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Community-Based Circular Food Innovation: Nutritional and Sensory Evaluation of Tofu Residue – Based Cookies in Pakiskembar Village, Malang Regency

Bifil Tanjung Perkasa [1*], Sheinia Indhy Aurellia [2], Miranda Nadar Ayu[2], Ananda Sekar Kinanti[3], Marisa Ajeng Pratiwi[4], Falda Rahma Nurfitriani[4], Lola Alifa Ikhtiarani[4], and Destriana Nabila [4]

[1)] Department of Food Science and Biotechnology, Faculty of Agricultural Technology, Brawijaya University, Malang, Indonesia
[2)] Department of Fisheries Product Technology, Faculty of Fisheries and Marine Sciences, Brawijaya University, Malang, Indonesia
[3)]Department of Fisheries Product Technology, Faculty of Fisheries and Marine Sciences, Brawijaya University, Malang, Indonesia
[4)]Department of Fisheries and Marine Social Economy, Faculty of Fisheries and Marine Sciences, Brawijaya University, Malang, Indonesia

Abstract

The rapid expansion of agro-industrial food production has increased waste generation, posing sustainability challenges at both the local and global levels. In Pakiskembar Village, Malang Regency, tofu processing produces large amounts of residue (okara) that remain underutilized despite their nutritional potential. This study aimed to evaluate the nutritional composition and sensory acceptance of okara-based cookies developed through a community-based circular food innovation approach. A participatory method was implemented over five months, involving members of the local Family Welfare Empowerment (PKK) group in processing, production, and evaluation activities. Proximate analysis was conducted to determine moisture, protein, fat, carbohydrate, fiber, ash, and energy content, while sensory evaluation used a five-point hedonic scale with 30 untrained panelists. The results showed that the cookies contained 4.22% moisture, 6.27% protein, 0.43% fat, 78.5% carbohydrates, and 9.09% crude fiber, with an energy value of approximately 314.9 kcal/100 g. Sensory evaluation indicated that the formulation containing 20 grams of okara achieved the highest overall acceptance across sensory attributes. These findings demonstrate that moderate okara substitution improves fiber content while maintaining acceptable sensory quality and supporting community-based waste valorization. Further optimization is recommended to improve fat and energy content to meet conventional quality standards without compromising product acceptability.

Keywords: community empowerment; proximate analysis; rural sustainability; valorisation; waste utilization

[*] **Corresponding author**: bifiltanjungperkasa@gmail.com

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Inovasi Pangan Sirkular Berbasis Komunitas: Evaluasi Nutrisi dan Sensori Cookies Ampas Tahu di Desa Pakiskembar, Kabupaten Malang

Abstrak

Perkembangan pesat sektor agroindustri pangan telah meningkatkan volume limbah yang dihasilkan, sehingga menimbulkan tantangan keberlanjutan baik di tingkat lokal maupun global. Di Desa Pakiskembar, Kabupaten Malang, proses produksi tahu menghasilkan ampas tahu (okara) dalam jumlah besar yang masih belum dimanfaatkan secara optimal meskipun memiliki potensi nilai gizi. Penelitian ini bertujuan untuk mengevaluasi komposisi nutrisi dan tingkat penerimaan sensori cookies berbasis okara yang dikembangkan melalui pendekatan inovasi pangan sirkular berbasis komunitas. Metode partisipatif diterapkan selama lima bulan dengan melibatkan anggota kelompok PKK dalam proses pengolahan, produksi, dan evaluasi produk. Analisis proksimat dilakukan untuk menentukan kadar air, protein, lemak, karbohidrat, serat, abu, dan nilai energi, sedangkan uji sensori menggunakan skala hedonik lima tingkat dengan 30 panelis tidak terlatih. Hasil penelitian menunjukkan bahwa cookies mengandung kadar air 4,22%, protein 6,27%, lemak 0,43%, karbohidrat 78,5%, serat kasar 9,09%, serta energi sekitar 314,9 kkal/100 g. Uji sensori menunjukkan bahwa formulasi dengan penambahan 20 gram okara memiliki tingkat penerimaan tertinggi pada seluruh atribut sensori. Temuan ini menunjukkan bahwa substitusi okara dalam jumlah moderat dapat meningkatkan kandungan serat tanpa menurunkan kualitas sensori, sekaligus mendukung pemanfaatan limbah berbasis komunitas. Penelitian lanjutan disarankan untuk mengoptimalkan kandungan lemak dan energi agar memenuhi standar mutu konvensional tanpa mengurangi tingkat penerimaan konsumen.

