Food and Humanity 4 (2025) 100526

Contents lists available at ScienceDirect

Food and Humanity

journal homepage: www.editorialmanager.com/foohum/journal_overview.html

Oyster mushroom as a main ingredient in nuggets alternative formulation combined with red bean and catfish powder: Preliminary study

Tiar Lince Bakara *, Rumida

Department of Nutrition, Polytechnic of Health, the Ministry of Health Indonesia, Politeknik Kesehatan, Kementerian Kesehatan Medan, Indonesia

ARTICLE INFO

Keywords:
Food product development
Functional food
Plant-based food products
Sustainable food ingredients

ABSTRACT

The transition from meat-based into plant-based food products has led to a massive plant-based food products development. The study investigated the formulation of nuggets alternatives made of oyster mushroom (OF) as a main ingredient with catfish (CF) and red bean flour (RF) as the minor ingredients. 10 formulations of nuggets were prepared with a variety of CF (10–55 g) and RF (50–5 g) for every 400 g OF. The results showed that the nuggets made of OF combined with 55 g CF and g 5 RF had the highest acceptability compared to that of other formulations. This formulation was desired and accepted for its color, texture, taste, and aroma. Chemical composition analysis revealed that the nuggets contained 8.5–9.3 % protein, 2.9–4.4 % ash, and 5.0–7.4 % dietary fiber. The nuggets had a dietary fiber and lower calorie value at a range of 5–7.4 g/100 g and 129–144 kcal/100 g, respectively. Nuggets contained Calcium (265–208 mg/kg), Iron (2.1–2.4 mg/kg), Zink (1.4–1.9 mg/kg), and Phosphorus (1853–1875 mg/kg). In conclusion, the nuggets can be formulated from oyster mushrooms combined with a small amount of catfish and red bean flour, which also can be potentially used as a local-based functional food product.

1. Introduction

The transition from meat-based consumption to plant-based consumption has become a popular issue to this day due to several considerations including health, environmental impact, religion, and other reasons (González et al., 2020; Parlasca & Qaim, 2022). Meat-based consumption has a higher environmental impact and footprints and is linked with the health issue. Although plant-based consumption offers more sustainable impact, it might not be suitable for all depending on the community preferences. Depending on the economic situation, certain countries might face challenges in the transition phase towards sustainable food production (Parlasca & Qaim, 2022). Capability, opportunity, and motivation are the three main factors which have been identified in the transition of meat-based consumption into plant-based consumption (Graça et al., 2019). This issue leads to a massive development of plant-based food products which includes meat replacement and meat substitution. This phenomenon affects the market value of plant based food products which continuously grow. The market value of plant-based foods increased from USD 29.4 billion in 2020 to USD 64.7 billion in 2024. This number is predicted to spike in 2030 to reach USD 161.9 billion (Wunsch, 2024).

Nuggets is one of the meat-based food products which was initially made of chicken. Nuggets and/or its alternatives have been mimicked by substitution and/or replacement by other ingredients such as fish or other meat products. The main aim of this phenomenon is not only for the transition to plant-based nuggets processing, but also for nutritional improvement. For instance, meat nuggets were modified by the addition of natural antioxidants using acerola fruit powder, rosemary extract, and licorice extract as well as rosemary, hydroxytyrosol, pomegranate, grape, and harpagophytum to enhance its shelf life (De Paiva et al., 2021; Martínez et al., 2020). Taste compounds (volatile and nonvolatile) of chicken nuggets was modified by the addition of milk fat up to 14 % and mashed potato up to 6 % (Sabikun et al., 2021). The addition of green peas up to 12 % was expected to enhance the dietary compounds of the chicken nuggets (Binti Mohd Zaini et al., 2021). The addition of food by-products in chicken nuggets has also been a new valorization trend. Banana peel powder (6 %) and dragon fruit peel (3 %) were utilized for nutritional improvement of chicken nuggets (Akram et al., 2022; Madane et al., 2020). Fish-based nuggets was modified by the addition of dragon fruit peel powder 2 % (Biswas et al., 2022) and moringa leaf powder 5–15 % (Solichah et al., 2022).

