

Effect of Oat Bran Incorporation on the Physicochemical and Sensory Properties of Tempeh Crisp

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ABSTRACT

Tempeh, a fermented soybean product, is known as a cost-effective, protein-rich, and health-promoting food. Tempeh crisp, a preserved version of tempeh, extends its shelf life by removing moisture and halting fermentation. However, this product's low fibre content and the limited research on its characteristics and acceptability limit its commercialization. Oat bran, a byproduct of oats rich in dietary fibre, vitamins, and minerals, offers the potential to enhance the tempeh crisp's nutritional profile. This study investigates the effects of incorporating oat bran (OB) on the physicochemical properties and sensory attributes of tempeh crisps. Tempeh crisp was prepared with varying ratios of oat bran and tapioca flour (TF): Control A (0% OB: 100% TF), B (10% OB: 90% TF), C (20% OB: 80% TF), and D (30% OB: 70% TF). Proximate analysis revealed significant differences ($p < 0.05$) in moisture, ash, crude fat, crude protein, carbohydrate, and dietary fibre content between formulations. Notably, dietary fibre content increased from 3.12% in the control to 8.21% in the oat bran-enriched samples. Physical analysis showed texture hardness ranging from 0.74 to 1.93 and crispness from 7.57 to 9.95. The colour profile recorded L^* from 63.58 to 71.84, a^* from 3.46 to 8.67, and b^* from 24.05 to 28.19. Sensory evaluation indicated that Formulation B (10% OB: 90% TF) achieved the highest overall acceptability. As a result, this research successfully managed to improve the nutritional content of tempeh crisps by adding oat bran.

INTRODUCTION

Tempeh crisp, a legume snack derived from fermented soybeans, offers a nutritious and protein-rich alternative to traditional snacks. Tempeh is indeed a fermented product, known for its unique texture and flavour. Studies have highlighted the health benefits of tempeh, including its potential to manage conditions like atherosclerosis, diabetes mellitus, obesity, and osteopenia, emphasizing its role as a functional food with diverse health advantages. Tempeh fermentation has been recognized as a low-cost, health-promoting, and sustainable food processing technology, making it a valuable source of protein-rich foods with positive implications for human health [1]. Despite the potential of tempeh crisps as a functional snack, limited research has been conducted to explore their physicochemical characteristics, sensory acceptability, and overall nutritional potential. Research on tempeh snacks is relatively limited, but existing studies highlight the potential of tempeh as a versatile and nutritious ingredient in various snack forms and focus on

marketing strategies [2]. In recent years, there has been a growing interest in developing functional foods that not only satisfy hunger but also contribute to overall health and well-being. One such ingredient that has garnered significant attention is oat bran, a by-product of oat milling, which is a rich source of dietary fibre, beta-glucan, vitamins, and minerals [3]. The consumption of oat bran has been linked to various health benefits, including improved digestive health, lower cholesterol levels, and reduced risk of chronic diseases such as heart disease and diabetes [4].

Incorporating oat bran into food products has been shown to enhance their nutritional profile, particularly in terms of fibre content and health benefits, such as improved cardiovascular health and glycemic control [5]. The integration of oat bran into tempeh crisp production is justified as a strategy to address the reduction in dietary fibre caused by traditional processing methods such as fermentation and frying. By incorporating oat bran into tempeh crisps, this study aims to enhance the nutritional profile of the product, providing a snack option that meets

consumer demand for health-conscious, fibre-enriched foods. This approach also aligns with the increasing trend of functional food innovation, offering both convenience and added nutritional benefits. Understanding the impact of oat bran on attributes such as texture, moisture content, and flavour is crucial for optimizing product quality and consumer satisfaction. This study will contribute to the small body of knowledge on tempeh snacks, addressing gaps in existing studies. The findings can help future innovations in tempeh-based products, supporting their development as a versatile and nutritious snack option for health-conscious consumers.

MATERIALS AND METHODS

Materials

Tempeh crisps are made using soybeans, along with other ingredients and seasonings. The ingredients included a tempeh starter culture, oat bran, vinegar, and oil purchased from TMG Mart, Gong Badak, Terengganu. All of the chemicals and instruments used for physicochemical analysis were provided by the Faculty of Fisheries and Food Science at Universiti Malaysia Terengganu (UMT).

