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Valorization of Okara (Soybean Pulp) as a Raw Material for Non-Flaky Crackers: Food Technology and Nutritional Evaluation

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Abstract:
Okara, a by-product of soybean milk production, remains underutilized despite its high protein and fiber content and potential contribution to sustainable food development. This study evaluated the use of okara as a raw material in non-flaky crackers by examining sensory acceptance and nutritional characteristics across five wheat flour–okara ratios: 50:50, 40:60, 30:70, 20:80, and 10:90. Organoleptic assessment included color, aroma, taste, and texture, while chemical analysis measured moisture, ash, protein, fat, crude fiber, carbohydrate content, and caloric value. The formulation containing 30:70 wheat flour to okara ratio showed the most acceptable sensory quality, particularly in taste and texture. Nutritional analysis of the selected product indicated 18.23% protein, 2.40% crude fiber, 33.54% fat, 40.86% carbohydrate, 4.95% ash, 2.41% moisture, and 551.18 cal/100 g. These results demonstrate that okara can be valorized as a functional ingredient in non-flaky crackers, improving nutritional value while supporting food waste reduction and sustainable product development for small- and medium-scale enterprises.

Keywords: okara, soybean pulp, cracker, organoleptic evaluation, nutritional content

1. Introduction

Soybean processing for products such as soy milk and tofu generates a significant amount of okara, commonly known as soybean pulp, which is often treated as industrial waste. Okara contains substantial amounts of dietary fiber, protein, lipids, and bioactive compounds, making it nutritionally rich but underutilized in food systems due to spoilage risk and challenging sensory properties when incorporated directly into foods (Chavan, Kadam, & Salunkhe, 2023; Delgado-Nieblas & Serna-Saldívar, 2021).

Soy milk itself is a popular alternative to cow's milk due to its plant-based protein content, affordability, and suitability for lactose-intolerant consumers. The standard production process involves soaking, grinding, filtering, and heating soybeans, which consistently generates okara as a by-product (Cahyadi, 2007; Muchtadi, 2010). Valorization of okara aligns with circular economy principles, transforming a high-volume residue into functional food ingredients that can reduce environmental impact and add economic value to the food processing chain (Rosenthal & Kaur, 2025; Delgado-Nieblas & Serna-Saldívar, 2021).

Despite its rich nutritional profile, okara's functional potential is limited by its high proportion of insoluble fiber and off-flavors, which can negatively affect texture and consumer acceptance when incorporated into food products without proper processing or formulation strategies (Nugraha, Widjaja, & Putri, 2023). Recent studies have applied techniques such as extrusion, fermentation, and enzymatic hydrolysis to improve the techno-functional and nutritional properties of okara, enabling its use in bakery products, extruded snacks, and other cereal-based matrices (Guimarães, Chaud, & Alvim, 2022; Malik & Saini, 2024).

Non-flaky crackers, which are crisp, single-layered products with low gluten content, represent a promising food matrix for okara incorporation. Standard ingredients include flour, sugar, shortening, and leavening agents, and partial substitution with okara can improve protein and fiber content while maintaining sensory acceptability (Manley, 1983; Nadra, 2008; Puspita & Komarudin, 2021). Incorporating okara into such products contributes to functional food development and creates sustainable snack alternatives that add value to agro-industrial by-products.

The present study investigates the formulation and sensory acceptance of non-flaky crackers with varying levels of okara substitution, alongside an analysis of their nutritional profiles. The aim is to evaluate the feasibility of okara valorization as a functional ingredient in food product development and to provide insights for small- and medium-scale enterprises (SMEs) seeking to produce nutritious and sustainable snacks (Rosenthal & Kaur, 2025).

2. Material and Method

Material

The Okara (Soybean Pulp) in this study have been materials and Equipment: Wheat flour, dried okara, sugar, shortening, baking powder, oven, mixer. The formulations used in the production of non-flaky crackers in this study refer to the Center for Food and Nutrition Studies (CFNS) and have been modified with the proportions of raw materials, namely dried soybean pulp and wheat flour. The formulation for each treatment can be seen in Table 1.