Kata kunci*: analisis proksimat; keberlanjutan pedesaan; pemberdayaan masyarakat; valorisasi; utilisasi limbah*

INTRODUCTION

The rapid expansion of the global agro-industrial food sector has significantly increased food production capacity; however, it has simultaneously generated substantial volumes of waste and intensified complex sustainability challenges. Food waste remains a critical issue within the global food system, with approximately 1.3 billion tonnes, equivalent to nearly one-third of total global food production, discarded annually (Handoyo & Asri, 2023). This condition reflects a structural paradox between rising production levels and inefficient resource utilization, where productivity gains are not matched by proportional improvements in resource efficiency and residual management. In Indonesia, this imbalance is exacerbated by limited advances in distribution systems, post-harvest handling, and waste infrastructure relative to production growth (Bachmida & Afni, 2025).

Consequently, agro-industrial residues, including soybean by-products, constitute a substantial organic waste stream that remains underutilised despite their nutritional and economic value (Ernawati et al., 2022). In response, the circular economy has emerged as a transformative framework that replaces the linear extract–produce–dispose model with strategies centred on reduction, reuse, and recycling, thereby repositioning waste as a productive resource. Circular food innovation offers a practical mechanism to convert agro-industrial by-products into value-added commodities while reducing environmental burdens (Sari et al., 2025). Concurrently, village-level agro-industry is increasingly recognised for its role in strengthening local economies and advancing sustainable rural development (Liu et al., 2024). Although household enterprises generate employment and enhance commodity value, their rapid expansion is often not supported by adequate environmental governance, posing risks to business continuity and community well-being (Behzad, 2024; Listiawati, 2025). In residential settings, unmanaged residues may swiftly offset economic gains with sanitation, ecological, and public-health impacts.

Tofu production exemplifies village-based household agro-industry, providing affordable plant protein and sustaining small-scale livelihoods (Al-Qadri & Hikma, 2025; Ulandari & Sumartono, 2025). Nevertheless, tofu processing generates two major types of waste, namely solid residue (okara) and liquid effluent with high organic content (Duana et al., 2024). Tofu wastewater typically contains elevated Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD), posing significant pollution risks when discharged untreated (Budiyono & Syaichurrozi, 2020), while improper disposal also compromises neighbourhood sanitation and environmental comfort (Burhanuddin et al., 2024). Hence, sustainability depends not only on production capacity but on effective waste governance (Ramkaurthi et al., 2025). Among these residues, okara is a by-product of considerable yet underutilised potential. Generated during soy milk extraction, its volume increases proportionally with soybean production. Global estimates of okara production vary considerably across studies. Okara production may reach up to 1.4 billion tonnes annually, highlighting its magnitude as an agro-industrial by-product (Kamble & Rani, 2020). However, other studies provide more conservative estimates; for instance, Rahman et al. (2021) reported global production of approximately 14 million tonnes, with major contributions from Asian countries such as China (2.8 million tonnes), Japan (0.8 million tonnes), Korea (0.3 million tonnes), and Singapore (0.01 million tonnes). It is estimated that one tonne of soybeans can yield up to two tonnes of okara. In Indonesia, annual availability reaches approximately 1.1–1.2 million tonnes, largely diverted to animal feed, with limited processing into products such as tempe gembus (Ginting et al., 2024). Its high moisture content makes it highly perishable, shortening shelf life and increasing environmental risks if unmanaged. In parallel, tofu processing effluent contains elevated Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS), threatening surrounding water bodies (Patmawati et al., 2021).

These challenges are clearly reflected in Pakiskembar Village, Pakis District, Malang Regency, East Java, a recognized center of tofu and tempe production with at least 31 household enterprises. Each unit generates approximately 25 kg of solid waste and 250 liters of liquid effluent daily, producing considerable cumulative residues. Although economically significant, inadequate waste management poses long-term environmental risks. Solid residues are generally used as low-value animal feed or discarded, limiting their economic potential (Mulyono, 2022). Barriers are not purely technical but relate to limited access to processing knowledge, appropriate technology, and marketing strategies for value-added products.

From a scientific perspective, okara possesses notable nutritional and functional properties. Fresh okara contains approximately 81.6% moisture, 19.9–21.7% protein (dry basis), and 4.7% ash. On a dry weight basis, it may contain around 30% protein, 10% fat, and 55% crude fiber (Ginting et al., 2024).

Other studies report protein contents of 24.0–33.4%, fat contents of 8.5–20.0%, and crude fiber contents of 12.2–58.1%. Dried okara contains 50–60% total dietary fiber and bioactive compounds, including isoflavones and saponins (Y. Liu et al., 2021), which are associated with improved lipid profiles and reduced cardiovascular risk (Wen et al., 2026). These attributes substantiate its repositioning as a functional ingredient rather than a disposal burden.