Methods

Table 1 shows that tempeh incorporated with oat bran was substituted in four formulations: Control A (0% oat bran), B (10% oat bran), C (20% oat bran), and D (30% oat bran). These formulations were then carried out in triplicate. Fermented tempeh was produced using the method previously described by Erdiansyah [6]. The fermented tempeh cakes were sliced into 3 mm thicknesses suitable for making crisps. The tempeh slices were deep-fried in hot oil (palm oil) until crispy and golden brown.

The frying temperature was controlled at 160°C, and the frying time was maintained at 3 minutes to ensure even cooking and prevent burning. Proximate analysis was conducted by following the AOAC method [7]. Calorie analysis was done by using a Bomb calorimeter (Model-IKA C2000) [8]. For colour analysis, lightness (L*), redness (a*), and yellowness (b*) were measured using a Chroma Meter CR-410 with a 50-mm aperture and D65 illumination settings [9]. Texture analysis was carried out as described by Chakraborty et al. [10], employing a TA. XT Plus Texture Analyser (Stable Microsystem, UK) fitted with a 5-kg load cell and a spherical probe (P/0.25S, ¼-inch diameter).

Table 1. The formulation for Tempeh Crisp.

Ingredients	Control (Formulation A)	Formulation B	Formulation C	Formulation D
Soybean	500g	500g	500g	500g
Oat bran	0g (0%)	40g (10%)	80g (20%)	120g (30%)
Tapioca flour	400g (100%)	360g (90%)	320g (80%)	280g (70%)
Tempeh starter	5g	5g	5g	5g
Vinegar	45g	45g	45g	45g
Total weight	950g	950g	950g	950g

A total of 35 respondents of students from the Faculty of Fisheries and Food Science were selected to become a panel in a sensory evaluation (10 males and 25 females between the ages of 23 and 26). Panels were provided a set of tempeh crisps that were randomly coded, and they were asked to give a score based on the appearance, colour, aroma, crispness, and overall acceptance. The 7-point hedonic scale was used, with a scale of 1 as “dislike extremely” to 7 as “like very much.”

Statistical Analysis

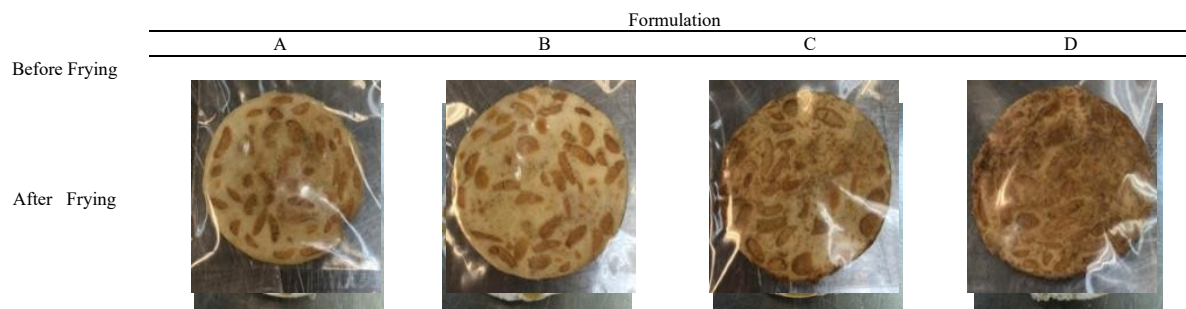
All the resulting data were analysed using one-way analysis of variance (ANOVA) through Minitab 21 software (Minitab Inc., USA). The means of the four formulations of oat bran tempeh crisp were compared using Tukey’s test at a 95% significance level ($p < 0.05$).

RESULT AND DISCUSSION

Proximate composition and caloric values

Table 2 below shows the visual appearance of Tempeh Crisp with different formulations before and after frying. Each formulation maintained its structural integrity before and after frying, showing that the incorporation of oat bran and tapioca flour was effective in forming cohesive products. Based on visual observations, a significant colour change occurs after frying, becoming darker due to the Maillard reaction or caramelisation. Before frying, the surfaces appear uniform but porous. After frying, the surfaces look crispier and more compact.

