



International Journal of Biology Sciences

ISSN Print: 2664-9926
ISSN Online: 2664-9934
NAAS Rating (2026): 4.82
IJBS 2026; 8(2): 26-33
www.biologyjournal.net
Received: 03-12-2025
Accepted: 13-01-2026

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Optimization of seaweed enriched fish cutlets: Nutritional, sensory, and textural characterization

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DOI: <https://www.doi.org/10.33545/26649926.2026.v8.i2a.570>

Abstract

In order to improve nutritional, sensory, and textural qualities for better value-added food formulations, this study investigates the optimisation of fish cutlets fortified with *Hypnea musciformis* seaweed. Different concentrations of seaweed powder were added to tilapia-based cutlet mixtures to create formulations, which were then thoroughly examined. This study aims to strike a balance between consumer-preferred sensory and textural profiles in the optimization of seaweed-enriched foods. Seaweed's dietary fiber promotes gut microbiota health by functioning as a prebiotic in addition to improving texture and moisture retention, both of which are valued in sensory evaluation. Another beneficial feature is the potential for seaweed to partially replace fat, which could aid in the creation of healthier, lower-calorie foods without sacrificing flavour or consumer acceptance. By enabling the creation of functional fish products with enhanced shelf life, additional health benefits, and appealing sensory qualities, seaweed fortification introduces innovation to the seafood industry and positions seaweed-fortified cutlets as high-end, functional foods perfect for contemporary consumers looking for new flavours and healthier options.

Keywords: Fish cutlets, seaweed, *Hypnea musciformis*, texture profile analysis, standardization

Introduction

Value addition is a process that transforms low-value commodities into goods with improved qualities, functionality, and enhanced commercial appeal. This concept has expanded beyond just financial considerations to include a variety of improvements, such as better nutrition, improved sensory attributes, sustainability, and health-promoting qualities. Value-added food products have varying market potential, depending on the product category and geographic location. Value addition, or upcycling of food, is crucial in addressing the global issue of food waste, which accounts for approximately 17% of the world's total food production (Di Fraia *et al.*, 2024) ^[11]. One of the most rapidly growing markets for value addition is functional foods, whose estimated global market value is expected to reach USD 280 billion by 2025 (Hlaváčová *et al.*, 2022) ^[14]. Coming to fish and fishery products, bioactive substances obtained from low-value fish and fishery waste have a lot of potential for use in pharmaceutical and nutraceutical applications. These substances have a number of advantageous qualities, such as anti-inflammatory, anti-hypertensive, antimicrobial, antioxidant, and anti-obesity effects (Jimenez-Champi *et al.*, 2024) ^[15]. While in global agricultural markets, where primary commodities frequently experience price fluctuations and declining terms of trade, it is very important that significant economic benefits are produced throughout the value chain by value addition in fisheries. By making additional value from the same resource, value addition can boost profits for both fishermen and processors. Apart from that, Fishermen can improve income stability and lessen their exposure to market swings by diversifying into value-added products. This can be achieved through product differentiation and the creation of niche markets (Siddiqui *et al.*, 2024) ^[30]. The focus on value-added foods as a preventive health strategy is growing due to the global rise in diet-related diseases, such as obesity, diabetes, cardiovascular conditions, and certain types of cancer. Functional food-rich diets have been shown to help regulate physiological processes and lower disease risk factors (Hlaváčová *et al.*, 2022) ^[14]. Fish are known for their incredibly high-quality protein, essential amino acids, omega-3 fatty acids (EPA and DHA),

and essential micronutrients like calcium, iron, zinc, selenium, and iodine. In addition to promoting the growth of muscles and tissues, these nutrients are essential for preventing malnutrition, particularly in young people. Value-added fish products, such as fish powder, fortified foods, fish oil capsules, and hydrolysates, can be consumed to help vulnerable groups, including children, pregnant women, and people at risk of chronic deficiencies, receive specialized nutrition. Value-added fish products contain polyunsaturated and monounsaturated fatty acids, which are known to improve cognitive function and reduce the risk of coronary heart disease. Additionally, value-added processing methods work to maintain these essential nutrients, guaranteeing high nutritional retention and promoting food security and improved health outcomes for a variety of communities (Ali *et al.*, 2022; Noreen *et al.*, 2025; Byrd *et al.*, 2025)^[1, 21].

Seaweeds are becoming more and more recognized as "superfoods" that are nutrient-dense foods that provide substantial health advantages above and beyond simple nutrition. They are a valuable addition to the human diet because of their exceptional nutritional qualities. Proteins, dietary fibers, omega-3 and omega-6 unsaturated fatty acids, vitamins A, B, C, D, E, and K, and vital minerals like calcium, iron, iodine, magnesium, and potassium are all abundant in seaweeds (Leandro *et al.*, 2020; Sobuj *et al.*, 2025)^[18, 31]. Seaweeds are a rich source of bioactive substances, including polysaccharides like alginate, carrageenan, fucoidan, laminarin, and ulvan; polyphenols like phlorotannins; proteins; flavonoids; sterols; essential fatty acids (especially EPA and DHA); vitamins; minerals; and dietary fiber. A vast array of biological activities, including antioxidant, anti-inflammatory, antimicrobial, antiviral, anticoagulant, anti-diabetic, anti-tumor, and immunostimulatory effects, are facilitated by these substances. They offer further health benefits due to their higher concentrations of EPA and DHA than terrestrial plants. In addition, seaweed contains new metabolites like oxylipins and phlorotannins that have special medicinal and functional qualities (Ghaliou *et al.*, 2024; Matos *et al.*, 2024)^[12, 20]. Fucoidan, which is mostly present in brown seaweed, is particularly well-known for its antiviral, antitumor, antioxidative, and anti-inflammatory qualities, whereas laminarin boosts immunity and has nutraceutical advantages. (Lomartir and Gonçalves, 2022)^[19].