To harness this potential, stabilization processes, particularly drying and flour conversion, are essential for extending shelf life and enhancing applicability. Previous studies demonstrate that okara flour can partially substitute wheat flour in bakery products, including cookies, cakes, brownies, noodles, and snack bars. Appropriate substitution levels increase protein and fiber content without significantly compromising sensory quality (Ginting et al., 2024). However, most research remains confined to laboratory-scale analyses and controlled sensory panels, offering limited insight into feasibility in community production contexts characterized by raw-material variability, equipment limitations, and routine practices.

Beyond technical formulation, community-based innovation must address consumer perception and market acceptance. Ingredients derived from waste streams may encounter skepticism, while sensory attributes, taste, aroma, texture, and color remain decisive determinants of purchase intention (Bibi et al., 2023). Sustainable innovation also requires participatory empowerment, training, and enterprise development, yet such mechanisms are rarely integrated with systematic nutritional and sensory evaluation. This limited integration represents a practical and analytical gap in rural agro-industrial centers where underutilized okara coexists with unrealized livelihood opportunities.

Accordingly, this study evaluates the nutritional composition and sensory characteristics of okara-based cookies developed through a community-based circular food innovation approach in Pakiskembar Village. It further examines the implementation of a participatory empowerment model designed to optimise agro-industrial waste utilisation into value-added food products. The novelty lies in integrating rigorous nutritional and sensory assessment with a locally grounded circular economy framework. Through this approach, okara is repositioned not merely as an alternative raw material but as a catalyst for transforming village production systems towards a more sustainable, inclusive, and economically viable food model. The findings are expected to contribute academically and practically to agro-industrial waste valorisation, community capacity strengthening, and long-term environmental sustainability.

METHOD

Research Design

This study employed a community-based participatory research design integrated with circular economy principles in food innovation (Obeng et al., 2025). Community members were positioned as active partners throughout raw material processing, product formulation, production training, and evaluation. Rather than serving as passive beneficiaries, participants collaborated in converting tofu residue into value-added food products. The design was practice-oriented and intervention-based, combining applied food processing with nutritional and sensory assessment to ensure contextual relevance and local ownership.

Research Site and Study Period

The research was conducted in Pakiskembar Village, Pakis District, Malang Regency, East Java, Indonesia, over a five-month period from July to November 2021. The site was selected due to the high availability of tofu residue generated by household-scale tofu industries and its limited utilization. The intervention aimed to strengthen community capacity to convert agro-industrial waste into marketable food products within a circular rural economy framework. The spatial accessibility of the research site from the Faculty of Fisheries and Marine Sciences, Universitas Brawijaya, is illustrated in Figure 1.

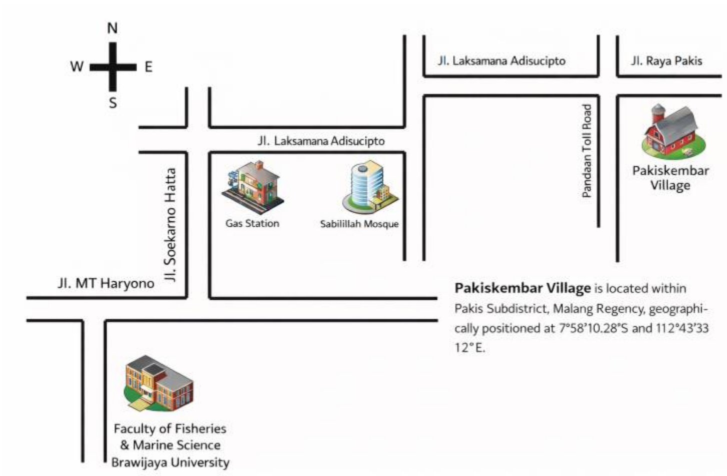

Figure 1. Accessibility map showing the location of Pakiskembar Village

Participants and Scope of Study

Participants were members of the Family Welfare Empowerment Group (PKK) of Pakiskembar Village. They were directly involved in training, production, and evaluation activities. The study encompassed three components: (1) processing tofu residue into flour, (2) developing and producing okara-based cookies, and (3) evaluating nutritional composition and sensory acceptance. Community participation during implementation was observed as an indicator of the effectiveness of empowerment.