In terms of a total transition concept, the development of plant-based

* Corresponding author.
E-mail address: tiarlincebakara@gmail.com (T.L. Bakara).

https://doi.org/10.1016/j.foohum.2025.100526
Received 19 November 2024; Received in revised form 29 January 2025; Accepted 31 January 2025
Available online 1 February 2025

nuggets has also been conducted which is mainly prepared by utilizing legumes (Younis et al., 2023). Nuggets alternatives made of oyster mushroom have never been reported. Oyster mushroom is one of the most consumed and cultivated mushrooms due to its abundance in bioactive compounds such as bioactive carbohydrates, phenolics, terpenes, and sterol (Corrêa et al., 2016). It is also rich in protein, vitamins, and minerals (Devi et al., 2024). The presence of those compounds offer health benefits for its bioactivity such as antimicrobial, anti-cancer, anti-hyperlipidemia, anti-diabetic, anti-inflammatory, and immunostimulant activity (Corrêa et al., 2016; Devi et al., 2024). Therefore, its benefits can be used in nuggets alternatives production. The potential of mushroom as a main ingredient in nuggets is rarely reported and thus needs further investigations. Phoenix mushroom at 15–70 % was combined with chickpea flour in nuggets formulation (Mazumder et al., 2024). Compared to the commercial nuggets, mushroom-based nuggets had low acceptability (Mazumder et al., 2024). Therefore, improving the acceptability of mushroom-based nuggets by different types of mushrooms and/or incorporating other ingredients seems needed. The study investigated the potential of oyster mushroom as a main ingredient in nuggets formulation, and supported by minor composition of red beans and catfish flour. In addition to that, food products development based on locally-available ingredients have been highlighted for beneficial impacts on sustainable food ingredients supporting the Sustainable Development Goals by the United Nations. Recently, food product development utilizing local-based ingredients such as oyster mushroom, kidney beans, and catfish flour was reported in cookie formulation (Bakara et al., 2024). Current study employed those ingredients at different formulations in muffin formulation for food products diversification. It was expected that different levels of red beans and catfish flour could generate alternative nuggets with acceptable sensory properties.

2. Materials and methods

2.1. Materials

Oyster mushrooms, red beans, catfish, onion, and garlic were purchased from a local traditional market in Medan, North Sumatera, Indonesia. Other supporting ingredients in muffin formulation were purchased from the local supermarket such as wheat flour, salt, and black pepper.

2.2. Ingredients preparation

The main ingredients were prepared in flour form following the procedures described previously (Bakara et al., 2024) as detailed below.

2.2.1. Oyster mushroom flour

Firstly, Oyster mushroom were sorted, washed, sliced, and blanched for 5 min at 70 °C. After that, the oyster mushroom then dried at 60 °C for 24 h using a drying cabinet to reach a stable weight. It was milled to pass 80 mesh sieving and then the oyster mushroom flour (OF) was stored in a polyethylene bag at 24 °C for further experiments.

2.2.2. Catfish flour

The head and intestinal organs of the catfish were removed to obtain the filets, followed by soaking the filets with lime juice for 30 min to remove the fishy odor. The filets were washed with distilled water and steamed for 30 min. After that, it was drained and dried on a cabinet dryer at 60 °C for 6 h. The dried filets were milled to pass 60 mesh of sieving. The obtained catfish flour (CF) was kept and stored in a polyethylene bag at controlled temperature, 24 °C, for further experiments.

2.2.3. Read beans flour

Red beans were sorted based on physical appearance, washed, soaked for 24 h, and then washed again. After that, it was dried using a dryer cabinet at 50 °C for 1–2 h. The beans were then milled to pass 100 mesh sieving. Red beans flour (RF) was kept in a polyethylene bag, sealed, and stored at 24 ℃.

2.3. Experimental design

The study was designed to formulate OF-based nuggets with the addition of 10 different levels of CF and 10 different levels of RF. OF was used as the main ingredients with around 87 % of the total main ingredients; CF ranged at 2–12 % (10–55 g) and RF ranged at 1–11 % (5–50 g) were adjusted for the rest 13 % of the ingredients. In total, 10 formulations of nuggets were obtained as presented in Table 1. Other ingredients such as wheat flour and minor ingredients were used at the same level in all formulations as detailed in the next section and Table 1. The 10 formulated nuggets underwent sensory analysis for acceptability of color, texture, taste, and aroma. Two of the best formulations were characterized for their chemical composition including proximate composition, calorie, dietary fiber, and mineral composition.

2.4. Preparation of nuggets

Firstly, a mixture of supporting ingredients was prepared consisting of 100 g wheat flour, pulped onion 14 g, pulped garlic 14 g, salt 7 g, and 5 g of powdered pepper. After that, the main ingredients such as OF, CF, and RF were added into the supporting ingredient mixture according to its ratio in Table 1, and mixed properly. 200 g of egg yolk was added into the mixture and mixed properly. The dough was then placed on a mold pan which had been smeared with oil. After that, it was steamed for 15 min. After cooking, the dough was sliced at 4,0 cm width, 5.0 length, and 1.5 cm thickness. All the nuggets were maintained at 20 ± 0.5 g of weight. The nuggets were dipped into a batter consisting of wheat flour and eggs, followed by a frying process for further analysis.