Seaweeds vary greatly in their nutritional and functional characteristics. For example, brown species (such as Sargassum) tend to have higher levels of protein, iodine, and specialized polysaccharides like fucoidan, while red species (like Gracilaria) contain more protein and carrageenan (Ullah *et al.*, 2023; Premarathna *et al.*, 2022)^[34, 24]. These species-specific compounds, such as alginate, carrageenan, and ulvan, increase viscosity, moisture retention, and mouthfeel. Their rich nutritional profile, fiber, minerals, and antioxidants add functional value, while distinct marine flavors with umami and salt notes elevate sensory appeal. These properties vary by species, influencing both the taste and performance of the final product, making seaweed a versatile ingredient for clean-label, health-focused formulations. Mamatha *et al.* (2007)^[28] prepared pakoda, a

common traditional snack food in India, using Enteromorpha, is a green seaweed.

Materials and Methods

Collection And Preparation of Fish and Seaweed

The Nile tilapia (*Oreochromis niloticus*) used in the present study was collected in very fresh condition, from Egumitta fish farms located in Nellore, and iced immediately after the catch in the ratio of 1:1 and transported to the Fish Processing laboratory of the College of Fishery Science, Muthukur.

Red seaweed used in this study, *Hypnea musciformis*, was obtained from the RK Algae Project Centre, which was collected from the intertidal region of Mandapam of the Gulf of Mannar, South East coast of India. Seaweed was air-dried without exposure to direct sunlight for two days in a clean and dry space. The dried seaweeds were powdered using an electric mixer, and the powder was sieved into minute particles. The seaweed powder was packed in polythene bags and stored at room temperature until further use for the preparation of products.

Characteristics of *Hypnea musciformis*

The red seaweed species *Hypnea musciformis* is distinguished by its cylindrical, loosely entwined branches that have flattened, hook-like tips. Its typical height is 10 to 20 cm. It has a lot of branches, is firm, cartilaginous, and frequently exhibits tendril-like branching. The seaweed, which grows in tide pools, rocky benches, and intertidal and shallow subtidal reef flats, is typically red but can turn yellowish-brown in conditions with low nutrient levels or intense light. Sulfated polysaccharides, especially carrageenans, which have strong anti-inflammatory, anti-cancer, and antioxidant effects, are abundant in *Hypnea musciformis*. Furthermore, it contains a wide range of phytochemicals, such as organic and fatty acids, amino acids, polyphenols like epicatechin, phloretin, and tannins, and others, which together give the seaweed its broad-spectrum bioactivities, including antimicrobial, antiviral, anti-inflammatory, and anti-obesity properties (Rafiquzzaman *et al.*, 2016; Roza *et al.*, 2019; Goutas *et al.*, 2024)^[25, 26, 13]. According to animal studies, supplementing with *Hypnea musciformis* reduces blood total cholesterol, triglycerides, and LDL cholesterol, which lowers risk factors for cardiovascular diseases (Saber *et al.*, 2024)^[27].

Fish Cutlet Preparation

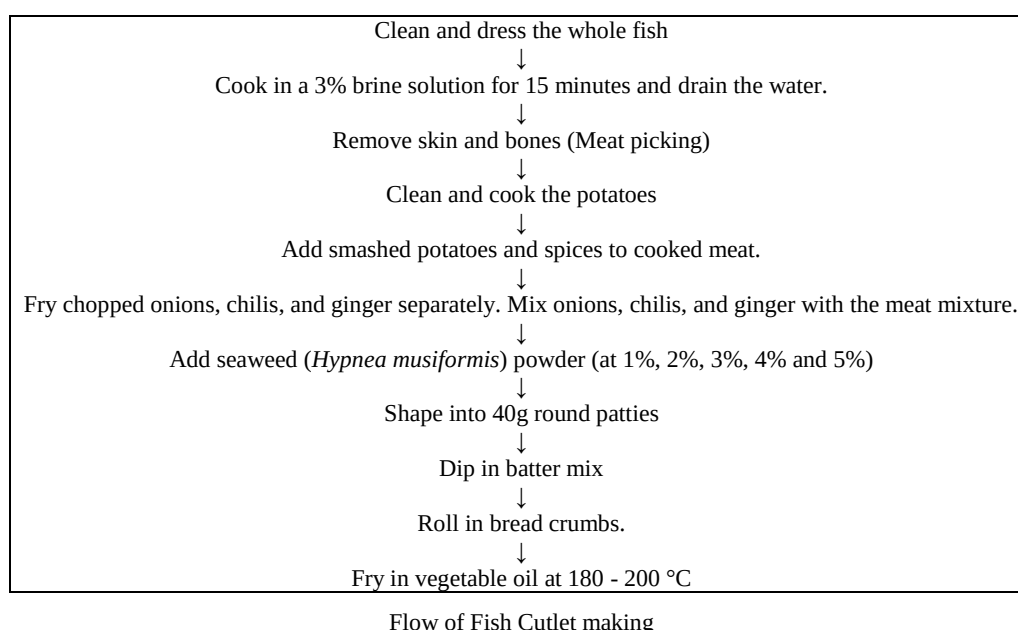
Fish cutlets were prepared using the standard recipe developed by the Central Institute of Fisheries Technology (CIFT), Kochi, with slight modifications. Seaweed-enriched fish cutlets were prepared with *Hypnea musciformis* seaweed powder, which was added in five different concentrations (designated as treatments T₁ through T₅) to create seaweed-enriched varieties. Following standardization, the enriched cutlets were subjected to traditional oil frying at 180- 200 °C. In this study, nutritional quality, textural profile analysis, and sensory acceptability were used to estimate the effects of these treatments on the finished product.