Materials and Equipment

The primary raw material was fresh okara, the solid by-product of tofu processing, obtained from local household producers and processed into flour prior to use. The cookie formulation consisted of 96 g wheat flour, 80 g okara flour, 140 g powdered sugar, 130 g margarine, ½ tablespoon skimmed milk powder (BMP), 1 teaspoon vanilla essence, 1 teaspoon baking powder, 1 egg, and ½ teaspoon salt. All ingredients were food-grade and handled in accordance with hygiene standards. Equipment for preparing okara flour included a ladle, stove, steamer pot, frying pan, spatula, flour-grinding machine, and oven. Cookie production utilized a large mixing bowl, a tablespoon, a teaspoon, a baking tray, and an oven. All utensils were cleaned before and after use to ensure safety and quality.

Okara Flour Procedure

Fresh okara was processed following a structured preparation stage in which materials and equipment were ensured to be clean and functional. The residue was first steamed to improve safety by reducing microbial load and inactivating enzymes. It was then dry-roasted in a frying pan with continuous stirring to reduce moisture and prevent clumping; oven drying was used when necessary to further optimize moisture removal. The dried material was milled with a flour grinder to obtain a fine, uniform flour, which was then stored in sealed containers at room temperature prior to formulation.

Cookie Procedure

Cookie preparation commenced by creaming margarine and refined sugar with a mixer until a soft, homogeneous consistency was achieved. Eggs, skimmed milk powder, baking powder, and vanilla essence were subsequently added and mixed thoroughly. Wheat flour and okara flour were gradually incorporated and mixed until a uniform dough formed. The dough was shaped according to the desired size and placed on baking trays lightly greased with margarine. Baking was performed in a pre-heated oven at 180°C for approximately 20 minutes. Once baked, the cookies were cooled at room temperature before being stored in airtight containers to preserve quality and extend shelf life. The sequential stages of okara cookie production are illustrated in Figure 2.

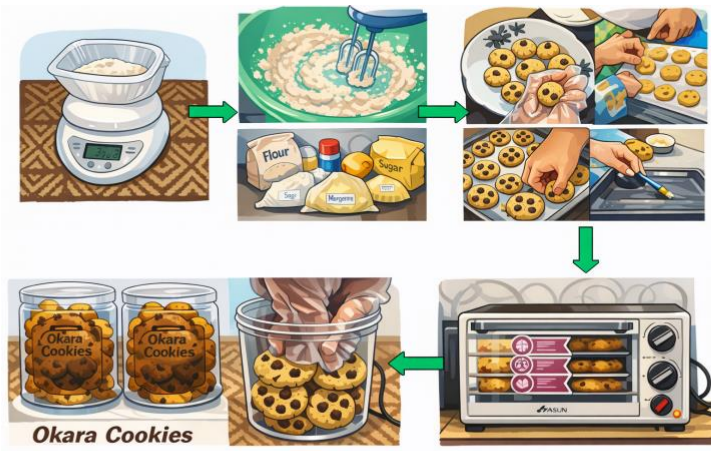

Figure 2. Schematic workflow of the okara cookie production process.

Sensory Evaluation

Sensory evaluation was conducted to assess community acceptance of the okara-based cookies. A five-point hedonic scale was used, where 1 indicated "strongly dislike", 2 "dislike", 3 "neutral", 4 "like", and 5 "strongly like". Evaluated attributes included color, aroma, taste, texture, and overall acceptability. The sensory assessment involved 30 untrained panelists, comprising community members and program participants (Eliza et al., 2023). Each panelist tasted the product samples and provided ratings based on subjective preference for the observed sensory attributes.

Nutritional Analysis

Nutritional composition was analyzed using proximate analysis methods. The measured parameters included moisture, ash, protein, fat, crude fiber, carbohydrate, and energy value. The objective of this analysis was to evaluate the nutritional contribution of okara flour as a substitute ingredient in the cookie formulation. Results were expressed as percentages and served as indicators of product nutritional quality.

Data Analysis and Interpretation

This study employed an experimental approach incorporating organoleptic testing to evaluate panelists' acceptance of okara-based cookies. Hedonic evaluation was conducted in accordance with SNI 01-2346-2006 sensory parameters (taste, aroma, color, and texture) involving 30 untrained panelists from the local community. Evaluations were performed using a five-point hedonic scale (1 = dislike extremely to 5 = like extremely), with samples presented in random order to minimize order bias. The treatments consisted of four formulations: T1 (0 g okara), T2 (20 g okara), T3 (40 g okara), and T4 (commercial product). The resulting ordinal data were analyzed using Minitab version 19. Each treatment was evaluated in three replicates, resulting in a total of 90 observations per treatment. Normality was assessed using the Shapiro–Wilk test, and significance values were interpreted according to established statistical criteria (Mulyo et al., 2022). As the data were not normally distributed ($p < 0.05$), non-parametric analysis was performed using the *Kruskal–Wallis* test, followed by the *Mann–Whitney* test for pairwise comparisons (Adi et al., 2026).