2.5. Evaluation of sensory acceptability of nuggets

The sensory analysis was conducted for hedonic evaluation (taste, odor, texture, and color) as previously described (Manalu et al., 2024). The scale from 1 to 5 was used to describe 1 = dislike, 2 = do not like much (set as neutral standard), 3 = like, 4 = very like, 5 = extremely like. The untrained participants consisted of 50 aged between 18–22 years old, 1 male and 49 female) from the Department of Nutrition, State Polytechnic of Health, Lubuk Pakam, North Sumatera, voluntarily participated.

2.6. Assessment of chemical composition of selected nuggets

Proximate analysis was conducted for moisture content, protein, fat, and ash following AOAC 2000 as described (Awolu et al., 2016). Carbohydrate was calculated as the difference after proximate quantification (100 - moisture - protein - ash - fat). All calculations were based on the dry weight of the matter.

Total dietary fiber was measured following AOAC 1995. Calorie was calculated based on proximate analysis for protein, fat and carbohydrate with the conversion value 9 calorie for 1 g fat and 4 calorie for 1 g of protein and carbohydrate.

Mineral content (Ca, Fe, Zn, and P) was measured by using methods of inductively coupled plasma - optical emission spectrometry (IOP - OES) following procedures in previous study (Souza et al., 2023).

2.7. Statistical analysis

The statistical analysis was done from three replicates for chemical composition analysis and from 50 participants for the hedonic sensory analysis. Statistical analysis was performed using SPSS for One-way analysis of variance (ANOVA). Significant difference was considered at 95 % ($p < 0.05$) by Duncan test.

Table 1
The ingredients used and its amount in nugget formulations composed of oyster mushroom flour, catfish, and red bean flour.

Ingredients	Formulation									
	1	2	3	4	5	6	7	8	9	10
Oyster mushroom flour (g)	400	400	400	400	400	400	400	400	400	400
Red bean flour (g)	50	45	40	35	30	25	20	15	10	5
Catfish flour (g)	10	15	20	25	30	35	40	45	50	55
Wheat flour (g)	100	100	100	100	100	100	100	100	100	100
Pulped onion (g)	14	14	14	14	14	14	14	14	14	14
Pulped garlic (g)	14	14	14	14	14	14	14	14	14	14
Salt (g)	7	7	7	7	7	7	7	7	7	7
Pepper (g)	5	5	5	5	5	5	5	5	5	5
Egg yolk (g)	200	200	200	200	200	200	200	200	200	200

3. Results and discussion

3.1. Evaluation on sensory acceptability of the nuggets

Sensory acceptability of the 10 formulated OF-based nuggets is presented in Table 2. The results showed that most of the formulated nuggets had an acceptability at scale higher than 3 (*like – very like*), except a formulation which contained the lowest amount of CF combined with the highest RF (Formulation 1) which significantly had the lowest acceptability score. Color acceptability shows that most of the formulated nuggets received 3.6–3.8 color acceptability demonstrating as '*like – very like*' perceptions. Statistical analysis (significant at $p < 0.05$) showed that the lowest color acceptability (2.7, '*do not like very much – like*') was obtained in nugget from the formulation 1, which contained the lowest amount of CF (10 g) and highest RF (50 g). Color formation of the formulated nuggets occurred depending on the ingredients used. OF has a light pink color which might have given a dominant color in the nuggets as it is the dominant ingredient. This can be shown by the high color acceptability in almost all of the formulated nuggets. CF and RF tend to have a darker color, therefore the highest RF significantly ($p < 0.05$) reduced the color acceptability in nuggets formulation 1. There was no significant trend on how the increase in CF and decrease in RF modified the color acceptability of the nuggets which might be due to the high impact of OF color hindered the impact of CF and RF in almost all formulations.

Texture acceptability of the nuggets also received the same perception, in terms of general acceptability category. Most of the formulated nuggets were scored at a range of 3.1–3.7, which is in between '*like*' and '*very like*'. Statistical analysis showed that this range was differentiated into two different significant ($p < 0.05$) groups. The highest (significant at $p < 0.05$) texture acceptability was scored at 3.6–3.7 which is nearly '*very like*' category. This range was found on three formulations. The lowest texture acceptability was obtained at formulation 1 (lowest CF and highest RF) at 2.9 which is nearly '*like*'. There were six of the formulations that received a range of 3.1–3.4 which is '*like*'. Textural formation of food products is affected by the chemical composition of its ingredients. Complex formation between protein, fat, and carbohydrate in all ingredients will affect the formed texture and thus its textural acceptability. In this study, the formulated nuggets had an acceptable texture sensory. This phenomenon demonstrates that all ingredients and its amounts formed a desirable texture of the nuggets. Although there was investigation on textural behavior and properties were made, which seem important in the future to understand how those ingredients form the texture of the nuggets. Oyster mushroom has been identified to have rubbery texture perception (Liu et al., 2006) which might contribute to the desired texture of the formulated nuggets. Oyster mushroom declines the textural formation in beef salami (Özünlü & Ergezer, 2021) however, it improves the textural properties of burger patty including hardness, springiness, cohesiveness, and chewiness, and cutting strength (Cho & Ryu, 2023). Consequently, it decreases the cooking loss and increases the cooking yield (Cho & Ryu, 2023; Pachekrepapol et al., 2022). These phenomena depict that textural acceptability of food products made of oyster mushroom based is highly dependent on its mixture ingredients.

