Development and Shelf-Life Study of Twin-Screw Extruded Fish Snacks Using Mackerel and Rohu Powder.

Abstract

Fish has a lot of promise for creating novel, nutrient-dense food products since it is a rich source of high-quality protein, vital amino acids, Omega-3 fatty acids, and other minerals. In order to improve the texture, nutritional profile, and shelf life of a fish-based extruded snack supplemented with corn and millet flour, this study used extrusion technology. Five formulations were made with different amounts of millet flour (20–40%), maize flour (50%), and fish powder (10–30%). To guarantee constant product quality, optimized extrusion parameters were used, such as a barrel temperature of 112°C, screw speed of 320 rpm, and feed rate of 210 g/min. Seasoning, tapioca starch (3–5%), and natural preservatives (tocopherols) were added to enhance the product's functionality and sensory qualities.Considering a protein level of 25% per 100 g and a well-balanced amino acid profile, Treatment 5 (30% fish powder, 50% maize flour, 20% millet flour) stood out as the best formulation among the others. Treatment 5 received a taste and texture rating of 8.5 on a 9-point hedonic scale, suggesting strong customer approval. The product demonstrated exceptional stability and sharpness, retaining its quality for three months in ambient circumstances. This study emphasizes how fish-based extruded snacks can offer a nutrient-dense, shelf-stable substitute for traditional snacks, encouraging the exploitation of underutilized fish resources and boosting both food security and economic expansion.

Keywords: Extrusion technology, Fish-based snacks, Fish powder, Konkan region, Nutritional enhancement, Protein-enriched snacks, Sensory evaluation, Value-added products.

Introduction

Fish plays a crucial role in human nutrition, offering exceptional dietary benefits and supporting overall health. It serves as an excellent source of easily digestible, high-quality protein, containing all essential amino acids vital for growth and tissue repair (FAO, 2020). Additionally, fish is a rich provider of Omega-3 fatty acids, including DHA and EPA, which are known for their significant roles in enhancing brain and heart health and reducing inflammation. Fish is the main source of animal protein for over a billion people, according to estimates from the Food and Agricultural Organization (FAO 1995) Shankar et al., 2010).

. Along with these healthy fats, fish is abundant in essential vitamins like A, D, and B-complex vitamins such as B12, niacin, and riboflavin, which are critical for various physiological processes (Nielsen et al., 2013). Furthermore, fish is loaded with vital minerals, including iodine, selenium, zinc, phosphorus, and calcium, which contribute to strong bones, thyroid regulation, and immune support.The majority of cereal-based, extruded snack-like goods are made mostly from rice, wheat, and corn. But the protein level of rice is very modest (6–8 g/100 g db), and anlysine is the limiting amino acid in an amino acid profile that is high in glutamic and aspartic acids.(Majumdar and Singh, 2014).Its low content of saturated fats aids in lowering bad cholesterol levels, thereby reducing the likelihood of cardiovascular issues (Jorgensen et al., 2014). Incorporating fish into one’s diet offers numerous advantages, such as improved cognitive function, better vision, effective weight control, and a lower risk of chronic ailments like arthritis and type-2 diabetes (Bishop et al., 2013). On average, fish provides 18-22 g of protein, 1-10 g of fat (depending on the type), 80-120 kcal of energy, and substantial amounts of Omega-3 fatty acids, Vitamin D, and essential minerals per 100 g of edible portion (Bordi et al., 2016). This nutrient-rich profile highlights the importance of fish as a key element in a balanced diet, contributing significantly to long-term health and well-being. Both conventional high-protein meals and combination starch–protein sources should be taken into account when trying to lower the amounts of fish meal in fish feed. It is well recognized that plant foods' globular proteins may have the ability to structure. (Kraugerud et al., 2011).

The incorporation of fish from regions like Konkan into extruded products not only leverages the area's rich biodiversity but also contributes to sustainable practices by utilizing underutilized species and by-products3while offering remarkable flexibility in creating affordable, nutritious, and convenient food products.Surasani, V. K. R. (2016). Extrusion offers several advantages, including improved texture, customizable product formulations, and the ability to produce shelf-stable, ready-to-eat or ready-to-cook products2as well as enhance nutrient retention, bioavailability, and digestibility, while using minimal heat and energy.(Prabha et al., 2021). This study focuses on the application of extrusion technology in developing fish-based extruded products, particularly utilizing the diverse fish resources of the Konkan region, exploring their nutritional profile, processing parameters, and potential for enhancing food security and economic growth.Fish Mineral oil used as coating material which leads to enhance shelf life of fruits, reduced the spoilage and improved the fruit quality by delaying the senescence during storage(Kahar et al.)."