Table 2. Picture of tempeh crisp with different formulations before and after frying.



Note: Formulation A (0% oat bran, 100% Tapioca flour); Formulation B (10% oat bran, 90% Tapioca flour); Formulation C (20% oat bran, 80% Tapioca flour); Formulation D (30% oat bran, 70% Tapioca flour)

Table 3 shows the proximate composition of tempeh crisps with different ratios of oat bran (0%, 10%, 20%, 30%). For moisture content, there was a significant difference ($p < 0.05$) between formulation D and other formulations. However, no significance exists between formulations A, B, and C. The Moisture content decreases as the oat bran content increases. Meanwhile, the crude protein content of tempeh crisp formulated with different ratios of oat bran increases as the oat bran content increases, with the highest protein content by formulation D (16.08%), whereas formulation A (11.56%) showed the lowest protein. This study found that higher oat bran inclusion contributes to protein content since oat bran contains more protein compared to tapioca flour. Studies by Gbolagade et al. [11] reported similar findings, adding that oat bran demonstrated that their products had higher protein content compared to controls, highlighting the nutritional enhancement provided by oat bran.

Table 3. Proximate composition and caloric value of tempeh crisps.

Proximate Composition [% Wet Basis (W.B)]	Formulation			
	A	B	C	D
Moisture	5.56 ± 0.37 ^a	5.55 ± 0.71 ^a	5.36 ± 0.56 ^a	3.44 ± 0.32 ^b
Crude Protein	11.56 ± 0.16 ^c	14.38 ± 0.44 ^b	16.00 ± 0.79 ^a	16.08 ± 0.23 ^a
Crude Fat	35.95 ± 1.04 ^a	26.62 ± 1.36 ^b	24.32 ± 1.82 ^{bc}	22.40 ± 0.40 ^c
Dietary Fibre	3.12 ± 0.15 ^c	5.90 ± 0.79 ^b	7.10 ± 0.28 ^{ab}	8.21 ± 0.56 ^a
Ash	0.59 ± 0.02 ^b	1.05 ± 0.08 ^a	1.09 ± 0.15 ^a	1.11 ± 0.13 ^a
Carbohydrate	43.30 ± 1.57 ^b	46.13 ± 1.66 ^{ab}	46.50 ± 1.37 ^{ab}	48.76 ± 1.21 ^a
Calories (Kcal/G)	5.05 ± 0.23 ^a	5.37 ± 0.10 ^a	5.30 ± 0.02 ^a	5.36 ± 0.05 ^a

Note: The presented data are mean values of three replications ± standard deviation, with different superscript letters in the same row are significantly different ($p < 0.05$). Where Formulation A (0% oat bran, 100% Tapioca flour); Formulation B (10% oat bran, 90% Tapioca flour); Formulation C (20% oat bran, 80% Tapioca flour); Formulation D (30% oat bran, 70% Tapioca flour).

There was a significant difference ($p < 0.05$) in crude fat content among all formulations, as the fat content decreases progressively as the proportion of oat bran increases in the formulations. The crude fat content of tempeh crisps formulated with different ratios of oat bran decreases as the oat bran content increases, with the highest fat content by formulation A (35.95% w.b), whereas formulation D (22.40% w.b) showed the lowest fat content. For dietary fibre content, formulation A (3.12% w.b) has the lowest dietary fibre content and is significantly different from all other formulations (B, C, D), while formulation D (8.21% w.b) has the highest dietary fibre content, and it is significantly different from formulation A and formulation B. According to the research by Harasym and Pejcz [12], the addition of oat bran to food products, such as wafers, can result in high fibre content, with some formulations achieving 21 g of fibre per 100 g of product. Furthermore, incorporating oat bran into snacks can significantly increase their dietary fibre content, with studies showing fibre content in extruded snacks ranging from 6.5% to 15.8% w.b [13]. Oat bran has been successfully incorporated into various food products, such as breakfast cereals, bread, and snacks, to enhance their fibre content without compromising taste or texture [5].