Sensory analysis on taste acceptability showed almost similar phenomenon with on texture acceptability, although the trend was observed in different formulations. The highest taste score was discovered on three formulations which ranged at 3.6–3.7 (nearly '*very like*'), followed by a range of 3.1–3.4 ('*like*') on 6 formulations, and 2.8 (nearly '*like*') as the lowest score (significant at $p < 0.05$) taste acceptability. Oyster mushroom powder, as the main ingredient, contains amino acids such as aspartic acid, threonine, serine, glutamate, glycine, alanine, valine, and methionine (Rohmah et al., 2022) which might have contributed to the high desirability of the taste due to the umami taste from aspartic acid and glutamate. Although red kidney beans have been reported for bitter taste and bitter after taste (Chigwedere et al., 2022), its addition in the nugget formulation seems undetected due to the high umami taste from oyster mushroom.

Different from other sensory parameters, all nuggets had aroma acceptability higher than 3 ('*like*'). Aroma sensory scored at a range of 3.1–3.7 which demonstrates between '*like*' – '*very like*'. These results might have occurred highly due to the dominant amount of oyster mushroom. Oyster mushroom application in meat analogue contributes to the formation of meat-like and fatty aroma due to the existence of nitrogen oxides and organic sulfides (Mazumder et al., 2024). In addition to that, thermal exposure on red kidney beans modifies the volatile compounds and thus forms 2-ethyl-3,5 dimethylpyrazine and *p*-vinylguaiacol, which possess roasted and smoky aroma (Mishra et al., 2017). Moreover, the presence of methanethiol, diethyl sulfide, dimethyl disulfide, methional and dimethyl trisulfide tends to give 'cooked kidney beans-like' odour perception (Du et al., 2021; Mishra et al., 2017).

As mentioned above, almost all the formulations had acceptable hedonic sensory properties, except formulation 1. By this, oyster-based nugget formulation combined with catfish and red bean flour can be potentially optimized in generating high desirable nuggets for meat-

Table 2
Sensory acceptability of nuggets made of oyster mushroom combined with catfish flour and red bean flour.

Formulation	Sensory acceptability			
	Color	Texture	Taste	Aroma
1	2.67 ± 0.21^{c}	2.87 ± 0.30^{c}	2.81 ± 0.21^{c}	3.21 ± 0.20^{b}
2	3.74 ± 0.05^{a}	3.68 ± 0.25^{a}	3.40 ± 0.20^{b}	3.58 ± 0.30^{ab}
3	3.56 ± 0.10^{ab}	3.14 ± 0.25^{bc}	3.12 ± 0.21^{bc}	3.09 ± 0.25^{b}
4	3.78 ± 0.15^{a}	3.69 ± 0.11^{a}	3.57 ± 0.21^{ab}	3.65 ± 0.25^{a}
5	3.71 ± 0.13^{a}	3.26 ± 0.13^{b}	3.29 ± 0.13^{b}	3.22 ± 0.25^{b}
6	3.76 ± 0.22^{a}	3.26 ± 0.13^{b}	3.39 ± 0.15^{b}	3.37 ± 0.15^{b}
7	3.43 ± 0.13^{b}	3.27 ± 0.22^{b}	3.17 ± 0.15^{bc}	3.21 ± 0.15^{b}
8	3.73 ± 0.13^{a}	3.36 ± 0.25^{b}	3.64 ± 0.15^{a}	3.58 ± 0.11^{ab}
9	3.78 ± 0.05^{a}	3.31 ± 0.11^{b}	3.37 ± 0.22^{b}	3.24 ± 0.11^{b}
10	3.76 ± 0.13^{a}	3.63 ± 0.11^{a}	3.72 ± 0.20^{a}	3.70 ± 0.13^{a}

Note: the data is presented as mean with standard deviation from 50 participants. Different subscriptions in the same column describe a significant difference at 95 %.

based nuggets replacement. This can be a green light for further steps in commercialization and/or biological properties of such products. In the current study, further investigation was carried out on chemical composition such as proximate compounds, dietary fiber, calorie, and mineral composition. Minerals such as Ca, Fe, Zn, and P are important nutrients and can be related to non-communicable diseases, child growth, and certain groups of people (Maguolo et al., 2023; Rai et al., 2022; Shankar, 2020). Therefore, mineral compositions, proximate composition, dietary fiber, and calorie of selected nuggets were further evaluated.

