

***Coleus amboinicus*-Enriched Plant-Based Patty from Fermented Kidney Beans and Oyster Mushroom: Nutritional Quality and Functional Potential of an Indigenous Food Innovation**

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Abstract

The growing demand for plant-based foods highlights the need for nutritionally adequate and functionally relevant meat alternatives. This study aimed to develop a plant-based patty derived from fermented kidney beans (tempeh) and oyster mushroom, enriched with *torbangun* leaves (*Coleus amboinicus* L.), an indigenous medicinal plant, and to evaluate its sensory acceptance and nutritional quality. Four formulations containing 0%, 2.0%, 2.5%, and 3.0% *torbangun* were produced. Sensory evaluation involving semi-trained panelists was conducted to determine the most acceptable formula. Proximate composition, dietary fiber, mineral content (iron, calcium, and magnesium), amino acid profile, and nutritional contribution based on dietary reference values were analyzed. The formulation containing 2.5% *torbangun* was selected as the optimal product due to superior sensory acceptance, particularly in taste. The selected patty contained 15.67% protein, 12.67% dietary fiber, 8.13% fat, and 72.86% carbohydrate (dry basis). Mineral contents were 1.24 mg iron, 46.39 mg calcium, and 24.21 mg magnesium per 100 g. Methionine was identified as the limiting amino acid. A 100 g serving provided approximately 10% of daily protein needs and nearly 20% of dietary fiber requirements, qualifying the product as a source of fiber. These findings demonstrate that *torbangun*-enriched patties from fermented legumes and mushrooms represent a promising indigenous plant-based meat analog with favorable sensory properties and meaningful nutritional value. The product offers functional potential as a sustainable food alternative for plant-based diets.

Keywords: *Coleus amboinicus*; fermented kidney bean tempeh; nutritional profiling; plant-based meat analog; sensory evaluation.

Abbreviations: AOAC, Association of Official Analytical Chemists; AAS, Atomic Absorption Spectrophotometry; ALG, Acuan Label Gizi (Indonesian Nutrition Label Reference); F0–F3, formulation codes containing 0%, 2.0%, 2.5%, and 3.0% *torbangun*, respectively; HPLC, High-Performance Liquid Chromatography

INTRODUCTION

The global shift toward plant-based diets has accelerated in recent years, driven by concerns related to environmental sustainability, animal welfare, and human health (Prentice, 2023). Plant-based meat analogs have emerged as a strategic response to this trend, offering alternatives that mimic the sensory and functional properties of meat while relying on renewable biological resources (Konrad, 2025; Webb *et al.*, 2023). However, many commercial products remain nutritionally suboptimal, particularly in terms of protein quality, dietary fiber, and micronutrient density (Soh *et al.*, 2024). This limitation is especially relevant in developing countries, where plant-based diets are increasingly promoted but often fail to meet essential

nutritional requirements (Jakše *et al.*, 2021; Niklewicz *et al.*, 2022; Dodd *et al.*, 2021).

Legumes and mushrooms represent promising raw materials for plant-based meat alternatives. Legumes are rich in protein, complex carbohydrates, and dietary fiber, while mushrooms contribute umami flavor, texture, and bioactive compounds (Akanni & Adebo, 2024; Al-Atijawi & Almusawy, 2021; Ayimbila & Keawsompong, 2023). Fermentation of legumes into tempeh further enhances their nutritional value by improving protein digestibility, reducing antinutritional factors, and increasing nutrient bioavailability (Ahnan-Winarno *et al.*, 2021; Purwandari *et al.*, 2024). Kidney beans (*Phaseolus vulgaris* L.), when processed into tempeh, provide a locally available and affordable protein source with improved functional properties (Purwandari *et al.*, 2024;

Hisyam & Kurniasih, 2024). Oyster mushroom (*Pleurotus ostreatus*) complements legumes through its fibrous structure, low fat content, and potential health benefits, including hypocholesterolemic and antioxidant effects (Dayanti *et al.*, 2021; El-Razek *et al.*, 2020).

Beyond macronutrient adequacy, the incorporation of functional plant ingredients offers an opportunity to enhance the biological relevance of plant-based foods. *Torbangun* (*Coleus amboinicus* L.) is an indigenous medicinal plant traditionally consumed in Indonesia, particularly among Batak communities. It is widely recognized for its galactagogue properties and is known to contain bioactive compounds and micronutrients associated with health-promoting effects (Rusandi & Sadek, 2024; Sari *et al.*, 2023). Despite its ethnobotanical significance, torbangun remains underutilized in modern food innovation, especially in products aligned with contemporary dietary trends.

Integrating *torbangun* into plant-based meat analogs provides a novel approach to bridging traditional knowledge with modern food systems. Such integration not only diversifies the functional profile of plant-based products but also strengthens the role of indigenous resources in sustainable nutrition (Ahmed *et al.*, 2022). In this context, fermented legume–mushroom patties enriched with torbangun may serve as functional foods that address both sensory acceptance and nutritional adequacy while contributing to dietary diversification and local food valorization.

MATERIALS AND METHODS

Materials

The main raw materials used in this study were kidney beans (*Phaseolus vulgaris* L.), oyster mushrooms (*Pleurotus ostreatus*), and torbangun leaves (*Coleus amboinicus* L.). Kidney beans were purchased from a

local traditional market in Bogor, Indonesia. Fresh oyster mushrooms were obtained from a local mushroom producer, while torbangun leaves were harvested from locally cultivated plants at the mature leaf stage. A commercial tempeh starter containing *Rhizopus spp.* was used for fermentation. Other food-grade ingredients included carrageenan, tapioca starch, garlic, sugar, salt, white pepper powder, nutmeg powder, mushroom seasoning, and red yeast rice extract (angkak).