Table 1. Formulation for non-flaky crackers used in the study

Ingredient	**Amount**				
	A	B	C	D	E
Wheat Flour (g)	50	40	30	20	10
Dried Soybean Pulp (g)	50	60	70	80	90
Sugar (g)	1.4	1.4	1.4	1.4	14
Shortening (g)	26.7	26.7	26.7	26.7	26.7
Soda (g)	0.1	0.1	0.1	0.1	0.1
Salt (g)	1.8	1.8	1.8	1.8	1.8
Yeast (g)	1	1	1	1	1
Tween 80 (g)	0.2	0.2	0.2	0.2	0.2
Water (ml)	40	40	40	40	40
Flavor (g)	3	3	3	3	3
Skim milk (g)	3.3	3.3	3.3	3.3	3.3

Implementation

This study was carried out through several stages, namely the production of dried soybean pulp, the production of non-flaky crackers using soybean pulp as raw material, followed by organoleptic testing and nutritional analysis of soybean pulp, dried soybean pulp, and the product most preferred by the panelists in the organoleptic test.

Production of dried soybean pulp

The production of dried soybean pulp in this study was based on preliminary research that used roasting for drying, as this method is easier to implement in small industries and can be applied later. Preliminary research also showed that roasting produced better results compared to oven drying. The procedure involved drying the soybean pulp obtained from soy milk filtration over a medium flame for 30 minutes, resulting in dried soybean pulp.

Production of non-flaky crackers

The non-flaky crackers in this study were produced based on Center for Food and Nutrition Studies (1997) as cited in Tresna (2005). The production steps included mixing, fermentation, sheet rolling (sheeting), relaxation, proofing, and baking.

1. Mixing
   First, shortening, sugar, skim milk, and Tween 80 were mixed, then dried soybean pulp (according to the treatment) was added and stirred for 5 minutes. After thorough mixing, wheat flour (according to

the treatment), beef flavor, yeast, baking soda, and cold water were added gradually and kneaded until smooth.

2. Fermentation
   After kneading, the dough was fermented for one hour in a covered container.
3. Sheet rolling and rutting
   The dough was manually rolled using a rolling pin to a thickness of 2 mm, then cut using a mold.
4. Relaxation and proofing
   Before baking, the dough was allowed to relax for 10 minutes and proofed for 15 minutes to allow dough expansion. Proofing aimed to enhance the crispness of the crackers.
5. Baking
   The initial baking temperature was 218°C for 5 minutes, then reduced to 121°C for 15 minutes.

Moisture content

Moisture content was determined using the oven-drying method. The sample was weighed in a previously dried and weighed dish, then dried in an oven at 105°C until a constant weight was obtained. After drying, the sample was cooled in a desiccator and weighed. Moisture content was calculated based on the weight loss after drying.

$$\text{Moisture content (\%)} = \frac{W_1 - W_2}{W_1 - W_0} \times 100 \qquad (1)$$

Where:
W_0 = weight of the empty dish
W_1 = weight of the dish and sample before drying
W_2 = weight of the dish and sample after drying.

Ash content

Ash content was determined using the dry ashing method with slight modification. A total of 3 g of sample was accurately weighed and placed in a previously weighed porcelain dish. The sample was then incinerated over a flame to remove volatile organic matter and to obtain a charred residue. After charring, the porcelain dish was transferred into an electric muffle furnace and heated at 550°C until complete ashing was achieved.

$$\text{Ash content (\%)} = \frac{b - c}{a}\, x\, 100\% \qquad (2)$$

Note**:**
a = weight of the sample before ashing (g)
b = weight of the sample plus crucible after ashing (g)
c = weight of the empty crucible (g)

Protein content

Protein content was determined using the semi-micro Kjeldahl method with slight modification. A total of 2 g of sample was placed into a Kjeldahl digestion flask, followed by the addition of 1.9 g selenium catalyst and 15 mL concentrated sulfuric acid. The mixture was digested for approximately 2 hours until the solution became clear green, indicating the conversion of organic nitrogen into ammonium sulfate. The digested solution was cooled and diluted to 100 mL with distilled water. An aliquot of 20 mL was pipetted into the distillation apparatus, followed by the addition of 25 mL of 30% NaOH to liberate ammonia. The ammonia was then distilled and collected in 25 mL of 3% boric acid containing Conway indicator. The distillate was titrated with 0.025 N HCl until the endpoint was reached.

$$\text{Protein (\%)} = \frac{(V_{spl} - V_{blk}) \times N \times 14.008 \times F_k \times DF \times 100}{W} \tag{3}$$

Where:
V_{spl} = volume of HCl used for sample titration
$V_{\beta lk}$ = volume of HCl used for blank titration,
N = normality of HCl,
F_k = nitrogen-to-protein conversion factor,
DF = dilution factor
W = sample weight