From sensory acceptability, formula 10 received the highest acceptability for all parameters including color, texture, taste, and aroma. Therefore, further investigation was made on formulation 10 which contained 55 g of CF and 5 g of RF added into 400 g OF. As a comparison, formulation 9 (50 g CF and 10 g RF) was selected representing all other formulations as it has a better performance during the mixing processing after formulation 10.

3.2. Proximate composition, dietary fiber, and calorie of selected nuggets

Proximate composition, dietary fiber, and calorie of the selected nuggets are presented in Table 3. The results showed that both nuggets had no significant ($p > 0.05$) amount of moisture, carbohydrate, and protein content. A significant difference ($p < 0.05$) was discovered in the amount of fat, ash, and total fiber and thus the calorie, as well as Ca, Fe, and Zn content. Higher amounts of CF and lower level of RF generated a higher content of fat and ash. This phenomenon might be due to the high amount of CF which contain higher fat and minerals. The 5 g higher in CF (from 50 g in formulation 9–55 g in formulation 10) increased the fat and ash content of the nuggets almost double. CF contains almost 10 fold higher amounts of fat content compared to that of RF (Bakara et al., 2024). Therefore, the increase in fat content is obvious due to the different amount addition in both formulations. CF and RF contain almost similar ash content, but the nuggets contain different levels of ash content which might be due to the fluctuations in ingredients. Compared to previous studies, protein content in the current study is lower. Previous studies reported nuggets with protein content at 12–26 % range while in the current study it was 8.5–9.3 %. However, fat, ash, and carbohydrate content are at the same level (Alina et al., 2009; Bonfim et al., 2020; de Carvalho et al., 2018; Martínez et al., 2020).

Formulation 10 contained also a significant ($p < 0.05$) higher of calorie which can be due to the higher fat content compared to that of in formulation 9. Compared to previous studies, current study generated a lower calorie value at 129–144 kcal/100 g while it was 158–246 kcal/100 g in previous investigations (Alina et al., 2009; Bonfim et al., 2020; de Carvalho et al., 2018; Martínez et al., 2020). This phenomenon might have potential benefits in generating lower calorie nuggets. From the point of view of dietary fiber, formulation 10 had a higher level of dietary fiber. This phenomenon might be due to the variability in fiber composition in red bean and catfish. Increasing CF and reducing RF might have intensified the dietary fiber content of the nuggets in formulation 10. The total dietary fiber in the current study ranged at 5–7.1 g/100 g which is higher than the previous investigation. In previous studies, the nuggets contained 2.3–4.9 % of dietary fiber (Alina et al., 2009; Bonfim et al., 2020; de Carvalho et al., 2018; Martínez et al., 2020). In other words, the current study generated the oyster-based nugget with a higher dietary fiber content.

Table 3
Chemical composition of selected nuggets made of oyster mushroom combined with catfish flour and red bean flour.

Parameters	Ratio formulation (Oyster: red bean: catfish)	
	(400: 10: 50)	(400: 5: 55)
Moisture (g/100 g)	69.49 ± 7.01[a]	66.46 ± 5.60[a]
Carbohydrate (g/100 g)	17.09 ± 1.16[a]	16.67 ± 1.21[a]
Protein (g/100 g)	8.47 ± 0.75[a]	9.33 ± 0.55[a]
Fat (g/100 g)	2.98 ± 0.22[b]	4.44 ± 0.32[a]
Ash (g/100 g)	1.96 ± 0.17[b]	3.21 ± 0.30[a]
Total fiber (g/100 g)	5.04 ± 0.50[b]	7.41 ± 0.72[a]
Ca (mg/kg)	265.42 ± 10.30[a]	208.37 ± 9.91[b]
Fe (mg/kg)	2.09 ± 0.19[b]	2.43 ± 0.22[a]
Zn (mg/kg)	1.38 ± 0.19[b]	1.86 ± 0.18[a]
P (mg/kg)	1875.4 ± 30.50[a]	1853.35 ± 41.17[a]
Calorie (kcal/100 g)	129.08 ± 9.32[b]	144.01 ± 8.22[a]

Note: the data is presented as mean with standard deviation from three replicates. Different subscriptions at the same row describe significant differences at 95 %.