RESULT AND DISCUSSION

Proximate Analysis of Okara Cookies

The nutritional composition of okara-based cookies was determined through proximate analysis, including moisture, protein, fat, carbohydrate, ash, crude fiber, and energy content. The results are presented in Table 1**.**

Table 1. Proximate Composition of Okara Cookies

Parameter	Okara	Okara & Banana Peel*	SNI 01-2973-2011**
Moisture (%)	4.22	5.27	Max. 5
Protein (%)	6.27	4.76	Min. 5
Fat (%)	0.43	24.22	Min. 9.5
Carbohydrates (%)	78.5	63.91	Min. 70
Ash (%)	1.49	1.86	Max. 1.6
Crude Fibre (%)	9.09	31.18	Max. 0.5
Energy (kcal/100 g)*	±314.9	–	Min. 400

Source: *Terati et al. (2023) **SNI (2011)

The results indicated that okara cookies contained 4.22% moisture, 6.27% protein, 0.43% fat, 78.5% carbohydrates, 1.49% ash, 9.09% crude fiber, and approximately 314.9 kcal/100 g energy. This profile reflects a high-fiber, low-fat product that differs markedly from okara–banana peel cookies reported by Terati et al. (2023) and from conventional cookie specifications under SNI 01-273-2011.

Moisture Content

The moisture content of the okara cookies was 4.22%, complying with the requirements of SNI 01-273-2011 (maximum 5%). The product can therefore be classified as a dry food with good stability. Wijaya et al. (2023) It is reported that okara contains hydrophilic proteins and fibers that may enhance the dough's capacity to bind and retain water through hydrogen bonding with free water molecules. Nevertheless, the final moisture level remained low, indicating that the baking process was conducted optimally, allowing most of the water in the dough to evaporate during heating. Thus, although the raw material characteristics tend to promote water retention, appropriate control of temperature and baking duration produced cookies with moisture content compliant with quality standards and potentially improved shelf life.

Protein Content

The protein content of the okara cookies was 6.27%, meeting the SNI 01-273-2011 minimum requirement of 5%. This value indicates that the inclusion of okara contributed protein to the product formulation. The protein is derived from residual soybean protein left after tofu production. As a by-product of soymilk processing, okara contains relatively high levels of protein, particularly the globulin and albumin fractions, which contribute to increased protein content in processed products. Okara flour reportedly contains approximately 20–35% protein on a dry basis (Sa'diah et al., 2025); therefore, its incorporation into cookies enhances nutritional value, particularly in terms of protein content.

Fat Content

The fat content of the okara cookies was 0.43%, substantially below the SNI 01-273-2011 minimum requirement of 9.5%, and therefore not compliant with conventional cookie standards. This low value is likely attributable to the limited addition of lipid-rich ingredients in the formulation and to the reduction of fat fractions in okara during tofu extraction. Furthermore, the insoluble fiber in okara may absorb and bind a portion of the lipid fraction, thereby influencing its distribution within the product matrix (Manurung et al., 2024). High-temperature baking may also cause lipid degradation or migration (Sa'diah et al., 2025). Given that fat contributes to crumb structure and imparts a rich flavor, excessively low levels may affect both texture and overall sensory quality.

Ash Content

The ash content of the okara cookies was 1.49%, which remained below the SNI 01-273-2011 maximum limit of 1.6%, thereby meeting quality standards. Ash content reflects the total mineral composition of the product, derived from raw materials such as okara and wheat flour. It serves as an indicator of mineral content in food, and variations may be influenced by processing techniques, ingredient composition, and the natural mineral content of primary materials (Sa'diah et al., 2025).

Increased ash values are generally associated with higher mineral content in the ingredients used. Ash determination involves combustion, during which organic components decompose and mineral residues remain; consequently, ash values directly represent the total mineral content of the product.

Carbohydrate Content

The carbohydrate content of the okara cookies was 78.5%, exceeding the SNI 01-273-2011 minimum requirement of 70%, indicating that the principal structural components of the product remained dominated by starch and sugar sources such as wheat flour and sugar. Changes in carbohydrate content are generally influenced by variations in other nutrients, as increases or decreases in protein, fat, and ash affect calculated carbohydrate values (Nurdiani et al., 2023). Carbohydrates were analyzed using the by-difference method, meaning that values depend heavily on the proportions of other nutrients in the formulation. When protein, fat, or ash levels are relatively low, carbohydrate values tend to increase proportionally. Therefore, the predominance of carbohydrates in okara cookies remains consistent with the typical characteristics of flour-based baked products.