Crude fiber

Crude fiber content was determined using an acid–alkali digestion method with slight modification. A total of 2 g of sample was first defatted using petroleum ether or *n*-hexane in a Soxhlet apparatus to remove fat that may interfere with the determination. The defatted sample was then transferred into a 500 mL Erlenmeyer flask, followed by the addition of 50 mL of 1.25% H_2SO_4 and boiled under a reflux condenser. The residue was filtered and washed with hot water until neutral. Subsequently, the residue was treated with 3.25% NaOH and boiled again for 30 minutes. The residue retained on the filter paper was dried and weighed. The crude fiber content was calculated using eq. 4.

$$\text{Crude fiber (\%)} = (b - a)/\text{sample weight} \times 100 \tag{4}$$

Where:
a = weight of empty filter paper or container
b = weight of filter paper or container with dried crude fiber residue

Fat content

Fat content was determined using the Soxhlet extraction method with slight modification (AOAC International, 2023a, 2023b). A known weight of sample was placed in an extraction thimble and extracted using an organic solvent such as petroleum ether or diethyl ether in a Soxhlet apparatus. During extraction, the solvent was repeatedly evaporated, condensed, and passed through the sample to dissolve and extract the lipid fraction. After the extraction process was completed, the solvent was evaporated, and the extracted fat residue was dried and weighed. Fat content was calculated using eq. 5.

$$\text{Fat content (\%)} = \frac{W_2 - W_1}{W} \times 100 \tag{5}$$

Where :
W_1 = weight of the empty extraction flask
W_2 = weight of the extraction flask with extracted fat
W = sample weight.

Carbohydrate analysis by difference

Carbohydrate content was calculated by difference using eq. 6.

$$\text{Carbohydrate content (\%)} = 100\% - (\text{protein} + \text{fat} + \text{ash} + \text{moisture content}) \tag{6}$$

Energy determination with adiabatic bomb calorimeter

Gross energy was determined using an adiabatic oxygen bomb calorimeter with slight modification (ISO, 1998; FAO, 2011). The sample was pelletized and placed in the combustion cup of the bomb calorimeter. The bomb was then filled with oxygen and the sample was completely combusted under standardized conditions. The heat released during combustion was recorded from the temperature rise of the calorimeter system and used to calculate the gross energy value, expressed as cal/g. Prior to sample analysis, the calorimeter was standardized using certified benzoic acid as a reference material, since benzoic acid is commonly used for bomb calorimeter calibration and validation of gross calorific value measurements (ISO, 1998; FAO, 2011; Parr Instrument Company, 2022; Sen et al., 2024).

$$\text{Gross energy (cal/g)} = \frac{W \times \Delta T - e_1 - e_2 - e_3}{m} \tag{7}$$

Where:
W = energy equivalent of the calorimeter
ΔT = the corrected temperature rise
e_1, e_2, and e_3 = the correction factors for nitric acid formation, sulfur correction, and ignition wire/cotton thread combustion, respectively
m = the sample mass.

Organoleptic testing

Organoleptic testing was conducted using a hedonic sensory evaluation method with slight modification (ISO, 2014; ISO, 2023) The non-flaky crackers were evaluated by 25 semi-trained panelists from the Faculty of Agricultural Technology, Andalas University. The sensory attributes assessed included color, taste, texture, crispness, and overall acceptance using a 5-point hedonic scale, where 1 = dislike very much and 5 = like very much (Rumapea et al., 2025). The use of hedonic testing is appropriate for measuring the degree of panelists' preference or liking toward food products, particularly under controlled sensory evaluation conditions. ISO 11136:2014 provides general guidance for conducting hedonic tests with consumers in a controlled area and remains current after being reviewed and confirmed in 2025. The product with the highest mean hedonic score was selected as the most preferred formulation and was subsequently analyzed for its physical and chemical properties.

3. Results and Discussion

Raw material transformation and nutrient enhancement

Roasting treatment substantially changed the physical and chemical characteristics of okara, as presented in Table 2. The moisture content decreased from 85.23% in fresh soy milk residue to 27.43% in dried soy milk residue, indicating that roasting effectively reduced water content and improved the stability of the raw material. At the same time, the drying process increased the concentration of major nutrients, including protein from 4.83% to 14.49%, crude fiber from 1.94% to 10.87%, fat from 0.35% to 6.38%, ash from 0.46% to 2.29%, and carbohydrates from 9.11% to 49.41%. These changes show that dried okara has better potential as a nutrient-dense ingredient for non-flaky cracker formulation (Kamble & Rani, 2020; Asghar et al., 2023). The high fiber and protein levels in okara contributed to the structural integrity and nutritional profile of the final cracker products, providing both functional and health benefits.

