using the straight dough method was produced as described by Sanful et al., (2010). Each formulation was mixed with standard quantities of yeast, salt, sugar, fat, and water. The dry ingredients (flour, sugar, salt, and yeast) were mixed before water and fat were added, and the mixture was stirred using a mixer until a uniform dough was formed. The dough was well kneaded and smooth and elastic. The kneaded dough was left on and fermented / Proofed in a warm temp for 2 hours. After the dough had risen and doubled, it was punched down, shaped and placed in oiled pans for baking. Another proofing process was applied; the dough fermented for another 60 minutes. After being shaped, the dough was baked in a preheated oven at 200 °C for 30 minutes. Upon baking completion, the bread was cooled at room temperature (27 °C) on racks and packaged in airtight polyethylene bags for analysis as shown in figure 2.

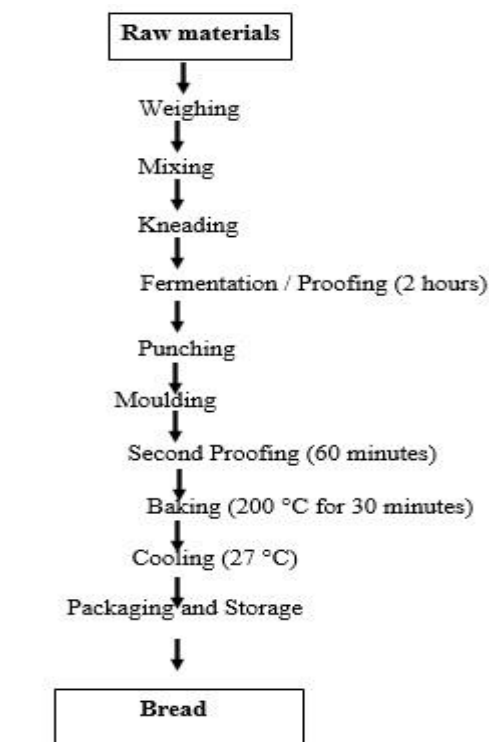


Figure 2: Production of Bread

Methods

Determination of functional properties

Bulk density, water absorption capacity (WAC), oil absorption capacity (OAC), and swelling index were determined using standard laboratory procedures. Bulk density was evaluated by measuring the weight of the sample in a graduated cylinder and expressed in g/cm³. WAC and OAC were assessed by mixing a known weight of flour with water or oil, centrifuging the mixture, and recording the volume of liquid retained (Onwuka, 2005). The swelling index was measured by soaking flour in distilled water and recording volume changes after a specified time.

Determination of physical characteristics

Loaf volume was determined using the rapeseed displacement method, and specific volume was calculated by dividing loaf volume by loaf weight. Bread height and diameter were measured using a Vernier calliper, and the crumb texture was evaluated manually and by texture profile analysis (TPA) using a texture analyzer as described by (Onwuka, 2005).

Determination of proximate composition

The proximate composition (moisture, ash, crude protein, fat, fibre, and carbohydrate by difference) was determined using AOAC standard methods (AOAC, 2015). Protein was estimated by the Kjeldahl method using a nitrogen conversion factor of 6.25. Crude fat was extracted using a Soxhlet apparatus, while moisture content was obtained by oven drying at 105 °C to constant weight. Ash content was measured by incinerating samples in a muffle furnace at 550 °C. Crude fibre was determined through acid-base digestion. Carbohydrate content was calculated by difference and Calories (or energy value) are calculated separately using the values obtained from the proximate analysis,

Determination of sensory evaluation

Sensory properties of the cookies were evaluated by 20 semi trained panelists (20–45 years) drawn from the staff and student of the Department of Food science and Technology, Ebonyi state University, Abakaliki, Nigeria. The sensory characteristics evaluated are appearance, taste, flavour, texture crispiness and overall acceptability of the bread. A 9-point hedonic scale questionnaire were, 9 - represents extremely like, 1 - represents extremely dislike while 5 - represents neither like nor dislike according to Iwe, (2002).

Statistical analysis

Data were analyzed using IBM SPSS Statistics 24.0 and Expert Design Software Version 11. Means were separated using Duncan Multiple Range Test at $p < 0.05$, following the procedures described by Steel and Torrie (1980). The experimental design employed for the study was a Completely Randomized Design (CRD).