Table 1: Ingredients for the preparation of Fish Cutlet

Ingredients For Brine Solution			
S. No	Ingredient	Quantity	Percentage
1	Potable Water	1,200 ml	97.00%
2	Salt	36 g	3.00%
3	Citric Acid	1 g	0.1%
Ingredients For Fish Cutlet			
5	Cooked Fish Meat	1,000 g	54. ± 5%
6	Seaweed Powder	10 to 50 g	1% to 5%
7	Potato	500 g	27.07%
8	Onion	250 g	13.5%
9	Salt	25 g	1.35%
10	Ginger	25 g	1.35%
11	Green Chilly	20 g	1.05%
12	Curry Leaves	10 g	0.54%
13	Mint Leaves	10 g	0.54%
14	Pepper (Powder)	3 g	0.16%
15	Clove (Powder)	2 g	0.10%
16	Cinnamon (Powder)	2 g	0.10%
For Batter			
16	Water	400 ml	66.45%
17	American Flour ³	165 g	27.41%
18	Bengal Gram Flour	17 g	2.82%
19	Corn Flour	17 g	2.82%
20	Salt	2.5 g	0.42%
21	Turmeric Powder	0.5 g	0.08%
22	Bread crumbs		
23	Refined vegetable oil	125 ml	

After cleaning, dressing, and cooking the fish for 15 minutes in 1.2 L of 3% brine (36 g salt and 1.2 g citric acid), the fish was drained and deboned. Then the meat is seasoned with salt and spices. Potatoes were washed and cooked, and added to the fish along with sautéed onions, ginger, and chili. Together with the fish meat, all ingredients were combined with 1-5% powdered *Hypnea musciformis*. After thoroughly mixing the seaweed, spices, and mashed potatoes, each 40 g cutlet was formed into a round shape. It was then coated in bread crumbs and dipped in batter, which

is a mixture of maida, corn flour, Bengal gram, salt, and turmeric combined with water in a 1:2 ratio, followed by deep-frying at 180 to 200 °C. In order to determine and standardize the ideal concentration for product development, the prepared cutlets were then assessed using proximate composition, sensory profiling, and textural analysis. The mean and standard deviation obtained from triplicate measurements of each parameter were analyzed using SPSS to conduct a one-way ANOVA in order to evaluate statistical significance across treatments.



Proximate Analysis

The proximate analysis of fish cutlets was conducted using validated protocols outlined by the Association of Official Analytical Chemists (AOAC, 2016) [3]. Moisture levels were measured through standardised drying procedures; protein

concentration was estimated via the Kjeldahl nitrogen determination method; lipid content was isolated using Soxhlet extraction; and mineral residue (ash) was quantified following conventional incineration techniques.

Textural Profile Analysis

Texture Profile Analysis (TPA) was performed with XT_{2i} Texture Analyzer (Stable Micro Systems, UK) following the protocol of (Kunnath *et al.*, 2015) [17] to evaluate key mechanical attributes of the Fish cutlet samples, including hardness, adhesiveness, cohesiveness, springiness, and chewiness. A texture analyser equipped with a 50 kg load cell and a 75 mm cylindrical compression platen (P/75) was used for the analysis. Cutlets were evenly sliced into discs 2.5 cm thick. Each slice was gently placed flat on the analyser platform and subjected to a two-cycle compression test to simulate the chewing process. The platen compressed the sample at a constant speed of 1 mm/s. A trigger force of 10 g was applied for 2 seconds, with both the pre-test and post-test speeds set at 3 mm/s. Between compressions, the probe was retracted to a return distance of 35 mm to allow partial recovery of the sample before the second cycle.

Sensory Analysis

Sensory evaluation was performed using the Hedonic scale method, as described by Peryam and Girardot (1998) [23], with slight modifications. This method involves systematically assessing key attributes, including appearance, colour, texture, odour, taste, and overall acceptability. These parameters are rated using a 9-point hedonic scale, which captures panel members' preferences ranging from "dislike extremely" to "like extremely," providing a structured framework for interpreting sensory responses.