Crude Fiber Content

The crude fiber content of the okara cookies was 9.09%, exceeding the SNI 01-273-2011 maximum limit of 0.5%, and thus differing from conventional cookie standards. This elevated value is associated with the use of fiber-rich okara, particularly its insoluble fiber content. On a dry basis, okara reportedly contains approximately 30% protein, 10% fat, and 55% crude fiber (Ginting et al., 2024), thereby contributing substantially to the product's increased fiber content. Sa'diah et al. (2025) stated that high fiber content may influence measured carbohydrate values in proximate analysis. Moreover, fiber readily absorbs water; thus, increasing the proportion of Soybean Residue Flour (TAK) enhances the dough's water-binding capacity and may reduce crispness. Wijaya et al. (2023) Further reported that fiber in TAK can interfere with matrix formation and reduce gas retention capacity in dough, leading to alterations in the physical characteristics of cookies.

Energy Value

The energy value of the okara cookies was approximately 314.9 kcal/100 g, below the SNI 01-273-2011 minimum requirement of 400 kcal/100 g, and therefore not meeting established quality standards. The relatively low energy value is primarily due to the low fat content, as lipids provide more energy than protein or carbohydrates. In general, the energy value of a food product is determined by its carbohydrate, fat, and protein content (Rejeki et al., 2024). Consequently, reductions in fat content directly decrease total caloric value. The energy content of the cookies is therefore strongly influenced by overall nutrient composition, particularly the proportion of fat in the formulation.

Effect of Okara Substitution on Proximate Composition

Substitution of okara in the cookie formulation influenced the product's nutritional composition, particularly by increasing fiber content and modifying the lipid profile. Proximate analysis revealed a crude fiber content of 9.09%, indicating a substantial contribution of okara as a dietary fiber source. This represents a key distinction compared with conventional wheat-based cookies, which are typically low in fiber. These findings are consistent with previous studies reporting the functional potential of okara in flour-based processed foods. Ginting et al. (2024) noted that okara contains considerable dietary fiber and can therefore be utilized as a flour substitute in bakery products to enhance functional value.

The protein content of 6.27% indicates that the tofu residue contributed plant protein fractions and met the minimum SNI requirement (≥5%). However, this level remains within the moderate protein category and does not qualify as a high-protein food. In terms of moisture, the value of 4.22% indicates that the addition of okara did not excessively increase the product's moisture and maintained the dry characteristics typical of cookies. Conversely, the low-fat content (0.43%) reflects that okara substitution produced a lower-fat nutritional profile compared with conventional cookies. These changes indicate a compositional shift resulting from reduced dominance of wheat flour and lipid-rich ingredients and an increased proportion of fiber-rich components.

Sensory Acceptance

Sensory acceptance was evaluated using a hedonic test involving 30 untrained panelists. Four formulations were assessed: T1 (0 g), T2 (20 g), T3 (40 g), and T4 (commercial product). Panelists rated taste, color, aroma, and texture using a five-point scale. The results are summarised in Table 2.

Table 2. Mean ± Standard Deviation of Sensory Evaluation of Okara Substitution Cookies (n = 30)

Parameter	T1	T2	T3	T4
Taste	3.10 ± 0.70^{b}	4.00 ± 0.63^{a}	3.90 ± 0.70^{a}	4.00 ± 0.63^{a}
Colour	3.00 ± 0.63^{d}	3.70 ± 0.46^{a}	3.50 ± 0.50^{b}	3.30 ± 0.46^{c}
Aroma	2.50 ± 0.50^{b}	3.50 ± 0.50^{a}	3.50 ± 0.50^{a}	3.50 ± 0.50^{a}
Texture	3.50 ± 0.50^{b}	4.30 ± 0.46^{a}	4.30 ± 0.46^{a}	3.50 ± 0.50^{b}

Overall, treatment T2 (20 g okara substitution) consistently showed the highest acceptance across most attributes, often matching the commercial product. This suggests that moderate incorporation of okara improves sensory quality without reducing consumer preference. The final product’s appearance and packaging for the optimized formulation are shown in Figure 3.