Results and discussions

Proximate composition of bread produced from flour blends of wheat and okara

The results of the proximate composition of bread produced from varying blends of wheat and soy okara flour (WSB1–WSB4) revealed notable nutritional enhancements with increased levels of okara inclusion. Protein content, showed a significant ($p < 0.05$) difference, increasing from 9.38% in WSB1 (100% wheat flour) to 13.76% in WSB4 (70 % wheat, 30 % okara). This is in agreement with findings by Agu et al., (2023), who reported that okara is a protein-rich by-product, and its inclusion in cereal-based products can significantly boost their protein content. Ash content, ranged from 1.75 % to 2.26 %, with the highest value in WSB1. However, no consistent trend was observed across the blends, variations in ash content could be attributed to processing methods or complex interactions between wheat and okara components during baking. These findings align with Torre et al., (1991), who noted that mineral bioavailability and retention may be influenced by the presence of fibre and phytic acid, which can chelate minerals. A significant increase in fat content was observed with higher okara inclusion, rising from 3.81 % in WSB1 to 7.21 % in WSB4. This trend aligns with previous studies such as Li et al., (2012), which highlighted okara's residual oil content resulting from the soybean milling process.

Moisture content increased marginally, with the highest observed in WSB3 (26.25 %). Fibre content demonstrated a clear upward trajectory, from 2.01 % in WSB1 to 4.60 % in WSB4. This is consistent with Lyu et al., (2021), who documented that okara is particularly rich in insoluble dietary fibre. Carbohydrate content declined progressively from 57.53% in WSB1 to 46.41% in WSB4. This aligns with Noorfarahzilah et al., (2014), who reported that composite flour substitution often lowers the glycaemic potential of baked goods. Such reductions may support dietary interventions for diabetes management and weight control. Lastly, energy content ranged from 301.93 kcal/100g in WSB1 to 305.57 kcal/100g in WSB4, with a slight increase attributed to the higher fat and protein content in the okara-enriched samples, as shown in Table 2.

Table 2: Proximate composition of bread produced from flour blends of wheat and okara

Parameters	Samples (%)			
	WSB1	WSB2	WSB3	WSB4
Protein	9.38 ^d ± 1.27	12.61 ^c ± 0.18	13.49 ^b ± 0.01	13.76 ^a ± 0.01
Ash	2.26 ^a ± 0.01	2.01 ^c ± 0.01	1.75 ^c ± 0.25	2.01 ^b ± 0.01
Fat	3.81 ^d ± 0.01	4.01 ^c ± 0.01	5.41 ^b ± 0.01	7.21 ^a ± 0.01
moisture	24.01 ^d ± 0.01	25.51 ^c ± 0.01	26.25 ^a ± 0.01	26.01 ^b ± 0.01
Fibre	3.01 ^b ± 0.01	2.01 ^c ± 0.01	3.00 ^b ± 0.01	4.60 ^a ± 0.01
Carbohydrate	57.53 ^a ± 0.74	53.85 ^b ± 0.01	50.10 ^c ± 0.01	46.41 ^d ± 0.01
Calories (kcal/100 g)	301.93 ^a ± 0.01	301.93 ^c ± 0.01	303.05 ^d ± 0.01	305.57 ^b ± 0.01

Values are means ± standard deviation of triplicate determinations. Means with same superscripts in a row were not significantly ($p > 0.05$) different. Key: WSB1 (Control) = 100 % wheat flour and 0 % soy okara flour, WSB2 = 90 % wheat flour and 10 % soy okara flour, WSB3 = 80 % wheat flour and 20 % soy okara flour, WSB4 = 70 % wheat flour and 30 % soy okara flour

Functional properties of composite flour blends from wheat and okara

The functional properties of wheat–soy okara composite flours—specifically bulk density, swelling capacity, water absorption capacity (WAC), and oil absorption capacity (OAC) were evaluated. Bulk density values ranged widely from 7.20 g/mL (WSB4) to 220.00 g/mL (WSB2). The peak observed at 10 % okara inclusion (WSB2) and the low bulk density in WSB4 (30 % okara). Swelling capacity, ranged from 7.10% (WSB4) to 60.15% (WSB2). This trend supports the work of Douiri et al., (2024), who demonstrated that high-fibre composite flours can hinder expansion by disrupting gluten-starch interaction networks critical to proper hydration and structural development.

Water absorption capacity (WAC), increased up to 85.05 % in WSB3 (20 % okara) but declined sharply to 6.95 % in WSB4. And at 30% inclusion, however, a drop in WAC was observed. Oil absorption capacity (OAC) ranged from 7.15% (WSB4) to 88.00 % (WSB3), with the highest value also seen at 20 % okara substitution. These results evaluated the functional potential of soy okara in wheat-based composite flours, particularly at moderate inclusion levels (10–20 %). The use of okara—an agro-industrial by-product—also aligns with sustainable food

systems by promoting waste valorization and affordable protein enrichment for nutritionally vulnerable populations, as shown in Table 3.