3.3. Mineral composition of selected nuggets

Mineral composition of the nuggets was investigated for Calcium (Ca), Iron (Fe), Zink (Zn), and Phosphorus (P) as presented in Table 3. The results showed that there is no significant difference ($p > 0.05$) in the amount of P in both formulations. Formulation 9 had a significant ($p < 0.05$) higher level of Ca and lower amount in Fe and Zn. by this, the formulated nuggets, particularly formulation 10 potentially used as a food product to meet the needs for Fe and Zn, and it also contained a considerably high amount of Ca and P. Mineral content of nuggets seemed to be less investigated to this date. This is for the very first time, mineral composition of nuggets reported, except for iron content (Alina et al., 2009; Bonfim et al., 2020; de Carvalho et al., 2018; Martínez et al., 2020). Iron content in the current study showed a higher value compared to that of in previous studies which contained 0.4–0.8 mg/kg Fe. In the current study, Fe ranged at 2.1–2.4 mg/kg. In another of our investigations (unpublished results), nuggets made of different ingredients contained 100 mg/100 g of Ca, 1.98 mg/kg of Fe, 1.01 mg/kg of Zn, and 1360 mg/kg of P. Those values are lower than that obtained in the current study. The presence of those important mineral compounds in biscuits and nuggets might show its feasibility for its potential as functional foods because of the importance of those minerals in preventing metabolic disorders and boosting the immune system (Ayo-Omogie, 2023).

4. Conclusion

The formulation of nuggets alternatives made of oyster mushroom flour combined with a small percentage of catfish- and red bean flour generated a desirable and acceptable taste, color, aroma, and texture. The obtained nuggets contain comparable protein (8–9 %), fat (3–4 %), and dietary fiber (5–7 %) content as well as calorie at 130–144 kcal/100 g. Thus the formulated nuggets can be used as lower calorie food products. Moreover, it also contains important minerals such as Ca (208–265 mg/kg), Fe (2.1–2.4 mg/kg), Zn (1.4–1.8 mg/kg), and P (1853 mg/kg) which are needed in the human body. Further investigation in other biological compositions and the biological properties of the nuggets are seemingly important in stepping up to the commercialization stage of the product.

Ethical statement

Ethical approval for hedonic sensory analysis is not required by national laws. It is confirmed that the appropriate protocols for protecting the rights and privacy of all participants were utilized during the execution of the research, e.g. no coercion to participate, full disclosure of study requirements and risks, written or verbal consent of participants, no release of participant data without their knowledge, ability to withdraw from the study at any time. No vulnerable populations (e.g. children, individuals with diminished physical or intellectual capacity, the socially or economically vulnerable or institutionalized individuals) were used in the research.

CRediT authorship contribution statement

Bakara Tiar: Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Purba Rumida:** Writing – review & editing, Supervision, Software, Resources, Project administration, Investigation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The study received funding from program "Penelitian Pemula Kerjasama Antar Perguruan Tinggi 2022" Politeknik Kesehatan Medan, Kementerian Kesehatan Indonesia, Medan, Sumatera Utara.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.foohum.2025.100526.

References

Akram, T., Mustafa, S., Ilyas, K., Tariq, M. R., Ali, S. W., Ali, S., Shafiq, M., Rao, M., Safdar, W., Iftikhar, M., Hameed, A., Manzoor, M., Akhtar, M., Umer, Z., & Basharat, Z. (2022). Supplementation of banana peel powder for the development of functional broiler nuggets. *PeerJ, 10*, Article e14364. https://doi.org/10.7717/peerj.14364

Alina, A. R., Babji, A. S., & Affandi, S. (2009). Nutritional quality of palm fat substituted chicken nuggets. *Nutrition Food Science, 39*(2), 181–188. https://doi.org/10.1108/00346650910943299

Awolu, O. O., Osemeke, R. O., & Ifesan, B. O. T. (2016). Antioxidant, functional and rheological properties of optimized composite flour, consisting wheat and amaranth seed, brewers' spent grain and apple pomace. *Journal of Food Science and Technology, 53*(2), 1151–1163. https://doi.org/10.1007/s13197-015-2121-8

Ayo-Omogie, H. N. (2023). Unripe banana and defatted sesame seed flours improve nutritional profile, dietary fibre and functional properties of gluten-free sorghum cookies. *Food Production, Processing and Nutrition, 5*(1), 41. https://doi.org/10.1186/s43014-023-00147-y

Bakara, T. L., Rumida, & Naibaho, J. (2024). Development of cookies made from red kidney beans, oyster mushroom, catfish and fermented soybean flours as a food alternative for stunting kids in Indonesia. *Food and Humanity, 2*, Article 100308. https://doi.org/10.1016/j.foohum.2024.100308

Binti Mohd Zaini, H., Mantihal, S., Ng, F. W. Y., & Pindi, W. (2021). The incorporation of green peas as the source of dietary fiber in developing functional chicken nuggets. *Journal of Food Processing and Preservation, 45*(5). https://doi.org/10.1111/jfpp.15412

Biswas, O., Kandasamy, P., & Das, S. K. (2022). Effect of dragon fruit peel powder on quality and acceptability of fish nuggets stored in a solar cooler (5. *Journal of Food Science Technololy, 59*, 3647–3658. https://doi.org/10.1007/s13197-022-05377-5