Figure 3. Packaged okara cookies produced from the optimal formulation (P2)

Taste

Taste scores showed a clear pattern, with T2 (4.00 ± 0.63), T4 (4.00 ± 0.63), and T3 (3.90 ± 0.70) falling within the same group (A), indicating no significant differences among them ($p > 0.05$). In contrast, T1 (3.10 ± 0.70) formed a separate group (B) and received significantly lower ratings ($p < 0.05$). This pattern suggests that the inclusion of okara plays an important role in improving flavor acceptance. Treatments T2 and T3, which contained okara, were rated similarly to the commercial product (T4), indicating that okara-based cookies can achieve comparable sensory quality. Meanwhile, the lower score observed in T1 reflects a less appealing flavor profile when okara is not included. From a formulation perspective, okara likely contributes to flavor complexity through protein interactions and thermal reactions during baking, which enhance overall taste perception (Mulyo et al., 2022). However, excessive incorporation of okara may also introduce bitterness due to protein degradation and fiber interactions during processing (Sa'diah et al., 2025). In this study, the results indicate that moderate levels of okara (T2–T3) provide the most balanced flavor profile without negatively affecting acceptability.

Colour

Color scores varied across treatments, with T2 (3.70 ± 0.46) achieving the highest rating and classified in group A. T3 (3.50 ± 0.50) fell within group AB, indicating no significant difference from either T2 or T4. Meanwhile, T4 (3.30 ± 0.46) was grouped in B, and T1 (3.00 ± 0.63) showed the lowest preference and differed significantly from the other treatments. The higher preference observed in T2 suggests that moderate okara incorporation enhances visual appeal without negatively affecting color acceptance. This is likely related to browning reactions during baking, particularly the Maillard reaction, which contributes to the development of a desirable brown color. Protein-rich ingredients such as okara can intensify this reaction, thereby improving color formation (Mulyo et al., 2022). In addition, changes in color may also be influenced by variations in L^*, a^*, and b^* values, which are associated with brightness and browning intensity during thermal processing (Yuliarti et al., 2024). The formation of brown pigments (melanoidins) through non-enzymatic browning reactions further contributes to the visual characteristics of baked products (Wijaya et al., 2023). These findings support the present results, where an appropriate level of okara (T2) produced the most preferred color among panelists.

Texture

Texture scores showed a clear separation between treatments, with T2 (4.30 ± 0.46) and T3 (4.30 ± 0.46) grouped together (A) and rated significantly higher than T1 (3.50 ± 0.50) and T4 (3.50 ± 0.50), which formed a lower group (B) ($p < 0.05$). This indicates that moderate incorporation of okara improves textural acceptability. The improved texture in T2 and T3 may be attributed to the okara fiber's role in modifying dough structure and water distribution, resulting in a firmer, more compact product. Okara has been reported to influence hardness and gluten network structure in baked products (Yuliarti et al., 2024). In addition, moisture plays a key role in texture formation, with higher water content softening products (Inayah et al., 2024), whereas fiber-rich materials tend to produce firmer textures

(Noviyanti et al., 2023). These findings suggest that the formulations in T2 and T3 achieved a balanced texture despite increased fiber content.

Aroma

Aroma scores showed that T2 (3.50 ± 0.50), T3 (3.50 ± 0.50), and T4 (3.50 ± 0.50) were grouped together (A) and did not differ significantly, while T1 (2.50 ± 0.50) formed a separate group (B) with significantly lower acceptance ($p < 0.05$). This indicates that the presence of okara improves aroma acceptability, although increasing its level does not further enhance preference. The improved aroma in okara-containing samples may be associated with a more balanced flavor profile and reduced undesirable raw notes. Soy-based ingredients are known to contribute to aroma development and minimize off-flavors during processing (Mulyo et al., 2022). However, previous studies have reported that higher levels of okara may introduce a beany aroma due to lipid oxidation and lipoxygenase activity, which generate volatile compounds such as aldehydes and alcohols (Wang et al., 2022; Wijaya et al., 2023). In the present study, this effect was not clearly observed, suggesting that the okara levels used (T2–T3) remained within an acceptable range for aroma perception. Similar findings have also been reported in protein-enriched baked products, where aroma acceptance tends to stabilize beyond moderate inclusion levels (Adi et al., 2026).

Formula Optimisation

Formulation optimization was undertaken with a focus on balancing nutritional value and sensory acceptance. The objective was to determine a composition that achieved the most favorable equilibrium between enhanced nutritional quality and desirable organoleptic characteristics. Research on cookies enriched with okara flour indicates that additives such as hydrocolloids and fat replacers can help maintain textural quality and sensory acceptance when protein and fiber levels are increased (Balodi et al., 2026).