Preparation of Kidney Beans Tempeh

Kidney beans were sorted, washed, and soaked in water for approximately twelve hours to facilitate hydration and dehulling. The soaked beans were boiled until softened, manually dehulled, and drained. After cooling to room temperature, the beans were inoculated with tempeh starter and incubated at ambient temperature (28–30 °C) for forty-eight hours until complete mycelial growth was observed. Fermentation was applied to improve protein digestibility, reduce antinutritional compounds, and enhance nutritional quality, as reported in previous studies on tempeh fermentation (Pasquale *et al.*, 2021; Fitriani *et al.*, 2021; Byanju *et al.*, 2021). The resulting kidney bean tempeh was used as the primary protein source for patty formulation.

Formulation of Torbangun-Enriched Vegetarian Patty

Vegetarian patties were formulated using fermented kidney bean tempeh and oyster mushroom as the main base ingredients at a fixed ratio of one to one (w/w). Torbangun leaves were incorporated at different concentrations, while other ingredients were kept constant. Four formulations were prepared and coded as F0 (control, without *torbangun*), F1 (2.0% *torbangun*), F2 (2.5% *torbangun*), and F3 (3.0% *torbangun*). The detailed formulation of each patty is presented in Table 1.

Table 1. Formulation of torbangun-enriched vegetarian patties.

Ingredients	F0	F1	F2	F3
Base ingredients				
Kidney bean tempeh (g)	100	100	100	100
Oyster mushroom (g)	100	100	100	100
Total base ingredients (g)	200	200	200	200
Additional ingredients				
Carrageenan (g)	5	5	5	5
Tapioca starch (g)	15	15	15	15
Red yeast rice extract (mL)	10	10	10	10
Sugar (g)	1	1	1	1
Salt (g)	2	2	2	2
White pepper powder (g)	0.25	0.25	0.25	0.25
Nutmeg powder (g)	0.15	0.15	0.15	0.15
Garlic (g)	2	2	2	2
Mushroom seasoning (g)	1	1	1	1
Torbangun leaves (g)	0 (0.00%)	4 (2.00%)	5 (2.50)	6 (3.00%)

Processing of Torbangun-Enriched Vegetarian Patty

The processing steps for patty production followed a modified method adapted from Lee *et al.* (2024). and are illustrated in Figure 1. Fermented kidney bean tempeh and oyster mushrooms were initially chopped and homogenized using a food processor, followed by manual straining to reduce excess moisture. Moisture reduction is an important step to improve binding capacity and texture in plant-based patties (Portilla *et al.*, 2025; Moazzam, 2025).

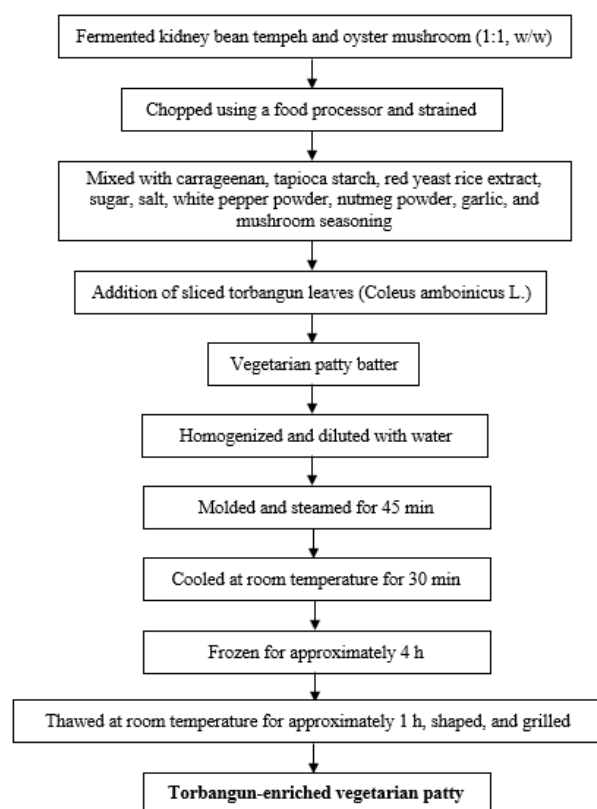


Figure 1. Flow diagram of torbangun-enriched vegetarian patty production, modified from Lee *et al.* (2024).

The homogenized mixture was then combined with carrageenan and tapioca starch as binding agents. Carrageenan was used to enhance gel formation and water-holding capacity, while tapioca starch contributed to structural integrity during thermal processing (Zhao *et al.*, 2023; Xie *et al.*, 2025). Seasonings, including garlic, sugar, salt, white pepper powder, nutmeg powder, mushroom seasoning, and red yeast rice extract, were added to improve flavor and appearance. Sliced *torbangun* leaves (*Coleus amboinicus* L.) were incorporated according to the formulation. The mixture was further homogenized and diluted with water to obtain a uniform batter-like consistency. The batter was poured into molds and steamed for forty-five minutes to induce protein denaturation, starch gelatinization, and gel

network formation, thereby stabilizing the patty structure.

After steaming, the patties were cooled at room temperature for approximately thirty minutes and then frozen for at least four hours to improve firmness and facilitate handling. Prior to sensory evaluation and further analyses, frozen patties were thawed at room temperature for approximately one hour, reshaped if necessary, and grilled until evenly heated. The final product was a torbangun-enriched vegetarian patty.