Material and Methodology

1. Finger Millet Flour:
   Finger millet flour was procured fresh from the local market in Dapoli. Its high nutritional value made it a vital ingredient in the snack formulation.
2. Fish Powder:
   Fish powder was sourced from the Ratnagiri market. It was used as a rich protein source to enhance the nutritional profile of the product.
3. Sensory Evaluation:

Sensory attributes, including taste, texture, aroma, colour, and overall acceptability, were assessed using a 9-point hedonic scale by a trained panel. Treatment T5 achieved the highest scores, indicating superior sensory appeal.

4. Chemical Properties:
   The chemical properties, such as protein, fat, essential amino acids, moisture, ash, and carbohydrate content, were analysed in the Department of Processing and Food Engineering. Treatment T5 demonstrated the best nutritional composition due to its optimized formulation.

Experimental Details

Treatment	Corn Flour %	Millet Flour %	Fish Powder %
1	50	40	10
2	50	35	15
3	50	30	20
4	50	25	25
5	50	20	30

Extrusion Parameters:

- **Barrel Temperature**: 112°C
- **Screw Speed**: 320 rpm
- **Moisture Content**: **15%**

Additional Ingredients (Optional):

- **Binding Agents**: Tapioca starch (3–5%)5
- **Seasoning**: Salt, spices, flavour enhancers (as needed)
- **Oil/Fat Content**: 2–5%
- **Preservatives**: Natural options like citric acid or tocopherols

Preparation of extrudates

Extrusion processing for fish-based snacks requires carefully optimized parameters to achieve the desired texture, shape, and nutritional quality. The barrel temperature typically112°C, which facilitates the gelatinization of starches and the denaturation of proteins, ensuring a cohesive structure. The screw speed, usually set between 320 rpm, plays a crucial role in controlling shear and mixing during extrusion. Maintaining a moisture content of 12 % is essential to ensure proper flow through the extruder and to prevent clogging or irregular extrusion

In addition to the primary ingredients, supplementary components can enhance the product's functionality and sensory appeal. Binding agents such as tapioca starch, used at 3–5%, improve the cohesion and structural integrity of the extrudates.1Raw materials are processed through a matrix under precise conditions involving mixing, heating, pressure, and friction, resulting in starch gelatinization and protein denaturation.(Goes et al., 2015)."Seasonings, including salt, spices, and flavour enhancers, can be incorporated as needed to achieve desirable taste profiles. A small percentage of oil or fat (2–5%) may be added to enhance flavour and mouthfeel. Natural preservatives, like citric acid or tocopherols, are recommended to extend shelf life without compromising the product's health benefits. These parameters and ingredients collectively contribute to creating a high-quality, nutrient-rich extruded snack.

Proximate analysis of developed fish-extrudates

Protein Content (%): It was determined by the Kjeldahl method (AOAC, 2000). The 0.5-1 g of sample was transferred to a digestion flask to which 5 g of catalyst mixture [9 parts of potassium sulphate (K_2SO_4) and one part of copper sulphate ($CuSO_4$)] and 20 ml of concentrated sulphuric acid was added. The content was digested till transparent liquid was obtained. The digested liquid was allowed to cool, and 100 ml of distilled water was added. Then it was distilled with an excess of 40% NaOH solution, and the liberated ammonia was collected in 50 ml of 4% boric acid solution containing 5-7 drops of mixed indicator [100 ml of 0.1% methyl red indicator (in 95% ethanol) + 200 ml of 0.2% bromocresol green (in 95% ethanol)]. The entrapped ammonia was then titrated against 0.1 N hydrochloric acid. A reagent blank was similarly digested and distilled. Nitrogen content in the sample was calculated as follows, and a factor of 6.25 was used to convert nitrogen content to protein content.

The percent protein content was calculated by using the following formula:

$$\text{Protein (\%)} = \frac{(S - B) \times N \times 14.01 \times 100 \times 6.25}{W \times 1000}$$

Where,

S = Volume of standard acid (0.1 N HCl) used for titration, ml

B = Volume of 0.1 N HCl used for blank, ml

W = weight of the sample, g

N = Normality of acid used for titration (0.1 N HCl)

Essential Amino Acids: Essential amino acids were analysed by High-Performance Liquid Chromatography (HPLC) after acid hydrolysis, as per AOAC (2005). Samples were hydrolyzed with 6N HCl at 110°C for 24 hours before HPLC analysis.