Based on proximate analysis, okara-based cookies demonstrated a substantial increase in fiber content and a protein level that met the minimum SNI requirement (≥5%). Although the product did not fulfill the BPOM criterion for high-protein foods (≥12%), it nonetheless offered improved nutritional value compared with conventional cookies. From a sensory perspective, hedonic test results showed that treatment P2 (80 g okara substitution) achieved the highest mean scores for taste (4.00), color (3.83), texture (3.72), and aroma (4.17). These results indicate that formulation P2 was the most acceptable among the tested treatments.

While higher substitution (90 g) maintained generally favorable acceptance, it did not consistently achieve the highest scores across all parameters. Conversely, the control formulation without okara recorded lower scores in several attributes, particularly texture. Accordingly, the 80 g substitution level was identified as the optimal formulation, as it enhanced fiber content and maintained protein levels in accordance with quality standards without diminishing consumer preference. This proportion reflects a balance between nutritional improvement and sensory characteristics and is therefore recommended for further development at the small- and medium-enterprise (SME) scale.

Community Participation and Empowerment Outcomes

The community empowerment program implemented in Pakiskembar Village demonstrated high participation, particularly among the 20 members of the Family Welfare Empowerment Group (PKK). Participants were directly involved in all stages of the activities, including processing tofu residue into flour, producing cookies, and evaluating the products. This active engagement contributed to increased knowledge and technical skills in agro-industrial waste processing. Community participation is a critical factor in the success of community-based waste management programs. Anggraini et al. (2025) emphasized that active involvement of community groups in program planning and implementation enhances technical capacity and supports the sustainability of waste-processing initiatives. A participatory approach positions community members not merely as beneficiaries but as primary actors in production and evaluation processes. The participatory training and production activities conducted with community members are illustrated in Figure 4.

Figure 4. Participatory training and hands-on production activities involving PKK members

Prior to program implementation, tofu residue was generally used only as low-value animal feed. Following training and socialization activities, participants gained a new understanding of okara's potential as a value-added food ingredient. Program evaluation demonstrated that participants were able to independently produce cookies after completing the training, indicating successful transfer of knowledge and technology. Active participation in waste management initiatives has been shown to improve community understanding and practical skills in transforming waste into economically valuable products. Karimuna et al. (2025) reported that education and training programs increase awareness of waste management importance and enhance the capacity to process waste into marketable goods. The program also strengthened community awareness of more effective management of organic waste from tofu and tempe. These findings confirm that a participatory approach is an effective strategy for community empowerment in the utilization of agro-industrial waste.

Integration into a Circular Food System Model

The use of tofu residue as a food ingredient exemplifies circular economy principles within a community-based food system. In this model, agro-industrial waste is no longer regarded as disposable residue but as a resource reintegrated into the economic value chain. This approach contributes to waste reduction and environmental protection while simultaneously generating new economic value. The conversion of okara into cookies aligns with circular food system principles, which emphasize reusing waste as a resource to preserve residual economic value while minimizing environmental impact through reduce, reuse, and recycle strategies. Therefore, processing tofu residue into food products constitutes a concrete form of agro-industrial waste valorization that supports resource efficiency and the sustainability of local food systems (Hotimah & Zain, 2024).

This program demonstrates that integrating food-processing innovation with community empowerment can yield a more sustainable production system. The transformation of tofu residue into cookies exemplifies effective resource valorization, while community involvement ensures continuity of implementation at the local level. Overall, the findings indicate that utilizing okara as a cookie ingredient not only enhances the nutritional and economic value of agro-industrial waste but also strengthens community empowerment and supports the development of a circular economy-based food system. This approach holds potential for further development as a sustainable community-based food innovation model.

CONCLUSION

This study successfully evaluated the nutritional and sensory characteristics of okara-based cookies developed through a community-based circular food innovation approach in Pakiskembar Village, Pakis District, Malang Regency. Proximate analysis showed that okara substitution increased crude fiber content (9.09%) and maintained protein levels above the minimum SNI requirement (6.27%), while moisture and ash met quality standards, although fat and energy values remained below conventional cookie standards, resulting in a distinct high-fiber product profile. Sensory evaluation involving 30 untrained panelists indicated that the formulation containing 20 g of okara achieved the highest overall acceptance across taste, color, texture, and aroma, demonstrating that moderate substitution provides an optimal balance between nutritional enhancement and consumer preference. The participatory implementation approach effectively strengthened the community's capacity to transform tofu residue into value-added products, thereby supporting the application of circular economy principles at the village level. Overall, okara valorization through this approach offers a promising model for sustainable rural food innovation, and future studies are recommended to optimize lipid and energy content, evaluate shelf-life stability, and assess market feasibility for broader implementation.

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