Sensory Evaluation

Sensory evaluation was conducted using a hedonic test involving thirty-four semi-trained panelists with a background in nutrition science. Attributes evaluated included color, aroma, texture, taste, mouthfeel, and aftertaste. A nine-point hedonic scale ranging from one (dislike extremely) to nine (like extremely) was used, following standard sensory evaluation procedures for food products (Passos *et al.*, 2025). Patties were evaluated both in plain form and when served as burgers with bread and standard condiments. The formulation with the highest overall acceptance was selected for further nutritional analysis.

Proximate and Dietary Fiber Analysis

Proximate composition, including moisture, ash, protein, fat, and carbohydrate content, was determined using standard analytical methods. Moisture and ash contents were analyzed gravimetrically, protein content was determined using the micro-Kjeldahl method, fat content by Soxhlet extraction, and carbohydrate content by difference. Dietary fiber was determined using an enzymatic-gravimetric method. All analyses followed procedures recommended by the Association of Official Analytical Chemists (Astuti *et al.*, 2022).

Mineral and Amino Acid Analysis

Mineral contents, including iron, calcium, and magnesium, were determined using Atomic Absorption Spectrophotometry after wet digestion of samples. Amino acid composition was analyzed using High-Performance Liquid Chromatography following acid hydrolysis and derivatization. The limiting amino acid was identified by comparing the essential amino acid profile with reference protein patterns (Machado *et al.*, 2020).

Nutritional Contribution and Data Analysis

Nutritional contribution per serving was calculated based on Indonesian nutrition labeling reference values. Sensory data were analyzed using analysis of variance, followed by post hoc tests when significant differences were observed. Nutritional data were presented descriptively as mean values.

RESULTS AND DISCUSSION

Formulation of Vegetarian Patty

Four vegetarian patty formulations were successfully produced using fermented kidney bean tempeh and oyster mushroom as the main base ingredients, with different levels of *torbangun* leaf addition. The formulation design was intended to evaluate the effect of *torbangun* incorporation while maintaining constant proportions of other ingredients to ensure comparability among treatments. The control formulation (F0)

contained no *torbangun* leaves, whereas F1, F2, and F3 contained 2.0%, 2.5%, and 3.0% *torbangun*, respectively. Figure 2 illustrates the physical appearance of vegetarian patties produced from red kidney bean tempeh and oyster mushroom with varying levels of *torbangun* leaf incorporation. The patties were presented in two serving forms, namely as individual patty portions and as mini sandwiches accompanied by bread, vegetables, salad dressing, and BBQ sauce.



Figure 2. Visual appearance of vegetarian patties with different levels of *torbangun* leaf addition, presented as individual patty portions and as mini sandwiches.

Visually, all formulations exhibited a compact structure with relatively uniform shape and surface texture, indicating adequate binding properties of the formulation matrix. Increasing levels of *torbangun* leaf tended to produce a darker brownish-green hue, which is associated with the natural chlorophyll content of the leaves. No visible structural defects, such as cracking or excessive crumbliness, were observed across

formulations, suggesting that the addition of *torbangun* leaf up to 3.0% did not negatively affect patty integrity.

Hedonic Evaluation

The hedonic evaluation of vegetarian patties served as sandwiches and sliced patties is presented in **Table 2**. Overall, all formulations demonstrated acceptable sensory scores, with mean values ranging from neutral to like.

Table 2. Hedonic evaluation of vegetarian patties served as sandwiches and sliced patties.

Formulation	Color	Aroma	Texture	Taste	Mouthfeel	Aftertaste
Sandwich presentation						
F0	6.32 ± 0.61 ^a	6.79 ± 0.69 ^a	6.39 ± 0.63 ^a	6.47 ± 0.65 ^a	5.59 ± 0.59 ^a	5.12 ± 0.51 ^a
F1	6.31 ± 0.63 ^a	6.50 ± 0.50 ^a	6.34 ± 0.63 ^a	6.38 ± 0.64 ^a	5.41 ± 0.51 ^a	5.03 ± 0.50 ^a
F2	6.35 ± 0.62 ^a	6.62 ± 0.66 ^a	6.09 ± 0.61 ^a	5.99 ± 0.60 ^a	5.15 ± 0.52 ^a	4.91 ± 0.49 ^b
F3	5.93 ± 0.59 ^a	6.27 ± 0.63 ^a	6.20 ± 0.62 ^a	5.93 ± 0.59 ^a	4.87 ± 0.49 ^a	4.38 ± 0.44 ^b
Sliced patty presentation						
F0	6.51 ± 0.65 ^a	5.98 ± 0.60 ^a	5.71 ± 0.57 ^a	5.83 ± 0.58 ^a	5.10 ± 0.51 ^a	5.18 ± 0.52 ^a
F1	6.47 ± 0.65 ^a	5.86 ± 0.59 ^a	5.78 ± 0.58 ^a	5.88 ± 0.59 ^a	4.96 ± 0.50 ^a	4.92 ± 0.49 ^a
F2	6.38 ± 0.64 ^a	5.97 ± 0.60 ^a	5.34 ± 0.53 ^a	6.13 ± 0.61 ^a	5.29 ± 0.53 ^a	4.43 ± 0.44 ^b
F3	5.44 ± 0.54 ^b	4.70 ± 0.47 ^b	4.96 ± 0.50 ^b	4.86 ± 0.49 ^b	4.11 ± 0.41 ^b	4.05 ± 0.41 ^b

Notes:

F0 = control formulation (0% *torbangun* leaf addition); F1 = formulation with 2.0% *torbangun* leaf addition; F2 = formulation with 2.5% *torbangun* leaf addition; F3 = formulation with 3.0% *torbangun* leaf addition

Hedonic scale: 1 = extremely dislike; 2 = very dislike; 3 = dislike; 4 = slightly dislike; 5 = neutral; 6 = slightly like; 7 = like; 8 = very like; 9 = extremely like

Values are expressed as mean scores.