Fat Content (%): Fat content was determined using Soxhlet extraction with petroleum ether, based on the method described by AOAC (1990). The extracted fat was dried, and the weight difference was used to calculate the percentage. The fat content of individual raw flour samples for all treatments will be determined by the Soxhlet fat extraction system (AOAC, 2010) by the Soxhlet apparatus (Elico, Hyderabad). In this method, initially the weight of the empty flask will be weighed. The 2 g of flour will be wrapped in filter paper. The sample with filter paper was kept in a siphoning tube, and the condenser will be fixed above it and siphoned for 9-12 times with the petroleum ether in a soxhlet apparatus. After removing the assembly, evaporation of petroleum ether will be allowed by heating the round-bottom flask. The residue remained at the bottom of the flask and will be reweighed with the flask. The quantity of residue will be determined as the fat content of flour. The experiment will be replicated, and an average value of fat content was reported. The fat content will be calculated by using the following formula:

$$\text{Fatcontent}(\%) = \frac{W_{\square} - W_2}{W} \times 100$$

Where,

W =weight ofsample,g

W_1=Initialweightofsamplewithflask, g

W_2=Finalweight ofsamplewithflask, g.

Moisture Content (%): The initial moisture content of turmeric rhizomes was determined using a hot air oven (AOAC 2000). The weighed turmeric samples were placed in an oven to remove moisture at 105±2°C for 24 hours. After which it was kept inside a desiccator for cooling to an ambient temperature, and the change in weight was measured using an electronic weighing balance with the least count of ±0.001 g, and the reading was noted. The moisture content was expressed by dry basis (db). The moisture content was determined by using the following expression:

$$\text{Moisture Content (\%)} = \frac{\mathbf{w_2 - w_3}}{\mathbf{w_2 - w_1}}$$

Where,

W_1 = Weight of empty sample box, g

W_2 = Weightofempty box + sample before drying, g

W_3 = Weight of empty box + sample after drying, g

Ash Content (%): Ash content was measured by incinerating the sample in a muffle furnace at 550°C for 6 hours, as per AOAC (2000). The residue weight was recorded as ash content. The ash content of flour samples for all treatments will be determined by using a muffle furnace. 5 g of flour will be taken in a crucible. The weight of the crucible and flour will be recorded and kept in a muffle furnace at 650°C for 4-5 h till constant weight will be achieved. It will be observed for three constant readings. The crucible will be cooled in desiccators, and the final weight of ash and crucible will be recorded. The experiment will be replicated, and an average value of ash content will be reported. The ash content will be calculated by using the following equation:

$$\text{Ash content (\%)} = \frac{\mathbf{w_2 - w}}{\mathbf{w1 - w}} \ldots \quad (3.10)$$

Where,

W = weight of crucible, g
W1 = weight of crucible and flour, g
W2 = weight of crucible with ash, g

Carbohydrate Content (%): The carbohydrate content was calculated by using a standard method of analysis (AOAC, 2000). It was determined as per dry weight basis by subtracting the sum of percent moisture, protein, crude fat, crude fiber, and total ash from hundred**,** and this was reported as a carbohydrate by difference.

% Carbohydrates = 100 - (% Moisture + % Protein + % Fat + % Fiber + % Ash)

Sensory evaluation

Sensory evaluation of the fish extruder samples was performed using a 9-point hedonic scale to assess key attributes, including appearance, texture, flavour, taste, and aroma. A panel consisting of 10–15 trained and semi-trained evaluators conducted the assessment under controlled conditions to ensure uniformity.

The hedonic scale ranged from 1 (extremely disliked) to 9 (extremely liked), with panelists assigning scores for each attribute. Samples were presented in a randomized sequence to reduce bias, and palate cleansing between samples was encouraged to maintain objectivity. Average scores for individual attributes were calculated, and the overall acceptability was determined by taking the mean of these scores, providing an insight into consumer preference and product quality.

Fig. 1 Process flow chart for development of fish-extrudates

1. **Fish Powder Preparation:** Fish is cleaned, deboned, and dried to remove impurities and enhance shelf stability. The dried fish is ground into a fine powder, making it suitable for blending with other ingredients.
2. **Blending and Moisture Adjustment**: The fish powder is mixed with rice flour, Bengal gram flour, and spices such as pepper powder, turmeric powder, and salt. This mixture is blended uniformly, and the moisture content is adjusted to achieve the desired dough consistency for extrusion.