For ash content, there was a significant difference ($p < 0.05$) between formulation A and other formulations. However, no significance exists between formulations B, C, and D. The Ash content of tempeh crisp formulated with different ratios of oat bran increases as the oat bran content increases, with the highest ash content by formulation D (1.11% w.b), whereas formulation A (0.59% w.b) showed significantly lowest ash content compared to others. The increase in ash content corresponds to the mineral contribution of oat bran. According to the research by Morsy [14], oat bran is known to have high ash content, ranging from 2.0% to 4.1% w.b, which indicates a significant mineral presence. Meanwhile, the results of carbohydrate content

showed that there was a significant difference ($p < 0.05$) between formulation A and formulation D. Total carbohydrate content of tempeh crisp formulated with different ratios of oat bran increases as the oat bran content increases, with the highest carbohydrate content by formulation D (48.76% w.b), whereas formulation A (43.30% w.b) showed lowest carbohydrate content. For the calorie content, the results showed there was no significant difference ($p > 0.05$) among all formulations. Calories in food products primarily come from macronutrients: carbohydrates, proteins, and fats. While the proportion of oat bran varies across samples, its contribution to the overall caloric value may be minimal relative to the other ingredients. Thus, the substitution of a high-fibre ingredient like oat bran did not significantly alter the caloric content of baked snacks because the fibre content has minimal caloric contribution compared to carbohydrates and fats [11].

Colour profile

Table 4 shows the effect of different ratios of oat bran (0%, 10%, 20%, 30%) on the colour profile analysis of tempeh crisp. For colour profile L*, Formulation D showed significant differences ($p < 0.05$) compared with A, B, and C, but there is no significant difference among A, B, and C. The colour profile analysis reveals that the lightness (L*) of tempeh crisp decreases as the oat bran content increases, with the highest lightness value exhibited by formulation A (71.84), whereas formulation D (63.58). This trend can be attributed to the darker colour of oat bran, which reduces the lightness of the final product. This is because oat bran contains natural pigments like polyphenols.

Furthermore, during the cooking process, reactions between proteins and reducing sugar (Maillard reaction) occur more prominently when oat bran is added, leading to browning and reduced lightness [13]. The finding was in the same agreement with Makowska et al. [13] where corn snacks were enriched with oat bran, a reduction in brightness and an increase in redness were observed as the oat bran content increased from 20% to 30%. While for colour profile a* formulation A is significantly different ($p < 0.05$) compared to B, C, and D, but there is no significant difference between C and D.

The redness (a*) values increase significantly with added oat bran, with formulation B (10% oat bran) recording the highest value (8.67). This increase suggests that oat bran promotes browning reactions, such as the Maillard reaction, during the cooking process. The lowest a* value (3.46) is found in formulation A, showing the least red tone or minimal colour development. The a* value increased with the inclusion of oat bran up to a certain level (formulation B) but decreased slightly in higher oat bran content (formulations C and D). The nonlinear trend is likely due to the interaction of pigment dilution and Maillard browning [15]. Additionally, the natural browning pigment in oat bran may mask the reddish tones.

Table 4. Colour profile of Tempeh Crisp with different formulations.

Formulation	L*	a*	b*
A	71.84 ± 1.32 ^a	3.46 ± 0.15 ^c	24.05 ± 2.24 ^a
B	68.96 ± 2.06 ^a	8.67 ± 0.35 ^a	24.89 ± 3.11 ^a
C	67.93 ± 1.72 ^a	6.59 ± 0.51 ^{ab}	28.19 ± 1.07 ^a
D	63.58 ± 0.96 ^b	4.60 ± 1.91 ^{bc}	28.19 ± 2.51 ^a

Note: The presented data are mean values of three replications ± standard deviation with different superscript letters in the same column are significantly different ($p < 0.05$). Where Formulation A (0% oat bran, 100% Tapioca flour); Formulation B (10% oat bran, 90% Tapioca flour); Formulation C (20% oat bran, 80% Tapioca flour); Formulation D (30% oat bran, 70% Tapioca flour).