Results and Discussion

Proximate composition

The proximate composition analysis showed clear nutritional differences between seaweed and fish. Seaweed contains a very high ash content ($37.58 \pm 2.5\%$), indicating its richness in minerals, whereas fish contains only $1.03 \pm 0.61\%$. It also contained moderate levels of protein ($13.34 \pm 0.75\%$) and very low fat ($0.32 \pm 0.05\%$), while fish had a higher protein content ($17.55 \pm 0.52\%$) and fat level ($2.18 \pm 0.07\%$). In terms of moisture, fish contained substantially more ($77.29 \pm 1.10\%$) than seaweed ($12.05 \pm 1.2\%$). These findings highlight that while fish is superior in protein and fat content, seaweed serves as a valuable source of minerals with low fat, making it a functional complementary ingredient in fish-based products.

Table 2: The proximate composition of *Oreochromis niloticus* and *Hypnea musciformis*

Parameter	Seaweed (%)	Fish (%)
Moisture	12.05 ± 1.2	77.29 ± 1.10
Protein	13.34 ± 0.75	17.55 ± 0.52
Ash	37.58 ± 2.5	1.03 ± 0.61
Fat	0.32 ± 0.05	2.18 ± 0.07

* Each value is represented by the mean $\pm$ SD of $n = 3$

Hypnea musciformis, as shown in the presented data, is exceptionally rich in ash, reflecting its high mineral content, while also having moderate protein and very low fat content. Similar values are reported by Siddique *et al.* (2013) [29] for *H. musciformis* collected in Bangladesh as: protein ($18.64 \pm 1.12\%$), ash ($21.57 \pm 1.04\%$), lipid ($1.27 \pm 0.41\%$), and moisture ($11.54 \pm 0.96\%$). And in another report, Olopade *et al.* (2016) [22], analysing Nile tilapia (*Oreochromis niloticus*), reported moisture $81.32 \pm 2.23\%$, protein $13.66 \pm 2.19\%$, fat $0.54 \pm 0.08\%$, and ash $1.36 \pm 0.22\%$. This makes tilapia a lean, high-protein fish with lower mineral content

Proximate of seaweed-enriched cutlets

The moisture, ash, protein, and fat content of seaweed enriched cutlets increased significantly with the increase in seaweed concentration (Control to T₅). The moisture content ranged from $53.17 \pm 0.10\%$ in the control to $55.61 \pm 0.11\%$ in T₅. Similarly, ash content increased from $1.94 \pm 0.06\%$ to $2.42 \pm 0.01\%$. The protein content showed a progressive decrease from $20.61 \pm 0.71\%$ in the control to $17.56 \pm 0.30\%$ in T₅. Fat content also decreased significantly, ranging from $7.28 \pm 0.05\%$ in the control to $5.81 \pm 0.04\%$ in T₅. These results clearly indicate that incorporation of seaweed in cutlets enhances their proximate composition, with notable improvements in moisture, ash, protein, and fat levels (Table 2).

Incorporation of seaweed into value-added fish products has shown consistent effects on proximate composition in fish cutlets fortified with *Eucheuma* powder, Senthil *et al.* (2005) [28] reported that increasing the incorporation of seaweed from 0% to 15% raised the moisture content from $45.80 \pm 0.37\%$ to $55.43 \pm 0.43\%$ and ash from $5.54 \pm 0.03\%$ to $9.33 \pm 0.04\%$, while protein and fat decreased from $22.97 \pm 0.13\%$ to $20.13 \pm 0.05\%$ and $44.00 \pm 0.01\%$ to $37.81 \pm 0.03\%$ and concluded that because of high hydrophilic fiber in seaweed increases water-holding capacity the moisture content also increases. Whereas the increase in ash content is due to increased mineral content present in seaweed. Seaweed addition has lower protein content than conventional protein sources (fish). This substitution reduces the overall protein percentage in the product (Kamunde *et al.*, 2019) [16], and the rigid seaweed cell wall structure (containing polysaccharides like carrageenan) can affect the overall protein percentage (Thiviya *et al.*, 2022) [33]. Another study conducted by Choi *et al.* (2012) [8] on the effects of *Laminaria japonica* on pork patties when added at 0 to 5% (1%, 3% and 5%) showed similar results, which aligns with the current study. It is recorded that the moisture content increased from $49.39 \pm 0.40\%$ in the control to $56.29 \pm 0.26\%$ and ash from $2.31 \pm 0.16\%$ to $3.87 \pm 0.24\%$, while protein and fat decreased from $20.88 \pm 0.71\%$ to $20.13 \pm 0.45\%$ and $13.71 \pm 0.82\%$ to $10.52 \pm 0.84\%$ which aligns with our study.