3. **Extrusion Process**: The extrusion process is conducted at a temperature of 112°C, with a screw speed of 320 rpm and a feed rate of 210 g/min. These parameters ensure proper cooking, texture formation, and consistent shaping of the Fish Kurkure.
4. **Post-Extrusion Coating**: The extruded product is coated with a taste-maker solution prepared with refined vegetable oil. This step enhances the flavor and gives the snack a glossy, appealing surface finish.
5. **Packaging and Storage**: After cooling, the Fish Kurkure is packed in airtight containers to retain its crisp texture and freshness. Proper packaging ensures an extended shelf life while maintaining quality and flavor.

Statistical Analysis

The data were analyzed using Analysis of Variance (ANOVA) to determine significant differences among treatments at a 5% significance level ($p < 0.05$).Standard Deviation (SD) was calculated to assess variability.Post-hoc tests (e.g., Tukey's HSD) were applied to determine pairwise differences where necessary.

Resultsand Discussion

Table 1 : Evaluation of Nutritional Value, Shelf Life, and Sensory Attributes

Sr.No	Parameter	Discussions	Results
1	**Nutritional Value**	Protein content compared to traditional cereal-based snacks.	**20-25% protein content** (per 100g).
		Essential amino acid composition providing a balanced and complete protein source.	**Optimal balance of essential amino acids.**
2	**Shelf Life**	Taste quality rated by a trained panel using a 9-point hedonic scale.	**3 months** (ambient storage).
3	**Sensory Evaluation**	Taste quality rated by a trained panel using a 9-point hedonic scale.	**8.5/9 for taste and texture**.

Table 2: Chemical Analysis

Treatment	Protein Content %	Essential Amino acid	Fat Content %	Moisture Content (%)	Ash Content (%)	Carbohydrate (%)
1	11.8	0.63	3.2	10.5	2.0	72.5
2	14.7	0.71	3.8	10.2	2.3	69.0
3	18.3	0.79	4.6	10.0	2.6	64.5
4	22.1	0.88	5.2	9.8	3.0	60.0
5	25.5	0.94	5.8	9.6	3.4	56.5

The chemical analysis of the fish-based extruded snack formulations (per 100 g) revealed significant variations across treatments. Protein content ranged from 11.8% in Treatment 1 to 25.5% in Treatment 5, with a corresponding improvement in the Essential Amino Acid Index (0.63 to 0.94), highlighting the nutritional enhancement with increasing fish powder. Fat content increased from 3.2% to 5.8%, contributing to flavor and satiety, while moisture content decreased slightly (10.5% to 9.6%), ensuring better shelf stability. Ash content, reflecting mineral richness, rose from 2.0% to 3.4%, while carbohydrate levels declined from 72.5% to 56.5%, making the product more protein-focused. Treatment 5 emerged as the most nutritionally balanced, offering a superior profile ideal for health-conscious consumers.

Table 3 :Statistical analysis

Treatment	Parameters	Mean (%)	SD	ANOVA
1	Protein Content	11.80	± 0.20	p<0.001(significant)
2	Protein Content	14.70	± 0.20	
3	Protein Content	18.30	± 0.20	
4	Protein Content	22.10	± 0.20	
5	Protein Content	25.50	± 0.20	
Essential Amino Acid				
1	Essential Amino Acid	0.60	±0.01	P<0.001 (significant
2	Essential Amino Acid	0.70	±0.01	
3	Essential Amino Acid	0.79	±0.01	
4	Essential Amino Acid	0.88	±0.01	
5	Essential Amino Acid	0.94	±0.01	
Fat Content				
1	Fat Content	3.20	±0.10	P<0.001 (significant)
2	Fat Content	3.80	±0.10	
3	Fat Content	3.60	±0.10	
4	Fat Content	3.20	±0.10	
5	Fat Content	2.80	±0.10	
Ash Content				
1	Ash Content	2.00	±0.10	P<0.001 (significant)
2	Ash Content	2.30	±0.10	
3	Ash Content	2.60	±0.10	
4	Ash Content	3.00	±0.10	
5	Ash Content	3.40	±0.10	
Carbohydrates Content				
1	Carbohydrates Content	72.50	±0.10	P<0.001 (significant)
2	Carbohydrates Content	69.00	±0.10	
3	Carbohydrates Content	64.50	±0.10	

4	Carbohydrates Content	60.00	±0.10	
5	Carbohydrates Content	56.60	±0.10	

1.Protein Content: Low variability (SD ±0.20) with a considerable increase over treatments, ranging from 11.8% (T1) to 25.5% (T5). A substantial difference ($p < 0.001$) was seen in the ANOVA findings.