Mean values within the same column followed by different superscript letters indicate significant differences ($p < 0.05$), while those followed by the same letter indicate no significant difference ($p > 0.05$).

In the sandwich presentation, no significant differences ($p > 0.05$) were observed among formulations for color, aroma, texture, taste, and mouthfeel. However, a significant decrease ($p < 0.05$) in aftertaste scores was observed in formulations containing higher levels of torbangun leaves (F2 and F3), suggesting the emergence of a distinctive herbal aftertaste at concentrations above 2.0%. In contrast, the sliced patty presentation revealed clearer sensory differences among formulations. The control and F1 formulations achieved higher acceptance scores across most attributes, whereas F3 consistently showed lower scores, particularly in aroma, texture, and

taste. This indicates that the presence of bread, vegetables, and condiments in the sandwich presentation may mask the herbal characteristics of torbangun leaves, leading to higher overall acceptability.

Hedonic Quality

The hedonic quality profile of vegetarian patties formulated with different levels of torbangun leaf addition is presented in **Figure 3**. Overall, the control formulation (F0) and F1 exhibited higher scores across most sensory quality attributes, particularly color, seasoning taste, firmness, and chewiness.

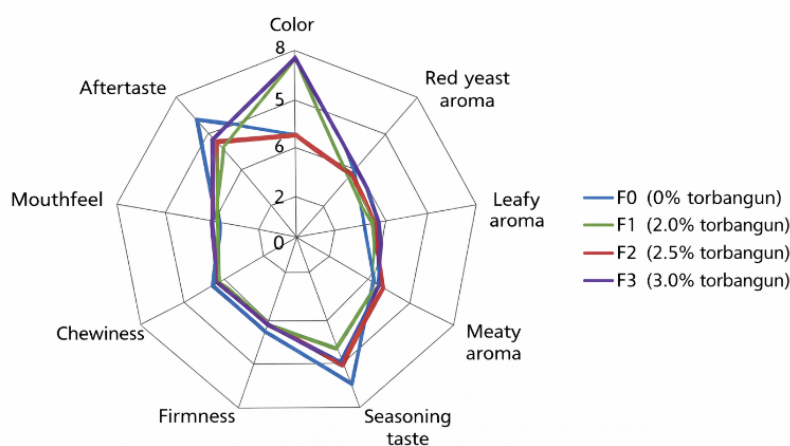


Figure 3. Visual appearance of vegetarian patties with different levels of torbangun leaf addition, presented as individual patty portions and as mini sandwiches.

Increasing levels of torbangun leaves tended to enhance leafy and herbal aroma characteristics, as indicated by higher scores for leafy aroma in F2 and F3. However, this increase was accompanied by a decline in aftertaste acceptance, suggesting that excessive torbangun incorporation may generate a persistent herbal note perceived less favorably by panelists. The radar profile clearly demonstrates a trade-off between functional ingredient enrichment and sensory quality, supporting the selection of F1 as the optimal formulation balancing acceptability and functional potential.

Macronutrient and Dietary Fiber Content of Control and Selected Vegetarian Patties

The macronutrient and dietary fiber composition of the control and selected vegetarian patties is presented in **Table 3**. The selected formulation showed a significantly higher moisture content ($p < 0.05$) compared to the control, which may be attributed to the water-holding capacity of *torbangun* leaves and the fibrous matrix of plant-based ingredients.

Table 3. Macronutrient and dietary fiber content of control and selected vegetarian patties.

Nutrient Content	Control vegetarian patty	Selected vegetarian patty
Moisture (% wb)	63.93 ± 0.71 ^a	65.16 ± 0.14 ^b
Ash (% db)	3.07 ± 0.08 ^a	3.31 ± 0.18 ^a
Fat (% db)	8.05 ± 0.06 ^a	8.13 ± 0.23 ^a
Protein (% db)	15.49 ± 0.22 ^a	15.67 ± 0.03 ^a
Carbohydrate (% db)	73.39 ± 0.25 ^a	72.86 ± 0.18 ^a
Dietary fiber (% db)	12.47 ± 0.05 ^a	12.67 ± 0.57 ^a

Notes:

Values are expressed as mean ± standard deviation.

Different superscript letters within the same row indicate significant differences ($p < 0.05$).

wb = wet basis; db = dry basis.

No significant differences ($p > 0.05$) were observed between formulations in ash, fat, protein, carbohydrate, and dietary fiber contents. The protein content of both patties remained above 15% (dry basis), indicating that the incorporation of torbangun leaves did not dilute protein density. Similarly, the dietary fiber content exceeded 12% (dry basis), supporting the potential of the product as a fiber-rich plant-based food. These findings suggest that the selected vegetarian patty formulation maintains comparable macronutrient quality to the control while offering additional functional value through the inclusion of torbangun leaves.

Mineral and Amino Acid Content of Selected Vegetarian Patty

The mineral and amino acid profiles of the selected vegetarian patty are presented in Tables 4 and 5. The selected vegetarian patty enriched with *torbangun* exhibited a favorable mineral profile, with calcium as the predominant mineral (46.39 mg/100 g), followed by magnesium (24.22 mg/100 g) and iron (1.25 mg/100 g). These minerals contribute to bone metabolism, enzymatic activity, and oxygen transport, supporting the nutritional relevance of the product as a plant-based protein source.

Table 4. Mineral content of selected vegetarian patty.

Mineral content	Vegetarian patty + torbangun
Iron (mg/100 g)	1.247
Calcium (mg/100 g)	46.393
Magnesium (mg/100 g)	24.215

Table 5. Amino acid composition of selected vegetarian patty.