Table 3: The proximate composition of seaweed-enriched cutlets

	Moisture* (%)	Ash* (%)	Protein* (%)	Fat* (%)
Control	53.17 ± 0.10^a	1.94 ± 0.06^a	20.61 ± 0.71^e	7.28 ± 0.05^f
Treatment 1	53.35 ± 0.03^b	2.01 ± 0.02^b	20.29 ± 0.08^d	7.03 ± 0.07^e
Treatment 2	54.54 ± 0.04^c	2.15 ± 0.01^c	19.66 ± 0.17^{cd}	6.96 ± 0.07^d
Treatment 3	54.69 ± 0.48^d	2.24 ± 0.01^d	19.13 ± 0.10^{bc}	6.59 ± 0.09^c
Treatment 4	55.23 ± 0.64^e	2.34 ± 0.01^e	18.37 ± 0.50^{ab}	6.16 ± 0.08^b
Treatment 5	55.61 ± 0.11^e	2.42 ± 0.01^f	17.56 ± 0.30^a	5.81 ± 0.04^a

* Each value is represented by the mean $\pm$ SD of $n = 3$

^{abcdef} Indicate significant difference among treatments ($p < 0.05$)

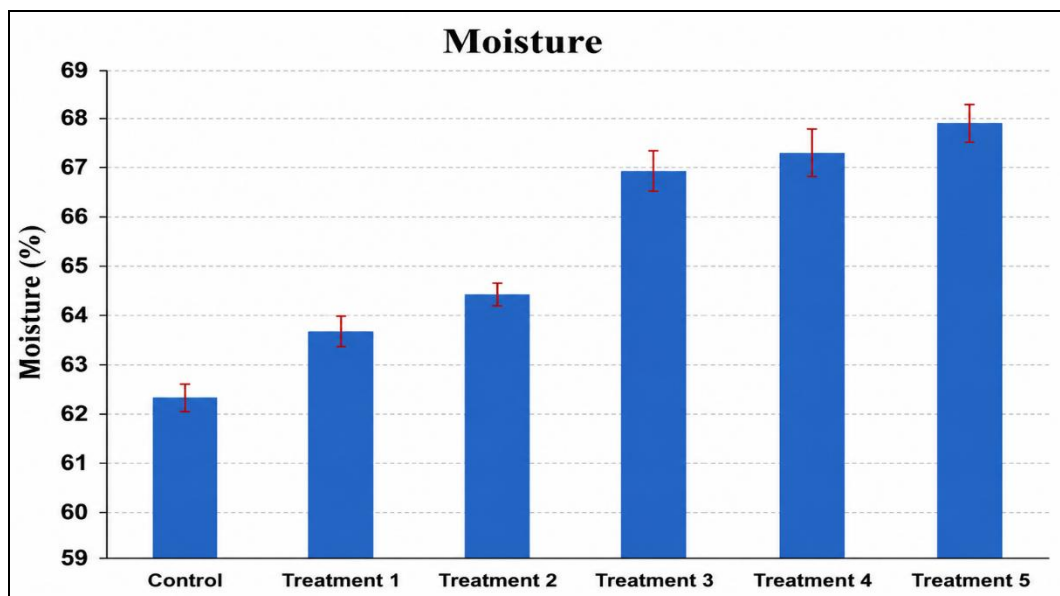


Fig 1: Moisture content

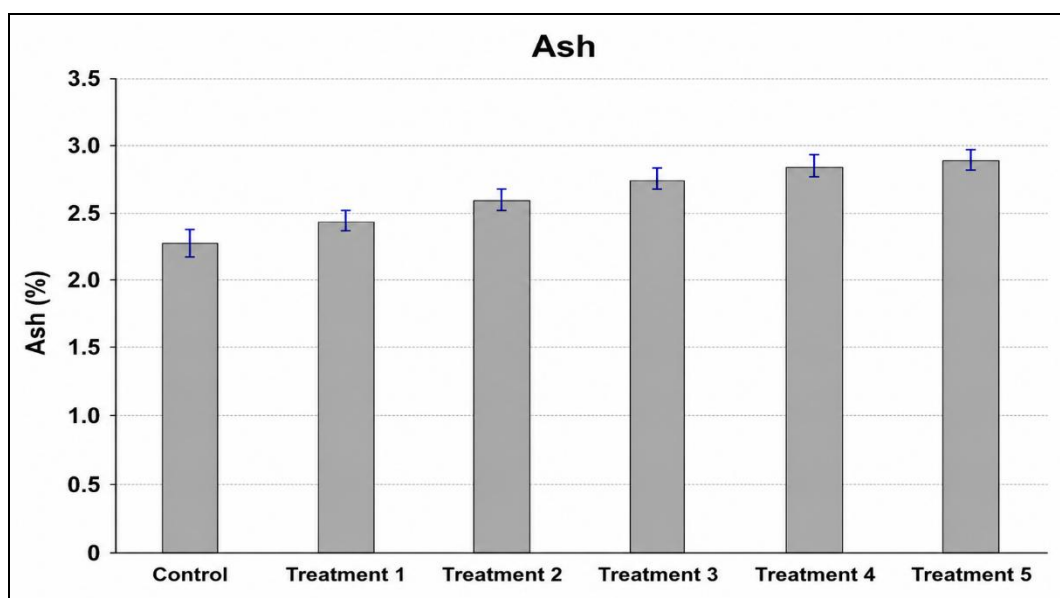


Fig 2: Ash content

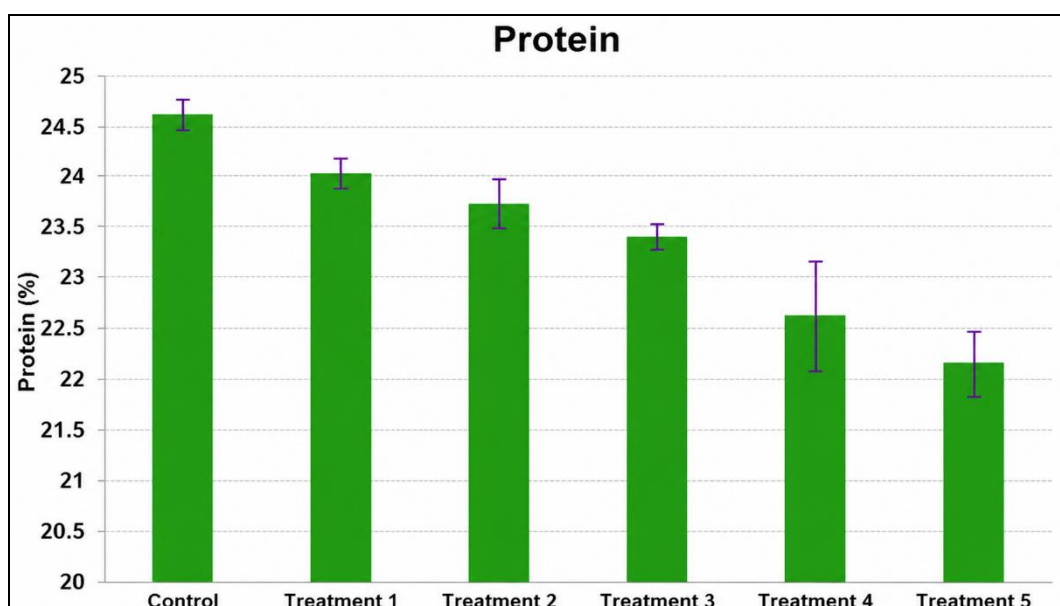


Fig 3: Protein content

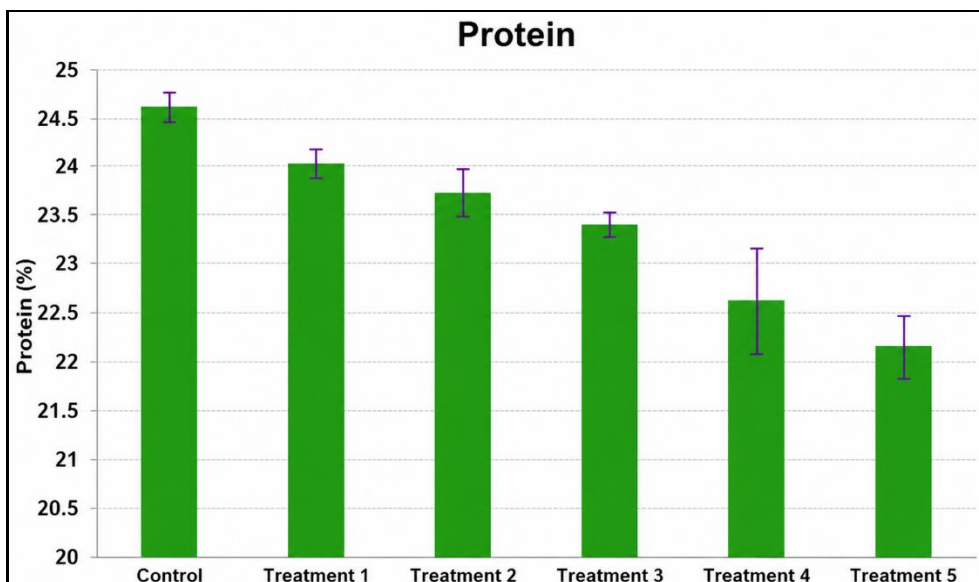


Fig 4: Fat content

Texture profile analysis

Despite statistical significance, the texture profile results show that hardness, springiness, cohesiveness, gumminess, chewiness, and resilience of the fish cutlet samples only marginally vary across treatments. Hardness, for instance, differs by less than 5%, ranging from 5.33 ± 0.09 in the control to 5.55 ± 0.05 in T_5 . Likewise, cohesiveness, gumminess, and chewiness all show slight increases

between treatments, while springiness progressively rises from 0.723 ± 0.05 (control) to 0.779 ± 0.05 (T_5). With values ranging from 0.34 ± 0.00 (control) to 0.27 ± 0.01 (T_5), the observed differences in resilience are negligible and stay within a very small numerical range. According to these results, there are statistically significant differences, but with incremental treatment additions, the practical differences in texture measurements are very small.