2. Essential Amino Acid: There was little fluctuation (SD ±0.01) and a gradual improvement from 0.63% (T1) to 0.94% (T5). There were proven significant differences ($p < 0.001$).

3. Fat Content: Although the variability was low (SD ±0.10), there was a significant difference ($p < 0.001$) between the ranges of 3.2% (T1, T4) and 3.8% (T2).

4. Moisture Content: Consistent SD readings (±0.10), gradually decreased from 10.5% (T1) to 9.6% (T5). Significant differences were verified by ANOVA ($p < 0.001$).

5. Ash Content: There was a noticeable increase trend with significant differences ($p < 0.001$), rising from 2.0% (T1) to 3.4% (T5).

6. Carbohydrate Content: From 72.5% (T1) to 56.5% (T5), there was a noticeable decrease across treatments. These differences were modest variable (SD ±0.10) and significant ($p < 0.001$).

Table 3 provides a conclusion. Significant variations were seen among treatments for all assessed parameters ($p < 0.001$). While moisture and carbohydrate quantities dropped, protein and key amino acid contents sharply increased, suggesting increased nutritional value. An upward trend in ash concentration indicated an improvement in the mineral composition.

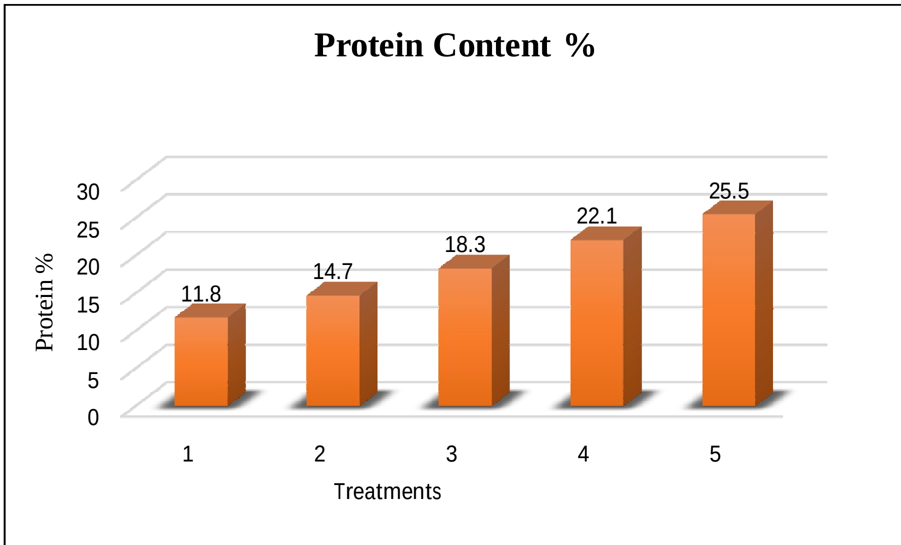

Fig. 2 Protein Content in Energy Bites

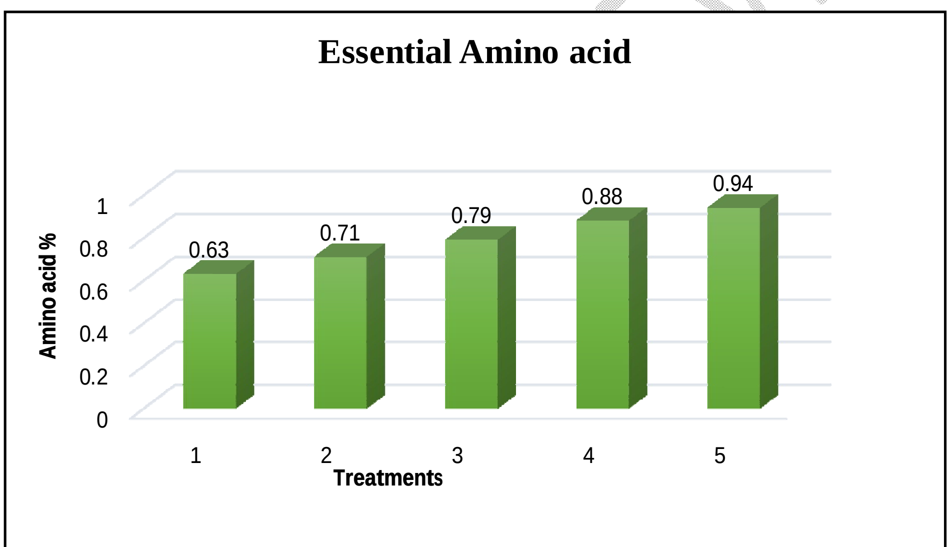

Fig. 3 Essential Amino acid in Energy Bites (%)