Furthermore, for colour profile b*, there is no significant difference ($p>0.05$) among the formulations. The consistent yellowness across formulations suggests that tapioca flour and oat bran do not significantly affect the yellow pigmentation of the final product. This could be due to similar carotenoid levels or a lack of pigmentation differences in ingredients. Excessive oat bran may dilute the starch concentration, reducing the available sugars needed for browning, and its natural pigments may contribute more to brown tones than yellow. Research by Chauhan et al. [16] on fibre-enriched snacks found that increasing fibre levels initially enhanced yellowness due to browning reactions but later caused a slight reduction as fibre levels exceeded optimal thresholds.

Texture profile

Table 5 shows the effect of different ratios of oat bran (0%, 10%, 20%, 30%) on the texture profile analysis (TPA) of tempeh crisp. Formulation D shows significant differences ($p<0.05$) compared with other formulations. The study found that as the concentration of oat bran increased, the hardness value of tempeh crisp significantly increased for formulations B to D, with the highest hardness exhibited by formulation D (1.93 N), whereas formulation B had the lowest (0.74 N). Hardness in the context of tempeh crisp refers to the force required to bite or break the crisp; it measures the tempeh crisp's firmness or resistance to deformation under pressure. A higher hardness value indicates that the tempeh crisp is firmer and denser, while a lower value means the tempeh crisp is more tender or fragile. In this study, the hardness of tempeh crisp increases as the oat bran content increases; this can be attributed to the higher fibre content of the oat bran, which absorbs water and reduces the moisture content of the tempeh crisp, leading to a denser and harder texture [13].

Table 5. Hardness and crispness value of tempeh crisp with different formulations.

Formulation	Hardness (N)	Crispness (N.s)
A	1.12 ± 0.24 ^{bc}	7.57 ± 0.07 ^b
B	0.74 ± 0.06 ^a	7.73 ± 0.35 ^b
C	1.43 ± 0.35 ^{ab}	8.41 ± 0.51 ^b
D	1.93 ± 0.31 ^a	9.95 ± 0.38 ^a

Note: The presented data are mean values of three replications ± standard deviation with different superscript letters in the same column are significantly different ($p<0.05$). Where Formulation A (0% oat bran, 100% Tapioca flour); Formulation B (10% oat bran, 90% Tapioca flour); Formulation C (20% oat bran, 80% Tapioca flour); Formulation D (30% oat bran, 70% Tapioca flour).

The structure of oat bran creates a more rigid matrix compared to tapioca flour alone, which has lower fibre and higher starch content [17]. Consequently, as oat bran is incorporated into the formulation, the resulting product becomes harder and less flexible. For instance, the addition of oat bran to lentil-based snacks resulted in a significant increase in hardness due to the formation of thicker cell walls and smaller cells in the extrudes [18]. Similarly, oat bran in bread formulation increased the hardness compared to control samples without oat bran due to the addition of dietary fibres that reduced water activity and a firmer crumb structure [19]. In summary, the hardness of tempeh crisp reflects the texture's firmness, which is influenced by its ingredients and moisture content.

Crispness increased with oat bran concentration, with formulation D (30% oat bran) exhibiting the highest value (9.95 N·s) and formulation A (0% oat bran) the lowest (7.57 N·s). Formulation D differed significantly ($p<0.05$) from A, B, and C, while no differences were observed among A, B, and C. Crispness denotes the brittle texture and audible fracturing of tempeh crisps under minimal force. The enhanced crispness with increased oat bran is attributed to its moisture-absorbing capacity, which reduces water activity and promotes a dry, brittle

matrix, consistent with findings in fiber-enriched snacks [18]. Conversely, higher fat content linked to oat bran may decrease expansion and crispness [20]. Pre-fermentation of oat bran improves crispness by reducing dough stickiness and increasing hardness, thereby enhancing sensory properties despite high fiber content [21]. Overall, oat bran enhances tempeh crispness through moisture reduction and structural reinforcement.

Sensory evaluation

Table 6 shows the mean score of acceptability of tempeh crisp incorporated with different formulations of oat bran. Regarding appearance attributes, formulation B (5.43) received the highest scores for appearance, followed by formulation A (5.27), formulation C (4.90), and formulation D scored the lowest (4.60). Despite the differences, there was no significant difference ($p>0.05$) in the appearance attribute of sensory acceptance, suggesting that panelists generally found all formulations acceptable in terms of appearance. According to Ustinova et al. [5], oat bran-enriched breakfast products did not show adverse effects on organoleptic characteristics, suggesting that appearance changes might not always negatively impact consumer acceptance.