Table 4: The Texture profile analysis of control and seaweed-enriched fish cutlets

	Hardness*	Springiness*	Cohesiveness*	Gumminess*	Chewiness*	Resilience*
Control	5.33 ± 0.09^a	0.723 ± 0.05^a	0.631 ± 0.002^a	3.36 ± 0.03^a	2.41 ± 0.006^a	0.34 ± 0.00^d
Treatment 1	5.36 ± 0.02^b	0.724 ± 0.01^a	0.633 ± 0.001^a	3.41 ± 0.11^b	2.53 ± 0.010^b	0.32 ± 0.01^c
Treatment 2	5.41 ± 0.01^{bc}	0.734 ± 0.10^b	0.639 ± 0.001^b	3.45 ± 0.10^c	2.54 ± 0.010^c	0.30 ± 0.01^b
Treatment 3	5.43 ± 0.15^c	0.744 ± 0.01^c	0.646 ± 0.003^c	3.50 ± 0.05^d	2.60 ± 0.001^d	0.29 ± 0.00^{ab}
Treatment 4	5.47 ± 0.03^d	0.759 ± 0.02^d	0.655 ± 0.004^d	3.58 ± 0.10^e	2.71 ± 0.040^e	0.27 ± 0.01^a
Treatment 5	5.55 ± 0.05^e	0.779 ± 0.05^e	0.671 ± 0.001^e	3.73 ± 0.10^f	2.90 ± 0.011^f	0.27 ± 0.01^a

* Each value is represented by the mean $\pm$ SD of $n=3$

abcdef Indicate significant difference among treatments ($p < 0.05$)

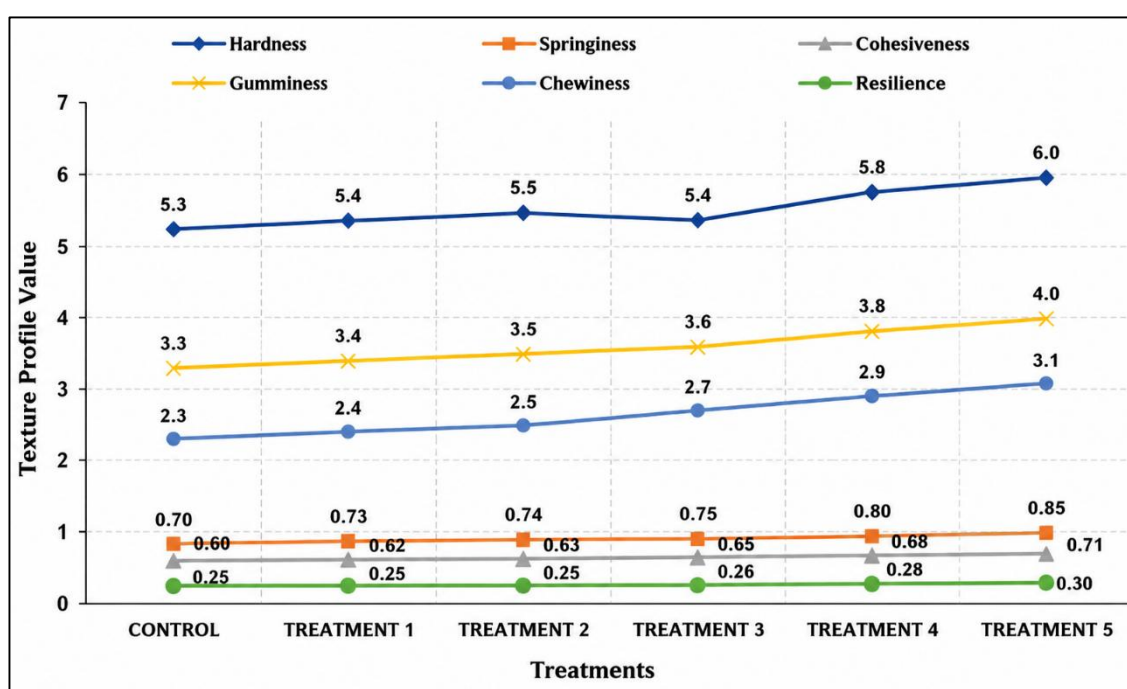


Fig 5: Texture profile analysis

Choi *et al.* (2012) [8] reported the effects of *Laminaria japonica* on pork patties at 0 to 5% (control, 1%, 3% and 5, the control (TC) without seaweed exhibited the lowest textural values, with hardness (4.60 ± 0.33 N), gumminess (2.10 ± 0.19 N), and chewiness (1.95 ± 0.28 N) being the lowest across all groups. In contrast, the highest values were observed in the seaweed-incorporated patties, particularly at T₃ with the highest concentration, where hardness reached 6.22 ± 0.47 N, gumminess 2.83 ± 0.39 N, and chewiness 2.66 ± 0.47 N, surpassing the control product as in our study, but overall differences between the treatments were very marginal. Whereas for springiness, the highest value was recorded in T₁ (0.98 ± 0.07) compared to the lowest in T (0.90 ± 0.04), indicating that moderate inclusion of seaweed slightly improved elasticity. Cohesiveness remained relatively stable, with minor fluctuations (0.45 – 0.47), showing no clear directional trend, just like in Table 3. According to Cofrades *et al.* (2008) [9], edible seaweeds slightly improve the textural profile of meat products by enhancing water retention and strengthening protein-polysaccharide interactions through the formation of a more rigid protein gel matrix. Choi *et al.* (2012) [8] suggested that improvement in texture with seaweed incorporation can be

attributed to the water-binding and dietary fibre in the seaweed. Taken together, the incorporation of seaweed powder effectively increases the desirable texture profile of the seafood and meat products. Thus, seaweed functions as a natural texture enhancer in value-added products.