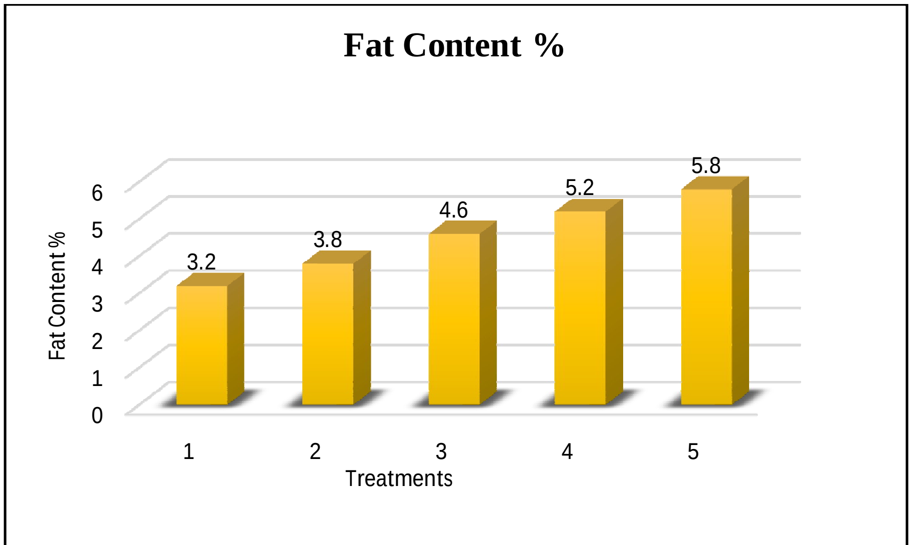

Fig. 4 Fat Content in Energy Bites (%)

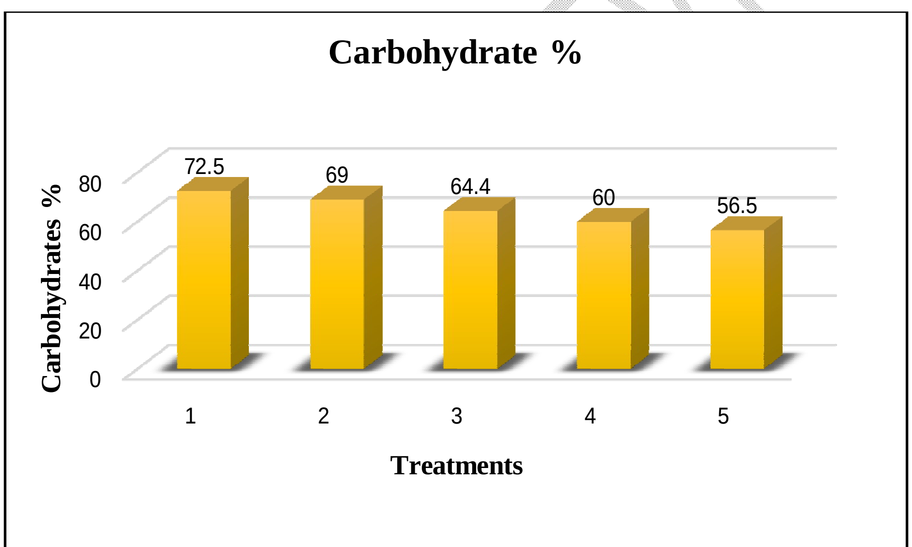

Fig. 5 Carbohydrates in Energy Bites (%)