Table 2. Physical and chemical analysis of fresh soy milk residue and dried soy milk residue

Parameter Analisis	Soy Milk Residue Fresh	Soy Milk Residue Dried
Moisture	85.23%	27.43%
Ash	0.46%	2.29%
Protein	4.83%	14.49%
Fat	0.35%	6.38%
Carbohydrate (by Difference)	9.11%	49.41%
Crude Fiber	1.94%	10.87%

The results in Table 2 confirm that drying is an important preliminary step in okara utilization. The reduction in moisture content is essential for minimizing spoilage risk, while the increased protein and crude fiber contents support the role of okara as a functional ingredient. Therefore, dried okara was considered suitable for further incorporation into non-flaky cracker formulations

Organoleptic evaluation

Sensory evaluation of five formulations revealed significant differences in sensory attributes. The 30:70 wheat flour to okara ratio consistently received the highest scores for color, aroma, taste, and texture. Formulations with higher okara ratios (20:80 and 10:90) displayed darker coloration, stronger beany aroma, and coarser texture, suggesting a threshold for sensory acceptability when using high okara inclusion. These observations are consistent with previous studies where excessive okara altered sensory qualities despite increasing nutritional content (Guimarães et al., 2022; Nugraha et al., 2023).

The sensory characteristics of the five cracker formulations were evaluated through panelist preference for color, aroma, taste, and texture. As shown in Table 3, color preference varied among treatments as the proportion of dried okara increased. Formulations B and C showed the highest color preference, with 48% of panelists indicating acceptance. Treatment C produced a slightly brownish-yellow color, which remained acceptable and visually attractive, while higher okara substitution in treatments D and E resulted in darker coloration.

Table 3. Percentage of panelists' preference for the Organoleptic of non-flaky cracker products

wheat flour : dried soybean pulp	color	aroma	taste	texture
A (50% :50%)	36	36	40	40
B (40% : 60%)	48	36	40	52
C (30% : 70%)	48	32	52	56
D (20% : 80%)	44	36	32	56
E (10% : 90%)	32	12	24	36

The darker color observed in higher okara formulations is attributable to intensified Maillard browning reactions between proteins and reducing sugars during baking, a trend supported by studies on okara-enriched baked products (Malik & Saini, 2024; Rosenthal & Kaur, 2025). This effect demonstrates the dual impact of okara on both nutrition and appearance, which must be considered in product formulation.

Panelist preference for aroma is presented in Table 3. Treatments A, B, and D showed the highest aroma preference, each reaching 36%, while treatment E had the lowest preference at 12%. This indicates that excessive okara addition may intensify the soybean aroma and reduce sensory acceptance. However, treatments A to D were still relatively acceptable, suggesting that okara can be incorporated at moderate to high levels without causing excessive aroma rejection.

The percentage of panelists who liked the aroma of non-flaky crackers across all treatments showed that the highest value was 36% for treatments A, B, and D. The lowest value was 12% for treatment E. These data indicate that the aroma of treatments A, B, C, and D was more preferred compared to treatment E. This is because, in treatment E, the soybean aroma became more pronounced, resulting in only 12% of panelists liking it. The aroma formed in the non-flaky cracker products originates from the aroma of soybean pulp.

The beany odor is a major challenge in developing soy-based foods. This odor can reduce the acceptability of soy-based products. According to Rackis (1970), soy contains the enzyme lipoxygenase, which can generate a beany odor during processing. This odor results from the breakdown of fats into smaller compounds, mainly carbonyl compounds such as aldehydes and ketones, due to lipid oxidation by oxygen at double bonds when the soy is broken and the enzymes are exposed to air and water or water vapor.

Cahyadi (2007) stated that the beany odor and taste can be eliminated by inactivating the lipoxygenase enzyme. Methods in soy milk processing include: (1) using hot water (80–100°C) during soybean grinding, or (2) soaking soybeans in hot water for 10–15 minutes before grinding.

In the soy milk production process, the beany odor in soybeans is removed by inactivating the lipoxygenase enzyme, thereby also minimizing the odor in the soybean pulp. This explains why the aroma of the resulting non-flaky cracker products is still preferred by panelists, even when a high proportion of soybean pulp is added.

Based on Table 3, panelist preference for taste showed that treatment C, consisting of 30% wheat flour and 70% dried soybean pulp, received the highest preference value at 52%. Treatments A and B had equal preference values of 40%, while treatments D and E decreased to 32% and 24%, respectively. This trend indicates that increasing okara concentration beyond 70% may reduce taste acceptance due to the stronger soybean flavor. Therefore, treatment C was considered the most balanced formulation in terms of taste acceptance.