Amino acid	Content (mg/g protein)
Arginine	2.3
Histidine	1.3
Isoleucine	2.8
Leucine	4.3
Lysine	1.5
Methionine	0.5
Phenylalanine	3.0

Amino acid	Content (mg/g protein)
Threonine	2.3
Valine	3.0
Alanine*	3.1
Aspartic acid*	5.8
Glycine*	2.0
Glutamic acid*	10.1
Tyrosine*	1.6
Serine*	3.0
Total essential amino acids (EAA)	21 mg/g protein
Sulfur amino acids (SAA)	0.036
Limiting amino acid	Methionine

*Non-essential amino acids

The amino acid analysis revealed a total essential amino acid (EAA) content of 21 mg/g protein. Leucine was the most abundant essential amino acid (4.3 mg/g protein), followed by valine (3.0 mg/g protein) and phenylalanine (3.0 mg/g protein). Among non-essential amino acids, glutamic acid showed the highest concentration (10.1 mg/g protein), which is characteristic of plant-based protein sources and contributes to umami flavor development.

Methionine was identified as the limiting amino acid, as reflected by the low sulfur amino acid (SAA) value (0.036). This finding is consistent with previous reports on vegetarian and legume-based protein products, where sulfur-containing amino acids are often present in limited amounts. Overall, the amino acid composition suggests that the selected vegetarian patty provides a balanced profile of essential and non-essential amino acids, although complementary protein sources may be required to improve sulfur amino acid adequacy.

Contribution of Vegetarian Patty Nutrients to Indonesian Nutrition Label Reference (ALG)

The contribution of nutrients from the selected vegetarian patty to the Indonesian Nutrition Label Reference (ALG) is presented in Table 6. A single serving (three patties, approximately 35 g) provided 6.98% of daily energy requirements and 10.20% of protein ALG, indicating a meaningful contribution to daily protein intake from a plant-based product.

Table 6. Contribution of selected vegetarian patty nutrients to Indonesian Nutrition Label Reference (ALG).

Nutrient	Per 100 g	Per serving (3 patties, ±35 g)	As sandwich	ALG	%ALG
Energy (kcal)	150	158	321	2.150	6.98
Protein (g)	6.12	6.43	10.88	60	10.20
Fat (g)	3.17	3.17	4.84	67	4.73
Carbohydrate (g)	24.26	24.26	57.86	325	7.46
Calcium (mg)	46.39	46.39	45.33	1.100	4.22
Iron (mg)	1.25	1.25	2.17	22	5.68
Magnesium (mg)	24.21	24.21	16.95	350	6.92
Dietary fiber (g)	4.94	4.94	4.93	25	19.76

The contribution of nutrients from the selected vegetarian patty to the Indonesian Nutrition Label Reference (ALG) is presented in Table 8. A single serving (three patties, approximately 35 g) provided 6.98% of daily energy requirements and 10.20% of protein ALG, indicating a meaningful contribution to daily protein intake from a plant-based product. Dietary fiber showed the highest contribution among micronutrients, reaching 19.76% of ALG, highlighting the potential role of the vegetarian patty in supporting gastrointestinal health. Mineral contributions were moderate, with magnesium, iron, and calcium contributing 6.92%, 5.68%, and 4.22% of ALG, respectively. Fat contribution remained relatively low (4.73% ALG), supporting the formulation's suitability for balanced and calorie-conscious diets.

Overall, the selected vegetarian patty demonstrates a favorable nutritional contribution profile, particularly in terms of protein and dietary fiber, supporting its positioning as a functional plant-based food within the context of Indonesian dietary recommendations.

Discussion

The development of *torbangun*-enriched vegetarian patties based on fermented kidney beans and oyster mushroom demonstrates how indigenous plant resources can be effectively integrated into modern plant-based meat analogs without compromising sensory acceptance or nutritional adequacy. The results of this study can be explained through the combined effects of fermentation, ingredient functionality, and formulation balance.

The acceptable sensory performance of patties containing up to 2.5% *torbangun* leaves indicates that the base matrix formed by fermented kidney bean tempeh and oyster mushroom provided a robust structural and flavor foundation. Fermentation of legumes into tempeh is known to enhance protein digestibility, reduce beany off-flavors, and generate flavor-active compounds through microbial metabolism, which improves palatability in plant-based products (Ahnman-Winarno *et al.*, 2021; Yanti *et al.*, 2023). The inclusion of oyster mushroom further contributed to texture and umami perception due to its fibrous structure and high glutamic acid content, which has been widely reported to enhance meat-like sensory characteristics in plant-based formulations (Mazlan *et al.*, 2020).

The decline in aftertaste acceptability observed at higher *torbangun* concentrations can be attributed to the presence of characteristic herbal volatiles and phenolic compounds inherent to *Coleus amboinicus*. While these compounds are associated with functional and medicinal properties, their accumulation at higher levels may result in persistent herbal notes that are less desirable in meat analog applications. The masking effect observed when patties were served as sandwiches supports sensory interaction theory, where condiments, bread, and vegetables reduce the perception of herbal bitterness and aftertaste, thereby improving overall acceptance. This

finding highlights the importance of considering consumption context when evaluating sensory performance of functional plant-based foods.