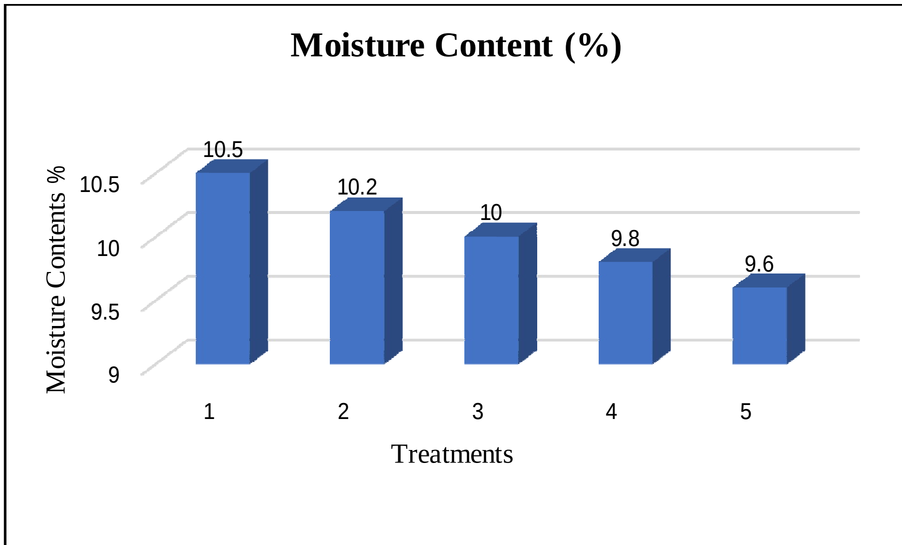

Fig. 6Moisture content in Energy Bites (%)

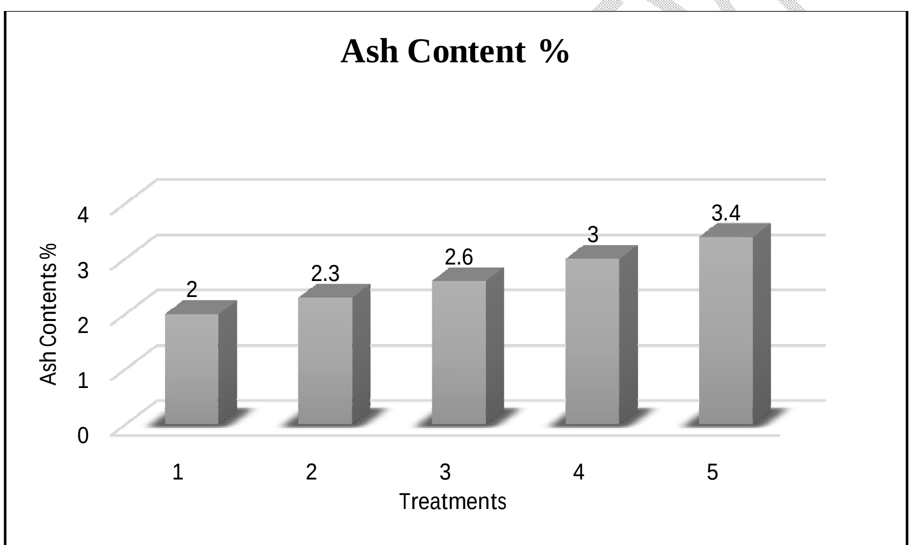

Fig. 7 Ash content in Energy Bites (%)

The chemical analysis of the fish-based extruded snack formulations (per 100 g) demonstrated significant variations in nutritional components across the five treatments. Fig.2 illustrates the steady increase in protein content, which ranged from 11.8% in Treatment 1 to 25.5% in Treatment 5. This progression highlights the enhancement of protein levels with increasing fish powder. Similarly, the improvement in protein quality is reflected in the Essential Amino Acid Index, as shown in Fig. 3, which rose from 0.63 in Treatment 1 to 0.94 in Treatment 5.

Fat content, depicted in Fig. 4, increased from 3.2% in Treatment 1 to 5.8% in Treatment 5, highlighting the lipid contribution of fish powder to the formulations. On the other hand, carbohydrate content, as shown in Fig. 5, exhibited a decreasing trend, declining from 72.5%

in Treatment 1 to 56.5% in Treatment 5, due to the replacement of carbohydrate-rich ingredients with protein-rich fish powder.The mineral composition, represented by ash content and displayed in Fig. 7, increased from 2.0% in Treatment 1 to 3.4% in Treatment 5, indicating enhanced mineral enrichment. Finally, moisture content, as illustrated in Fig. 6, showed a gradual decline from 10.5% in Treatment 1 to 9.6% in Treatment 5, suggesting better moisture reduction with higher fish incorporation.These findings collectively emphasize the nutritional enhancement achieved by increasing the proportion of fish powder in the formulations, resulting in a protein-enriched product with balanced macronutrients and essential amino acids.