Table 3: Functional properties of composite flour blends from wheat and okara

Parameters (%)	Samples			
	WSB1	WSB2	WSB3	WSB4
Bulk density	125.00 ^a ± 0.00	220.0 ^c ± 0.00	180.05 ^a ± 0.00	7.20 ^b ± 1.64
Swelling capacity	35.00 ^a ± 0.00	60.15 ^c ± 0.00	55.05 ^a ± 1.42	7.10 ^b ± 1.06
Water absorption capacity	75.40 ^a ± 0.00	80.0 ^c ± 0.00	85.05 ^a ± 0.75	6.95 ^b ± 0.81
Oil absorption capacity	85.55 ^a ± 0.00	82.33 ^c ± 0.69	88.00 ^a ± 1.42	7.15 ^b ± 0.67

Values are means ± standard deviation of triplicate determinations. Means with same superscripts in a row were not significantly ($p > 0.05$) different. Key: WSB1 (Control) = 100 % wheat flour and 0 % soy okara flour, WSB2 = 90 % wheat flour and 10 % soy okara flour, WSB3 = 80 % wheat flour and 20 % soy okara flour, WSB4 = 70 % wheat flour and 30 % soy okara flour

Physical characteristics of bread produced from blends of wheat and okara flour blends

Physical characteristics such as loaf weight, loaf volume, and specific volume of bread produced from blends of wheat and soy okara composite flours at varying substitution levels (WSB1–WSB4) were assessed. Loaf weight increased modestly from 213.10 g in WSB1 (100 % wheat) to 221.94 g in WSB4 (30 % okara). The higher weight observed with increasing soy okara inclusion is likely a result of soy okara's high water-holding capacity, as reported by Li et al., 2012. Loaf volume decreased progressively with rising okara substitution, from 327.00 ml in WSB2 (10 %) to 250.00 ml in WSB4 (30 %). While WSB1 (control) and WSB2 maintained higher volumes, the decline at 20–30 % inclusion was statistically significant. This phenomenon is consistent with findings by Gobetti et al., 2020, who attributed reduced loaf volume in legume-fortified breads to dilution of gluten by non-gluten proteins and fibres present in the substitute flour.

Specific volume, it ranged from 1.52 ml/g (WSB2) to 1.14 ml/g (WSB4). The highest value at 10 % okara inclusion (WSB2). This pattern aligns with reports from Bojňanská et al., 2021, who observed that legume flour inclusion beyond 20% compromises dough elasticity, reducing aeration and leading to heavier, denser loaves. Moderate inclusion of soy okara (10 %) in bread formulations supports acceptable physical quality, while higher levels (20–30 %) significantly impact loaf volume and specific volume due to gluten interference. However, increased loaf weight, attributed to fibre and moisture retention, may offer functional benefits in nutrition-dense formulations aimed at combatting food insecurity and undernutrition, as shown in Table 4.

Table 4: Physical characteristics of bread produced from blends of wheat and okara flour blends

Parameters (%)	Samples			
	WSB1	WSB2	WSB3	WSB4
Loaf weight (g)	213.10 ^a ± 15.31	216.01 ^a ± 0.00	218.03 ^a ± 2.61	221.94 ^a ± 13.51
Loaf volume (ml)	308.00 ^a ± 11.00	327.00 ^a ± 0.00	272.00 ^b ± 8.00	250.00 ^c ± 12.00
Specific volume (ml/g)	1.46 ^b ± 0.01	1.52 ^a ± 0.00	1.26 ^c ± 0.701	1.14 ^d ± 0.01

Values are means ± standard deviation of triplicate determinations. Means with same superscripts in a row were not significantly ($p > 0.05$) different. Key: WSB1 (Control) = 100 % wheat flour and 0 % soy okara flour, WSB2 = 90 % wheat flour and 10 % soy okara flour, WSB3 = 80 % wheat flour and 20 % soy okara flour, WSB4 = 70 % wheat flour and 30 % soy okara flour

Sensory evaluation of bread produced from blends of wheat and okara flour

This study assessed six key sensory attributes; appearance, colour, taste, texture, flavour, and overall acceptability of bread produced from varying proportions of wheat and soy okara composite flour blends (WSB1 to WSB4). Appearance scores ranged from 6.80 (WSB2) to 7.40 (WSB1 – control). While the 100 % wheat bread (WSB1) had the highest rating, the decline observed in composite samples was not statistically significant ($p > 0.05$), suggesting that moderate inclusion of soy okara (up to 30 %) did not detract from the visual appeal of the bread. This observation is in agreement with Tutu et al., 2024., who reported that composite breads containing up to 20 % legume flour retained consumer-acceptable appearance scores. Colour ranged from 7.10 (WSB4) to 7.20 (WSB1). This aligns with Bojňanská et al., 2021, who found that composite flours with legume additions could slightly alter bread crumb colour without negatively affecting consumer perception. Taste ranged from 6.65