From a nutritional perspective, the maintenance of protein content despite *torbangun* incorporation suggests that the added plant material did not dilute protein density. This is consistent with previous studies reporting that moderate inclusion of leafy vegetables primarily increases moisture and fiber content without substantially affecting macronutrient composition (Jibrin *et al.*, 2024). The high dietary fiber content observed in the selected formulation can be explained by the synergistic contribution of legumes, mushrooms, and *torbangun* leaves, all of which are rich in non-digestible polysaccharides. High fiber intake has been strongly associated with improved gut health, glycemic control, and reduced risk of non-communicable diseases, reinforcing the functional relevance of the product (Megur *et al.*, 2022). The amino acid profile revealed methionine as the limiting amino acid, a common characteristic of legume-based protein sources. This limitation reflects the inherently low sulfur-containing amino acid content in most plant proteins, particularly legumes and leafy vegetables (Fahmy *et al.*, 2023; Yobi *et al.*, 2023). However, the relatively high levels of branched-chain amino acids, especially leucine, suggest that the protein matrix may still support protein synthesis and maintenance when consumed as part of a diversified diet. These findings emphasize that plant-based meat analogs should be evaluated not as sole protein sources, but as components of complementary dietary patterns, where amino acid balance can be achieved through food diversity (Cutroneo *et al.*, 2024).

The mineral contribution of the selected vegetarian patty, particularly calcium and magnesium, reflects the natural mineral composition of legumes, mushrooms, and *torbangun* leaves. Although iron contribution was moderate, this is consistent with the known limitations of non-heme iron bioavailability in plant-based foods (Henjum *et al.*, 2021; Craig *et al.*, 2021). Nonetheless, fermentation has been shown to improve mineral bioavailability by reducing phytic acid content, suggesting that the nutritional value of the product may be underestimated when evaluated solely based on mineral concentration.

Assessment of nutrient contribution relative to the Indonesian Nutrition Label Reference (ALG) demonstrated that a single serving of the vegetarian patty can provide meaningful contributions to daily protein and dietary fiber requirements. The high percentage of fiber contribution supports the positioning of the product as a fiber source according to national nutrition labeling standards. This aligns with current dietary recommendations that promote increased consumption of plant-based, fiber-rich foods to address the rising prevalence of obesity and diet-related chronic diseases (Choi *et al.*, 2020; Verma *et al.*, 2023).

Overall, the findings indicate that torbangun-enriched vegetarian patties represent a viable indigenous plant-based meat analog with balanced sensory quality and meaningful nutritional contribution. The study underscores the importance of optimizing functional ingredient levels to balance health potential and consumer acceptance, while highlighting the role of traditional plant resources in advancing sustainable and culturally relevant food innovations.

CONCLUSIONS

This study confirms that *torbangun* can be effectively utilized as a functional ingredient in plant-based patties derived from fermented kidney beans and oyster mushroom. The 2.5% *torbangun* formulation demonstrated optimal sensory acceptance while delivering high dietary fiber and meaningful protein and mineral contributions. Although methionine remained the limiting amino acid, the product shows potential as a complementary protein source within diversified dietary patterns. Future research should focus on improving protein quality through amino acid complementation and evaluating bioactive and antioxidant properties of *torbangun*-enriched formulations. Scale-up studies and consumer-based acceptance trials are also warranted to support commercial application of this indigenous plant-based meat analog.

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Authors' Contributions: Holif Fitriyah designed the study, conducted the experimental work, performed data collection, and drafted the manuscript. Muhammad Rizal Martua Damanik and Eny Palupi supervised the research, provided critical guidance on study design, data interpretation, and manuscript revision. Muhammad Faisal Pratama contributed to data analysis, interpretation of nutritional results, and critical review of the manuscript. All authors read and approved the final version of the manuscript.

Competing Interests: The authors declare that there are no competing interests.

REFERENCES

- Ahmed, S., Warne, T., Stewart, A. L., Shanks, C. B., & Dupuis, V. (2022). Role of Wild Food Environments for Cultural Identity, Food Security, and Dietary Quality in a Rural American State. *Frontiers in Sustainable Food Systems*, 6. <https://doi.org/10.3389/fsufs.2022.774701>
- Ahnan-Winarno, A. D., Cordeiro, L., Winarno, F., Gibbons, J. G., & Xiao, H. (2021). Tempeh: A semicentennial review on its health benefits, fermentation, safety, processing, sustainability, and affordability. *Comprehensive Reviews in Food Science and Food Safety*, 20(2), 1717-1767. <https://doi.org/10.1111/1541-4337.12710>
- Akanni, G. B. and Adebo, O. A. (2024). Metabolite perturbations in fermented legumes as elucidated using metabolomics: a review. *International Journal of Food Science & Technology*, 59(6), 4234-4250. <https://doi.org/10.1111/ijfs.17122>
- Al-Atijawi, S. H. and Almusawy, R. S. (2021). The Effect of Adding Different Rates of Mushroom Powder to the Wheat Flour on the Nutritional Value of Proteins, Sensory and Physical Properties of Local Bread. *Journal of Life Science and Applied Research*, 2(2), 35-40. <https://doi.org/10.59807/jlsar.v2i2.33>
- Astuti, E. J., Rafikayanti, A., Cahyani, D. I., & Putri, D. B. (2022). Comparison of Vitamin C Analysis Using High-Performance Liquid Chromatography Versus Potentiometric Titration. *KnE Medicine*. <https://doi.org/10.18502/kme.v2i3.11890>
- Ayimbila, F. and Keawsompong, S. (2023). Nutritional Quality and Biological Application of Mushroom Protein as a Novel Protein Alternative. *Current Nutrition Reports*, 12(2), 290-307. <https://doi.org/10.1007/s13668-023-00468-x>
- Byanju, B., Hojilla-Evangelista, M. P., & Lamsal, B. (2021). Fermentation performance and nutritional assessment of physically processed lentil and green pea flour. *Journal of the Science of Food and Agriculture*, 101(14), 5792-5806. <https://doi.org/10.1002/jsfa.11229>
- Craig, W. J., Mangels, A. R., Fresán, U., Marsh, K., Miles, F. L., Saunders, A. V., Haddad, E. H., Heskey, C. E., Johnston, P., Larson-Meyer, E., & Orlich, M. (2021). The Safe and Effective Use of Plant-Based Diets with Guidelines for Health Professionals. *Nutrients*, 13(11), 4144. <https://doi.org/10.3390/nu13114144>
- Choi, Y., Larson, N., Gallaher, D. D., Odegaard, A., Rana, J. S., Shikany, J. M., ... & Jacobs, D. R. (2020). A Shift Toward a Plant-Centered Diet From Young to Middle Adulthood and Subsequent Risk of Type 2 Diabetes and Weight Gain: The Coronary Artery Risk Development in Young Adults (CARDIA) Study. *Diabetes Care*, 43(11), 2796-2803. <https://doi.org/10.2337/dc20-1005>
- Cutroneo, S., Prandi, B., Pellegrini, N., Sforza, S., & Tedeschi, T. (2024). Assessment of Protein Quality and Digestibility in Plant-Based Meat Analogues. *Journal of Agricultural and Food Chemistry*, 72(14), 8114-8125. <https://doi.org/10.1021/acs.jafc.3c08956>
- Dayanti, D., Permatasari, W., Khaerunnisa, I., & Winarni, S. (2021). Quantitative Analysis of Histidine Amino Acid as a Predictor of Ergothioneine in the Drying and Frying Process of White Oyster Mushrooms (*Pleurotus ostreatus*). *Amerta Nutrition*, 5(4), 360. <https://doi.org/10.20473/amnt.v5i4.2021.360-369>
- Dodd, S., Dewey, C., Khosa, D. K., & Verbrugghe, A. (2021). A cross-sectional study of owner-reported health in Canadian and American cats fed meat- and plant-based diets. *BMC*