Bonfim, B. C., Monteiro, M. L. G., Santos, A. F. G. N. dos, Vilar, J. dos S., & Conte-Junior, C. A. (2020). Nutritional improvement and consumer perspective of fish nuggets with partial substitution of wheat flour coating by fish (Priacanthus arenatus, Cuvier, 1829) waste flour. *Journal of Aquatic Food Product Technology, 29*(1), 28–42. https://doi.org/10.1080/10498850.2019.1693462

Chigwedere, C. M., Wanasundara, J. P. D., & Shand, P. J. (2022). Sensory descriptors for pulses and pulse-derived ingredients: Toward a standardized lexicon and sensory wheel. *Comprehensive Reviews in Food Science and Food Safety, 21*, 999–1023. https://doi.org/10.1111/1541-4337.12893

Cho, S. Y., & Ryu, G. H. (2023). Effects of oyster mushroom addition on quality characteristics of full fat soy-based analog burger patty by extrusion process. *Journal of Food Process Engineering, 46*(10), Article e14128. https://doi.org/10.1111/jfpe.14128

Corrêa, R. C. G., Brugnari, T., Bracht, A., Peralta, R. M., & Ferreira, I. C. F. R. (2016). Biotechnological, nutritional and therapeutic uses of Pleurotus spp. (Oyster mushroom) related with its chemical composition: A review on the past decade findings. *Trends in Food Science Technology, 50*, 103–117. https://doi.org/10.1016/j.tifs.2016.01.012

de Carvalho, L. R. S., da Silva, C. H. D., & Giada, M. de L. R. (2018). Physical, chemical and sensorial properties of low-fat and gluten-free chicken nuggets. *Journal of Culinary Science Technology, 16*(1), 18–29. https://doi.org/10.1080/15428052.2017.1310071

De Paiva, G. B., Trindade, M. A., Romero, J. T., & Da Silva-Barretto, A. C. (2021). Antioxidant effect of acerola fruit powder, rosemary and licorice extract in caiman meat nuggets containing mechanically separated caiman meat. *Meat Science, 173*, Article 108406. https://doi.org/10.1016/j.meatsci.2020.108406

Devi, P. V., Islam, J., Narzary, P., Sharma, D., & Sultana, F. (2024). Bioactive compounds, nutraceutical values and its application in food product development of oyster mushroom. *Journal of Future Foods, 4*(4), 335–342. https://doi.org/10.1016/j.jfutfo.2023.11.005

Du, X., Sissons, J., Shanks, M., & Plotto, A. (2021). Aroma and flavor profile of raw and roasted Agaricus bisporus mushrooms using a panel trained with aroma chemicals. *LWT, 138*, Article 110596. https://doi.org/10.1016/j.lwt.2020.110596

González, N., Marquès, M., Nadal, M., & Domingo, J. L. (2020). Meat consumption: Which are the current global risks? A review of recent (2010–2020) evidences. *Food Research International, 137*, Article 109341. https://doi.org/10.1016/j.foodres.2020.109341

Graça, J., Godinho, C. A., & Truninger, M. (2019). Reducing meat consumption and following plant-based diets: Current evidence and future directions to inform integrated transitions. *Trends in Food Science Technology, 91*, 380–390. https://doi.org/10.1016/j.tifs.2019.07.046

Liu, J., Vijayakumar, C., Hall III, C. A., Hadley, M., & Wolf-Hall, C. E. (2006). Sensory and chemical analyses of oyster mushrooms (Pleurotus sajor-caju) harvested from different substrates. *Journal of Food Science, 70*(9), 586–592.

Madane, P., Das, A. K., Nanda, P. K., Bandyopadhyay, S., Jagtap, P., Shewalkar, A., & Maity, B. (2020). Dragon fruit (Hylocereus undatus) peel as antioxidant dietary fibre on quality and lipid oxidation of chicken nuggets. *Journal of Food Science and Technology, 57*(4), 1449–1461. https://doi.org/10.1007/s13197-019-04180-z

Maguolo, A., Gabbianelli, R., & Maffeis, C. (2023). Micronutrients in early life and offspring metabolic health programming: A promising target for preventing non-communicable diseases. *European Journal of Clinical Nutrition, 77*(12), 1105–1112. https://doi.org/10.1038/s41430-023-01333-4

Manalu, M., Rumida, Julianti, E., & Romauli, N. D. M. (2024). Composites flour formulation made from yellow pumpkin, purple sweet potato, corn, and wolf-herring flour for replacement of wheat flour on low- and high- moisture foods part I: Cookies and muffin. *Food and Humanity, 2*, Article 100261. https://doi.org/10.1016/j.foohum.2024.100261

Martínez, L., Ros, G., & Nieto, G. (2020). Effect of natural extracts obtained from food industry by-products on nutritional quality and shelf life of chicken nuggets enriched with organic Zn and Se provided in broiler diet. *Poultry Science, 99*(3), 1491–1501. https://doi.org/10.1016/j.psj.2019.11.008