Sensory evaluation

The sensory evaluation of seaweed-enriched cutlets showed notable variation across the control and treatments. Treatment 3 emerged as the best-performing sample, recording the highest scores in appearance (8.6), colour (8.8), taste (8.8), texture (8.3), and an overall acceptability of 8.5, compared to the control's 7.8. Treatment 1 and Treatment 2 also performed slightly better than the control, with improved overall acceptability scores of 7.9 and 8.0. This shows that both Treatments 1, 2, and 3 were rated more favorably than the control, with Treatment 3 clearly standing out as the most accepted. Whereas treatments 4 and 5 showed a notable decline, with Treatment 5 receiving the lowest overall acceptability score (7.2). In summary, Treatment 3 achieved the highest consumer preference, followed by Treatment 2, while the control remained moderate, and Treatments 4 and 5 were least favoured.

Table 5: The Sensory analysis of control and seaweed-enriched fish cutlets

	Appearance	Colour	Taste	Odour	Texture	Overall Acceptability
Control	7.8 ± 0.28	8.2 ± 0.25	7.8 ± 0.28	7.3 ± 0.28	8.0 ± 0.50	7.8 ± 0.15
Treatment 1	7.9 ± 0.17	8.1 ± 0.28	7.5 ± 0.50	7.7 ± 0.25	7.8 ± 0.27	7.9 ± 0.14
Treatment 2	8.3 ± 0.50	8.2 ± 0.25	8.4 ± 0.51	7.5 ± 0.50	7.9 ± 0.17	8.0 ± 0.22
Treatment 3	8.6 ± 0.57	8.8 ± 0.28	8.8 ± 0.28	7.8 ± 0.28	8.3 ± 0.28	8.5 ± 0.10
Treatment 4	7.5 ± 0.11	7.3 ± 0.11	7.8 ± 0.28	7.3 ± 0.28	7.6 ± 0.28	7.5 ± 0.12
Treatment 5	7.2 ± 0.17	7.1 ± 0.20	7.4 ± 0.32	7.0 ± 0.20	7.1 ± 0.02	7.2 ± 0.10

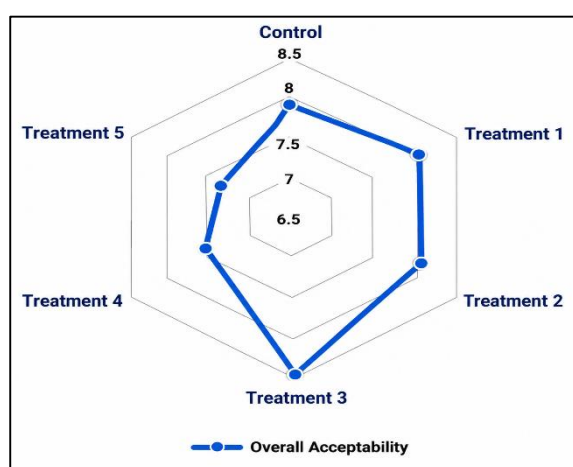


Fig 6: Overall Acceptability

The present study on fish cutlets fortified with seaweed at different concentrations demonstrated that moderate inclusion significantly improved sensory attributes, with Treatment 3 achieving the highest overall acceptability score (8.5), compared to the control (7.8) and Treatment 2 (8.0). Similar trends were reported by Cullano and Ann (2025) [10] in seafood crackers, where balanced seaweed levels enhanced crispness and palatability, but high inclusion led to rejection because of strong seaweed aroma. In line with our findings, a study on the incorporation of *Alaria esculenta* into fish patties reported that seaweed addition did not significantly alter the odour or flavour compared to controls, although textural changes such as increased rubberiness were observed with certain treatments (Sund *et al.*, 2025) [32]. This supports the observation in our study where moderate inclusion levels (T₂ and T₃) enhanced

overall acceptability without compromising core sensory traits, while higher inclusion may negatively impact texture and consumer perception.

Conclusion

Seaweed fortification in fish cutlets results in increased moisture and ash content, alongside slight decreases in protein and fat levels. Among the treatments, T₃ emerged as the optimal formulation, displaying the best balance between enhanced nutrition and sensory acceptability. Sensory evaluations revealed that T₁, T₂, and T₃ had superior acceptability to the control, while T₄ and T₅, with excessive seaweed content, showed reduced preference. Textural profile analysis indicated only minor increases in parameters such as hardness and cohesiveness, suggesting that the textural integrity of the cutlets was well maintained with seaweed incorporation. The slight decline in protein and fat at higher inclusion levels is offset by mineral enrichment and moisture retention, highlighting the value addition through improved nutritional quality. This balance in T₃ promotes consumer appeal without compromising product quality, emphasizing the importance of moderation in fortification to maximize benefits. Overall, the findings support that moderate seaweed inclusion enhances the functional and nutritional profile of fish cutlets while sustaining desirable sensory and textural characteristics, making T₃ the most favourable formulation for producing value-added, health-promoting seafood products.

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