- Veterinary Research, 17(1). <https://doi.org/10.1186/s12917-021-02754-8>
- El-Razek, A. A., Ibrahim, A., El-Attar, A., & Asker, D. (2020). Utilization of Agro-Wastes to Produce Oyster Mushroom (*Pleurotus ostreatus*) with High Antioxidant and Antimicrobial Activities. *Alexandria Journal of Food Science and Technology*, 17(1), 1-15. <https://doi.org/10.21608/ajfs.2020.105625>
- Fahmy, H. A., El-Shamy, S., & Farag, M. A. (2023). Comparative GC–MS based nutrients profiling of less explored legume seeds of *Melilotus*, *Medicago*, *Trifolium*, and *Ononis* analysed using chemometric tools. *Scientific Reports*, 13(1). <https://doi.org/10.1038/s41598-023-45453-0>
- Fitriani, A., Santoso, U., & Supriyadi, S. (2021). Conventional Processing Affects Nutritional and Antinutritional Components and In Vitro Protein Digestibility in Kabau (*Archidendron bubalinum*). *International Journal of Food Science*, 2021, 1-8. <https://doi.org/10.1155/2021/3057805>
- Henjum, S., Groufh-Jacobsen, S., Stea, T. H., Tonheim, L. E., & Almendingen, K. (2021). Iron Status of Vegans, Vegetarians and Pescatarians in Norway. *Biomolecules*, 11(3), 454. <https://doi.org/10.3390/biom11030454>
- Hisyam, D. M. and Kurniasih, N. (2024). Tempe Made from Green Beans (*Vigna radiata* L.) and Red Beans (*Phaseolus vulgaris* L.) as Functional Food. *Istek*, 13(1), 12-16. <https://doi.org/10.15575/istek.v13i1.968>
- Jakše, B., Jakše, B., Godnov, U., & Pinter, S. (2021). Nutritional, Cardiovascular Health and Lifestyle Status of ‘Health Conscious’ Adult Vegans and Non-Vegans from Slovenia: A Cross-Sectional Self-Reported Survey. *International Journal of Environmental Research and Public Health*, 18(11), 5968. <https://doi.org/10.3390/ijerph18115968>
- Jibrin, M., Micah, R. M., & Omotehinwa, F. H. (2024). Comparative Evaluation of the Proximate, Phytochemical and Antioxidant Properties of Selected Leafy Vegetables (Bitter, Pumpkin and Spinach Leaves). *Lafia Journal of Scientific and Industrial Research*, 60-64. <https://doi.org/10.62050/ljsir2024.v2n1.293>
- Konrad, T., Ngo, J., Rathnayake, D., Hassall, E., Ha, M., Ronquest-Ross, L., ... & Moura Nadolny, J. (2025). Comparing the Sensory Properties of Commercially Available Plant-based and Animal Mince. *Journal of Food Science*, 90(11). <https://doi.org/10.1111/1750-3841.70714>
- Lee, D., Jeong, S., Yun, S., & Lee, S. (2024). Artificial intelligence-based prediction of the rheological properties of hydrocolloids for plant-based meat analogues. *Journal of the Science of Food and Agriculture*, 104(9), 5114-5123. <https://doi.org/10.1002/jsfa.13334>
- Machado, M., Machado, S., Pimentel, F. B., Freitas, V. d., Alves, R. C., & Oliveira, M. B. P. (2020). Amino Acid Profile and Protein Quality Assessment of Macroalgae Produced in an Integrated Multi-Trophic Aquaculture System. *Foods*, 9(10), 1382. <https://doi.org/10.3390/foods9101382>
- Mazlan, M. M., Talib, R. A., Chin, N. L., Shukri, R., Taip, F. S., Nor, M. Z. M., ... & Abdullah, N. (2020). Physical and Microstructure Properties of Oyster Mushroom-Soy Protein Meat Analog via Single-Screw Extrusion. *Foods*, 9(8), 1023. <https://doi.org/10.3390/foods9081023>
- Megur, A., Daliri, E. B., Baltriukienė, D., & Burokas, A. (2022). Prebiotics as a Tool for the Prevention and Treatment of Obesity and Diabetes: Classification and Ability to Modulate the Gut Microbiota. *International Journal of Molecular Sciences*, 23(11), 6097. <https://doi.org/10.3390/ijms23116097>
- Moazzam, M., Ali, S., Khan, M. A., Waseem, M., Javed, M. R., Rajput, N., ... & Osei Tutu, C. (2025). Impact of Soy Protein Concentrate and Storage on the Safety, Quality and Shelf Stability of Beef Patties. *Food Science & Nutrition*, 14(1). <https://doi.org/10.1002/fsn3.71327>