Mazumder, Md. A. R., Jongraksang, K., Kaewsiri, K., Keawnualborvornnij, S., Nenjatee, W., Kaur, L., Zhang, W., Phongthai, S., & Rawdkuen, S. (2024). Mushroom-legume-based alternative chicken nuggets: Physico-chemical and sensory properties. *Food Chemistry Advances, 5*, Article 100777. https://doi.org/10.1016/j.focha.2024.100777

Mishra, P. K., Tripathi, J., Gupta, S., & Variyar, P. S. (2017). Effect of cooking on aroma profile of red kidney beans (Phaseolus vulgaris) and correlation with sensory quality. *Food Chemistry, 215*, 401–409. https://doi.org/10.1016/j.foodchem.2016.07.149

Özünlü, O., & Ergezer, H. (2021). Possibilities of using dried oyster mushroom (*Pleurotus ostreatus*) in the production of beef salami. *Journal of Food Processing and Preservation, 45*(2). https://doi.org/10.1111/jfpp.15117

Pachekrepapol, U., Thangrattana, M., & Kitikangsadan, A. (2022). Impact of oyster mushroom (Pleurotus ostreatus) on chemical, physical, microbiological and sensory characteristics of fish burger prepared from salmon and striped catfish filleting by-product. *International Journal of Gastronomy and Food Science, 30*, Article 100598. https://doi.org/10.1016/j.ijgfs.2022.100598

Parlasca, M. C., & Qaim, M. (2022). Meat consumption and sustainability. *Annual Review of Resource Economics, 14*(1), 17–41. https://doi.org/10.1146/annurev-resource-111820-032340

Rai, R. H., Goyal, R. K., Singh, R. B., Handjiev, S., Singh, J., Darlenska, T. H., & Smail, M. M. A. (2022). Chapter 43—Vitamins and minerals as nutraceuticals in cardiovascular diseases and other chronic diseases. In R. B. Singh, S. Watanabe, & A. A. Isaza (Eds.), *Functional foods and nutraceuticals in metabolic and non-communicable diseases* (pp. 651–670). Academic Press. https://doi.org/10.1016/B978-0-12-819815-5.00037-9.

Rohmah, M., Saragih, B., Amaliah, N., Apriadi, R., & Rahmadi, A. (2022). Panelist acceptance, proximate characteristics of amino acids and volatile compounds, and color profile of fermented cempedak (Artocarpus champeden) and oyster mushroom (Pleurotus ostreatus) seasoning. *Journal of Food Quality, 2022*, 1–13. https://doi.org/10.1155/2022/3092246

Sabikun, N., Bakhsh, A., Rahman, M. S., Hwang, Y.-H., & Joo, S.-T. (2021). Volatile and nonvolatile taste compounds and their correlation with umami and flavor characteristics of chicken nuggets added with milkfat and potato mash. *Food Chemistry, 343*, Article 128499. https://doi.org/10.1016/j.foodchem.2020.128499

Shankar, A. H. (2020). 145—Mineral deficiencies. In E. T. Ryan, D. R. Hill, T. Solomon, N. E. Aronson, & T. P. Endy (Eds.), *Hunter's tropical medicine and emerging infectious diseases* (Tenth Edition, pp. 1048–1054). Elsevier. https://doi.org/10.1016/B978-0-323-55512-8.00145-9.

Solichah, E., Iwansyah, A. C., Pramesti, D., Desnilasari, D., Agustina, W., Setiaboma, W., & Herminiati, A. (2022). Evaluation of physicochemical, nutritional, and organoleptic properties of nuggets based on moringa (Moringa oleifera) leaves and giant catfish (Arius thalassinus). *Food Science and Technology, 42*, Article e72020. https://doi.org/10.1590/fst.72020

Souza, T. L., Souza, L. A., Barbosa, I. S., Santos, D. C. M. B., Araujo, R. J. O., & Korn, M. G. A. (2023). Mineral and Trace Elements in Nutritious Flours: Total Contents, In Vitro Bioaccessibility and Contribution to Dietary Intake. *Biological*

Trace Element Research, 201, 4600–4611. https://doi.org/10.1007/s12011-022-03534-7

Wunsch, N. -G. (2024). *Global plant-based food market size 2020–2030*. ⟨https://www.statista.com/statistics/1280394/global-plant-based-food-market-value/#:~:text=Global%20plant%2Dbased%20food%20market%20size%202020%2D2030&text=The%20global%20plant%2Dbased%20food,worth%2044.2%20billion%20U.S.%20dollars⟩.

Younis, K., Ashfaq, A., Ahmad, A., Anjum, Z., & Yousuf, O. (2023). A critical review focusing the effect of ingredients on the textural properties of plant-based meat products. *Journal of Texture Studies, 54*(3), 365–382. https://doi.org/10.1111/jtxs.12704