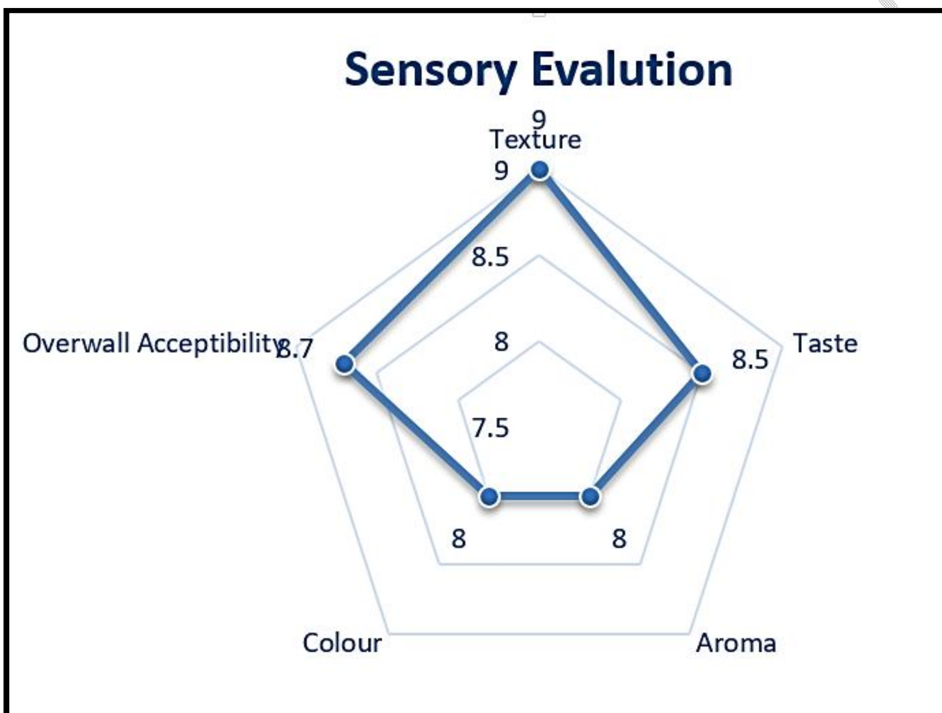

Fig. 8 Sensory Evaluation of T5

The sensory evaluation of Treatment T5, as illustrated in the radar graph, highlights its superior performance in all sensory attributes, making it the best among the tested formulations. Texture received the highest score of 9, indicating an ideal crispiness and mouthfeel desired in extruded snacks. Taste and aroma, both scoring 8.5, reflect the balanced flavor profile and pleasant fish-derived aroma that contributed to its overall acceptability. The color attribute achieved a score of 8, signifying an appealing appearance that aligns with consumer preferences. Overall acceptability was rated at 8.7, showcasing a well-rounded combination of sensory qualities. These results emphasize that Treatment T5 effectively optimized the ingredient proportions and processing parameters to deliver a nutritionally enriched, sensory-pleasing product suitable for consumer markets.

Conclusion

Fish Kurkure and other fish-based extruded snacks show how mixing fish powder, corn flour, and millet flour can result in a nutrient-dense, shelf-stable product. Compared to conventional cereal-based snacks, the addition of fish powder improves the protein level and amino acid profile, offering a more balanced nutritional supply. Treatment 5 (30% Fish Powder, 40% Corn Flour, 30% Millet Flour) was the most promising formulation among those studied. It had a high sensory evaluation score of 8.5/9 for flavor and texture, as well as an ideal balance of essential amino acids and protein content (20–25% per 100 g).Furthermore, the product maintained its flavor and crispness for three months while stored at room temperature. The manufacture of a premium snack with the desired texture and shape was guaranteed by the optimized extrusion settings, which included a barrel temperature of 112°C, a screw speed of 320 rpm, and a feed rate of 210 g/min. This study demonstrates how extrusion technology may be used to make creative, sustainable snack products that satisfy both nutritional and sensory needs by exploiting underutilized fish resources.

The study shows how fish powder, maize flour, and millet flour may be combined to create a fish-based extruded snack that is high in nutrients, shelf-stable, and well-liked by consumers. The most successful formulation was Treatment 5 (30% fish powder, 50% maize flour, 20% millet flour), which produced a balanced amino acid profile and an ideal protein concentration of 25% per 100 g. With a taste and texture score of 8.5 out of 9, this formulation also performed quite well in sensory evaluation, making it very appealing to consumers. The food maintained its flavor, crispness, and nutritional value for three months while being stored at room temperature.The production of a snack with a desired texture and consistent shape was made possible by the optimized extrusion settings, which included a barrel temperature of 112°C, a screw speed of 320 rpm, and a feed rate of 210 g/min. Significant differences were observed across treatments ($p < 0.001$). Moisture and carbohydrate levels decreased, while protein and essential amino acid contents increased, enhancing nutritional value. Additionally, the rise in ash content reflected better mineral composition.This study highlights how extrusion technology may be used to turn underutilized fish resources into creative, sustainable snack foods that satisfy consumers' nutritional and sensory needs. This presents a viable path for both food innovation and economic growth.

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