Meanwhile, the colour attribute of tempeh crisp has a mean value ranging from 4.63 to 5.38, formulation B had the highest score (5.38), while Formulation D scored the lowest (4.63). However, the statistical analysis result showed that there were no significant differences ($p>0.05$) between all formulas. Similar results are also shown for the attributes of aroma and crispness; there was no significant difference ($p>0.05$) between all formulations.

Table 6. The mean score of the sensory evaluation of tempeh crisp.

Attribute	Formulation			
	A	B	C	D
Appearance	5.27 ± 1.51 ^a	5.43 ± 1.41 ^a	4.87 ± 1.25 ^a	4.60 ± 1.33 ^a
Colour	5.13 ± 1.78 ^a	5.38 ± 1.33 ^a	4.90 ± 1.21 ^a	4.63 ± 1.43 ^a
Aroma	4.73 ± 1.48 ^a	5.43 ± 1.31 ^a	4.70 ± 1.21 ^a	4.93 ± 1.23 ^a
Crispness	4.93 ± 2.00 ^a	5.50 ± 1.55 ^a	5.13 ± 1.72 ^a	5.53 ± 1.41 ^a
Overall acceptability	5.27 ± 1.94 ^a	5.93 ± 1.51 ^a	4.33 ± 1.47 ^b	4.41 ± 1.29 ^b

Note: The presented data are mean values of three replications ± standard deviation with different superscript letters in the same row are significantly different ($p<0.05$). Where Formulation A (0% oat bran, 100% Tapioca flour); Formulation B (10% oat bran, 90% Tapioca flour); Formulation C (20% oat bran, 80% Tapioca flour); Formulation D (30% oat bran, 70% Tapioca flour).

Generally, panelists preferred formulation B (10% oat bran), which scored highest for overall acceptability (5.93), followed by formulation A (5.27), formulation D (4.41), and formulation C (4.33). Statistical analysis showed that formulation B and formulation A had no significant differences ($p>0.05$) between them but were significantly different ($p<0.05$) between formulations C and D. Formulation B achieves a balance between texture, aroma, and appearance due to its 10% oat bran content, which provides additional nutritional benefits without overwhelming sensory attributes. This suggests that moderate incorporation of oat bran (10%) enhances the sensory appeal, while higher oat bran levels (above 20%) reduce overall acceptance. A study by Majzoobi et al. [22] on fibre-enriched snacks found that moderate fibre addition (5 to 10%) improves sensory attributes, particularly crispness, and flavour. However, fibre levels above 15% negatively impacted overall acceptability due to texture and flavour changes. This supports that formulation B (10% oat bran) was most preferred, while formulations C and D (20% and 30% oat bran) scored lower. Thus, higher oat bran levels (20 to 30%) negatively impacted sensory characteristics, reducing overall acceptability. These results highlight the potential for incorporating moderate oat bran levels to develop nutritious and palatable snacks.

CONCLUSION

This study successfully evaluated the effects of different ratios of oat bran (0%, 10%, 20%, and 30%) on the physical, chemical, and sensory properties of tempeh crisps, achieving the stated objectives. The incorporation of oat bran significantly influenced the proximate composition, with higher oat bran ratios leading to increased crude protein and dietary fibre contents. Moisture content decreased as the oat bran ratio increased, likely due to its moisture-absorbing properties. However, calorie content showed no significant differences among the samples, as the caloric contributions of oat bran and tapioca flour balanced out. Sensory evaluation revealed that oat bran impacted key attributes such as crispness, texture, and overall acceptability. Samples with 10% oat bran (Formulation B) received the highest overall acceptability score, indicating an optimal balance between taste, texture, and appearance. Higher oat bran levels (20% and 30%) slightly reduced acceptability, possibly due to changes in texture and mouthfeel caused by increased fibre content. This suggests that moderate oat bran addition can balance enhanced nutrition with desirable sensory qualities in tempeh crisps, making the product more appealing to consumers.

CONFLICT OF INTEREST

The authors have declared that no conflict of interest exists.

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