The decrease in preference for the taste in treatments D and E, associated with higher soybean pulp content, is caused by the increasingly pronounced soybean flavor, which is less preferred. According to Koswara (1995), besides the beany taste, one of the factors causing off-flavors in soy is the bitter and chalky taste, which is due to glycoside compounds present in soybean seeds. Among these glycosides, soyasaponin and sapogenol are the primary contributors to the beany taste in soy and its non-fermented products. Saponins are soluble in hot water and alcohol, which can reduce bitterness. Additionally, 27% of saponins in soybeans are found in the seed coat, so peeling the soybean skin also reduces about one-third of the bitter taste.

During soy milk production, this bitterness can be minimized through the peeling and soaking in hot water, which removes saponin compounds. Furthermore, in the production of non-flaky crackers, beef flavor and salt are added to create a savory taste. Therefore, the treatment with a ratio of 70% dried soybean pulp to 30% wheat flour resulted in the most preferred taste of the non-flaky cracker product according to the panelists.

The texture of non-flaky cracker products originates from their fat and fiber content. According to Anas (1985) as cited in Fika (2007), fat functions to improve the texture of ingredients. Fennema (1985) in Fika (2007) added that fat has a structure similar to a plastic solid, and the plastic properties of fat make it act as a tenderizing agent in several food materials.

Based on Table 3, the highest panelist preference for texture was observed in treatments C and D, each reaching 56%. Treatment E showed the lowest texture preference at 36%. The increase in preference up to treatments C and D indicates that okara addition can contribute positively to cracker texture when used at an appropriate level. However, excessive okara addition in treatment E produced a slightly coarser texture, which may be associated with the higher fiber content of soybean pulp. The coarse texture is due to the fiber content in the soybean pulp. Nadra (2008) stated that proteins and fibers contain many hydrophilic groups capable of binding water; therefore, the higher the protein and fiber content in the non-flaky crackers, the more water is evaporated during baking, which leads to a lower moisture content and a coarser texture.

Enhanced nutritional profile

The chemical composition of the selected formulation is shown in Table 7. The 30:70 wheat flour to okara formulation contained 2.41% moisture, 4.95% ash, 18.23% protein, 2.40% crude fiber, 33.54% fat, 40.86% carbohydrates, and 551.18 cal/100 g. These values indicate that the selected product had a relatively low moisture content and improved nutritional quality, especially in terms of protein and fiber. The protein content of 18.23% demonstrates the contribution of okara as a plant-based protein source, while the crude fiber content supports its potential as a functional snack ingredient (Tami, 1982; Asghar et al., 2023; Kamble & Rani, 2020).

Table 4. Results of physical and chemical analysis of products

Properties	Value
Moisture (%)	2.41
Ash (%)	4.95
Protein (%)	18.23
Crude Fiber (%)	2.40
Fat (%)	33.54
Carbohydrate by Difference (%)	40.86
Calori (kal/100gr)	551.18

The data in Table 4 further support the selection of treatment C as the best formulation. In addition to receiving the highest taste preference and favorable texture acceptance, this formulation also provided improved nutritional value. Thus, the 30% wheat flour and 70% okara ratio achieved a balance between sensory acceptability and nutritional enhancement, making it the most suitable formulation for non-flaky cracker development.

Functional implications and valorization context

Beyond nutritional improvement, okara offers broader functional and health potential. Literature highlights its bioactive compounds, which may confer anti-diabetic, anti-obesity, and antioxidant effects when appropriately processed (Asghar et al., 2023; Rosenthal & Kaur, 2025). Incorporating smaller particle sizes and applying controlled dehydration methods can mitigate the gritty texture typically associated with high okara content, suggesting that texture optimization can be achieved through physical or enzymatic treatments, such as extrusion or hydrolysis (Guimarães et al., 2022; Malik & Saini, 2024).

Overall, the 30% wheat flour to 70% okara ratio strikes a balance between maximizing nutritional value and maintaining acceptable sensory quality. Formulations exceeding this ratio may require further processing interventions, including hydrothermal or enzymatic modifications, to preserve texture and flavor while allowing higher okara inclusion (Nugraha et al., 2023; Rosenthal & Kaur, 2025).

4. Conclusion

Roasting effectively stabilizes okara, concentrating its nutrients and enhancing its suitability for food applications. The optimal sensory acceptance was achieved with a 30:70 wheat to okara ratio, balancing texture, flavor, and color. Chemical analysis confirmed that protein (18.23%) and fiber (2.40%) levels were significantly improved, underscoring the potential of this product as a functional food. Overall, the valorization of okara not only improves nutritional quality but also contributes to reducing food waste and supports the production of sustainable snack products.

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