- Niklewicz, A., Smith, A.D., Smith, A. et al. The importance of vitamin B12 for individuals choosing plant-based diets. *Eur J Nutr* 62, 1551–1559 (2023). <https://doi.org/10.1007/s00394-022-03025-4>
- Passos, L. P., M. L. S. Galdino, A. H. Silas Souza, et al. 2025. “Impact of Product Labeling on Vegan Yogurt Acceptance.” *Journal of Sensory Studies* 40, no. 5: e70081. <https://doi.org/10.1111/joss.70081>.
- Pasquale, I. D., Verni, M., Verardo, V., Gómez-Caravaca, A. M., & Rizzello, C. G. (2021). Nutritional and Functional Advantages of the Use of Fermented Black Chickpea Flour for Semolina-Pasta Fortification. *Foods*, 10(1), 182. <https://doi.org/10.3390/foods10010182>
- Prentice, A. M. (2023). Foods for the future and their potential impact on child nutrition. *BMJ Nutrition, Prevention & Health*, 6(Suppl 2), s1-s2. <https://doi.org/10.1136/bmjnph-2023-000654>
- Portilla, R. P., Camargo, J. P., Córdoba, M., Buitrago, P. A. G., & Concha, J. L. H. (2025). Physicochemical and Nutritional Properties of Plant-Based Burger Patties: The Role of Hydrocolloids and Pea Protein. *Inge CuC*, 21(2). <https://doi.org/10.17981/ingecuc.21.2.2025.04>
- Purwandari, F. A., Fogliano, V., & Capuano, E. (2024). Tempeh fermentation improves the nutritional and functional characteristics of Jack beans (*Canavalia ensiformis* (L.) DC). *Food & Function*, 15(7), 3680-3691. <https://doi.org/10.1039/d3fo5379b>
- Rusandi, F. S. and Sadek, N. F. (2024). Comparison of different methods for evaluating the antioxidant activity of instant Torbangun (*Coleus amboinicus* L.) drinks. *IOP Conference Series: Earth and Environmental Science*, 1324(1), 012124. <https://doi.org/10.1088/1755-1315/1324/1/012124>
- Sari, M. I., Kusumawati, R. L., Pane, Y. S., & Sufitni, S. (2023). *Coleus Amboinicus* Lour. Leaf Extract as an Antioxidant in Sepsis. *Medical Archives*, 77(6), 451. <https://doi.org/10.5455/medarh.2023.77.451-454>
- Soh, B. X. P., Vignes, M., Smith, N. W., Hurst, P. R. v., & McNabb, W. C. (2024). Unsupervised machine learning to determine dietary protein distribution among New Zealand vegans across time periods of the day. *Proceedings of the Nutrition Society*, 83(OCE4). <https://doi.org/10.1017/s0029665124005731>
- Verma, P., Srivastava, R. K., & Jain, D. (2023). Effect of plant-based dietary intervention on Visceral Fat, Anthropometry and body Composition in individuals with metabolic syndrome. *International Journal of Agriculture and Nutrition*, 5(2), 57-63. <https://doi.org/10.33545/26646064.2023.v5.i2a.147>
- Webb, D., Doğan, H., Li, Y., & Alavi, S. (2023). Physico-Chemical Properties and Texturization of Pea, Wheat and Soy Proteins Using Extrusion and Their Application in Plant-Based Meat. *Foods*, 12(8), 1586. <https://doi.org/10.3390/foods12081586>
- Xie, S., Lei, Y., Chen, H., Liu, S., Lin, X., Guo, Z., ... & Zheng, B. (2025). Physicochemical Properties and Structural Study of Heat Treatment-Modified Chinese Yam (*Dioscorea opposita* Thunb.) Starch–Ferulic Acid Complexes. *Foods*, 14(10), 1761. <https://doi.org/10.3390/foods14101761>

- Yanti, Y., Violina, V., Putri, C. E., & Lay, B. W. (2023). Branched Chain Amino Acid Content and Antioxidant Activity of Mung Bean Tempeh Powder for Developing Oral Nutrition Supplements. *Foods*, 12(14), 2789. <https://doi.org/10.3390/foods12142789>
- Yobi, A., Ansaf, H., & Angelovici, R. (2023). A High-Throughput Absolute Quantification of Protein-Bound Sulfur Amino Acids from Model and Crop Plant Seeds. *Current Protocols*, 3(8). <https://doi.org/10.1002/cpz1.861>
- Zhao, Y., Sui, W., Zhang, J., Liu, R., Wu, T., Xu, J., ... & Zhang, M. (2023). Intervening effect of polysaccharides on structured soy-based meat analogues by high- moisture extrusion.. <https://doi.org/10.21203/rs.3.rs-3703308/v1>