(WSB3) to 7.40 (WSB1); WSB4 (30 % okara) scored 6.95, higher than WSB2 and WSB3. Texture scores ranged from 7.20 (WSB3) to 7.55 (WSB1). The textural differences among samples were not significant, indicating that fibre-rich okara could be included up to 30 %. Flavour ratings were fairly consistent, with values between 6.40 (WSB3) and 7.30 (WSB1 and WSB2) with slightly lower score in WSB3. Nevertheless, the 10 % and 30 % blends maintained acceptable flavour profiles, as supported by Pešić et al., 2023 confirming the functional and sensory compatibility of okara in composite bread systems. General acceptability scores ranged from 7.05 (WSB2) to 7.70 (WSB1), with WSB4 (30 % okara) and WSB3 (20 % okara) scoring 7.30 and 7.25, respectively. These results affirm that up to 30 % okara incorporation is well tolerated by consumers. These results are consistent with literature demonstrating that composite flours containing legumes or agricultural by-products can maintain high consumer acceptability when well-balanced (Olamiti et al., 2024). Such formulations offer a promising avenue for producing nutrient-enriched and culturally acceptable baked products that are affordable and beneficial for low-income populations, as shown in Table 5.

Table 5: Sensory evaluation of bread produced from blends of wheat and okara flour

Parameters	Samples			
	WSB1	WSB2	WSB3	WSB4
Appearance	7.40 ^a ± 1.27	6.80 ^c ± 1.57	6.85 ^a ± 1.42	7.20 ^b ± 1.64
Colour	7.20 ^a ± 1.27	7.15 ^c ± 1.57	7.15 ^a ± 1.42	7.10 ^b ± 1.06
Taste	7.40 ^a ± 1.54	6.70 ^c ± 1.21	6.65 ^a ± 0.75	6.95 ^b ± 0.81
Texture	7.55 ^a ± 1.40	7.25 ^c ± 0.69	6.90 ^a ± 1.42	7.15 ^b ± 0.67
Flavor	7.30 ^a ± 1.30	7.30 ^c ± 1.26	6.40 ^a ± 0.99	7.25 ^b ± 0.99
General Acceptance	7.70 ^a ± 0.92	7.05 ^c ± 1.42	7.25 ^a ± 1.32	7.30 ^b ± 1.49

Values are means ± standard deviation of triplicate determinations. Means with same superscripts in a row were not significantly ($p > 0.05$) different. Key: WSB1 (Control) = 100 % wheat flour and 0 % soy okara flour, WSB2 = 90 % wheat flour and 10 % soy okara flour, WSB3 = 80 % wheat flour and 20 % soy okara flour, WSB4 = 70 % wheat flour and 30 % soy okara flour

Conclusion

The study demonstrated the potential of soy okara, an underutilized agro-industrial by-product that is commonly overlooked, to enhance nutritional and functional value of wheat bread products. The incorporation of soy okara at varying levels, key parameters such as protein, fibre, and fat contents were enhanced significantly, aligning with the objective of developing nutrient-dense bakery products. Functional tests reported that at a range of 10 % to 20 % inclusion, soy okara demonstrated improved water and oil absorption, and improved bread-making efficiency. Loaf volume and specific volume decreased at 30 % soy okara inclusion. In terms of sensory evaluation, the sample containing 10% okara (WSB2) received the highest scores for appearance, taste, texture, and overall acceptability. This indicates that bread can be nutritionally enriched with a moderate amount of soy okara without consumers being able to detect any difference in sensory quality.

The study concludes that a 10% substitution of soy okara is optimal for improving the nutritional quality of bread while maintaining consumer acceptability and sensory appeal. This waste-to-nutrition innovation not only enhances the value of an underutilized by-product but also reduces dependence on imported wheat, aligning with national goals for food security and public health improvement. The findings support policy recommendations that promote the use of agricultural by-products, such as okara, in commercial food production. Expanding agro-processing capabilities and increasing awareness among consumers and bakers about the benefits of soy okara could foster greater acceptance and consumption of functional food products enriched with this ingredient. This approach strengthens local food systems and generates new economic opportunities in soy waste processing. Furthermore, encouraging research–industry collaboration is essential for scaling up the development and implementation of this innovation.

Future studies should examine the shelf-life stability of okara-enriched products over time and investigate their metabolic impact, particularly among diabetic and low-income populations.

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