

NUTRITIONAL AND FUNCTIONAL PROPERTIES OF TILAPIA (*OREOCHROMIS NILOTICUS*) FISH POWDER AND THEIR APPLICATION IN FORTIFICATION FOR PREPARATION OF FISH SNACKS

¹S. S*. Relekar, ²J. M. Koli, ³S.B. Gore, ⁴A. S. Desai, ⁵S.A. Joshi, ⁶V. K., Basunathe, ⁷G. P., Shende, ⁸B. D. Meshram, ⁹D. R. Bhaladhare

^{1,3&5}Department of Fish Processing Technology, College of Fishery Science, MAFSU Nagpur

^{2,4 & 8}Department of Fish Processing Technology, College of Fisheries, Ratnagiri

^{6,7,9}Maharashtra Animal & Fishery Sciences University, Nagpur

Corresponding Author: S. S. Relekar, Email: shailendrarelekar@mafsu.ac.in

ABSTRACT

This study assessed the nutritional composition, functional properties and food application potential of tilapia fish powder produced from whole fish. Fresh fish exhibited high moisture content with moderate protein and low lipid levels. Conversion into powder significantly concentrated nutrients, particularly protein (68.29%) and lipids (13.36%). Amino acid profiling identified balanced composition of essential and non-essential amino acids. Total essential amino acids were 29.66 g/100 g and non-essential were 32.43 g/100 g, with lysine as major essential and glutamic acid as predominant non-essential amino acid. Fatty acid profiling revealed 31 fatty acids, with saturated fatty acids (2027.94 mg/100g), palmitic acid was dominant, while monounsaturated and polyunsaturated fatty acids were 2072.83 and 769.29 mg/100 g, respectively. The powder contained valuable ω -3 fatty acids (589.67 mg/100 g), including EPA and DHA. Mineral analysis showed high levels of potassium, calcium, sodium, magnesium, zinc, and iron. Functional properties demonstrated near-neutral pH, high water and oil holding capacities, moderate foaming, and acceptable emulsifying activity, indicating suitability for food applications. Sensory evaluation of fish-fortified crackers showed that the 80:20 tapioca-to-fish powder formulation achieved the highest acceptability. Overall, tilapia fish powder proved to be nutrient-rich ingredient with favorable functional and sensory properties and use in fortified food products.

KEYWORD: Tilapia fish powder, amino acids, fatty acids, minerals & Functional properties

INTRODUCTION:

Global hunger rose sharply between 2019 - 2021 and remained unchanged through 2023, with about 733.4 million people undernourished worldwide. (FAO, 2024). Protein-energy malnutrition and micronutrient deficiencies remain major public health concerns, which can be mitigated by increasing access to protein from diverse sources. (Kabir et al., 2022). Although meat and poultry are major animal protein sources, high red meat consumption is associated with several noncommunicable diseases. (Larsson et al., 2011). Fish, however, is a superior alternative due to its high-quality protein and multiple health benefits.

Fish provides nutritionally valuable proteins, minerals, and essential amino and fatty acids. It is rich in essential amino acids such as lysine, methionine, and taurine, often deficient in other animal proteins, along with flavor-enhancing amino acids like glycine, alanine, aspartic acid, and glutamic acid (Dogan and Ertan, 2017) and supports tissue repair and growth. Additionally, fish is an important source of ω -3 long-chain polyunsaturated fatty acids, particularly DHA and EPA, which reduce the risk of inflammation, rheumatoid arthritis, cancer, and cardiovascular diseases. The European Food Safety Authority recommends 200 mg DHA and EPA daily, with an n-6/n-3 ratio of 2–5:1 to prevent several diseases. (Tufan et al., 2018). Nevertheless, fish is prominent source of minerals that maintain acid-base balance, water regulation, bone formation, and metabolic processes. (Adeyeye et al., 2019).

Fish protein powder (FPP) is a dehydrated, shelf-stable preparation with higher protein concentration than fresh fish flesh. It is highly digestible and can be used in the food industry as a binder, emulsifier, and dispersing agent. Moreover, FPP is a promising ingredient for fortified or ready-to-eat food and low-fat, white-fleshed fish species are considered ideal for FPP preparation. (Shaviklo et al., 2010).

Fish powders are vital sources of eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA), and essential amino acids. The observed polyunsaturated fatty acid to saturated fatty acid (PUFA/SFA) and omega-6 to omega-3 (n-6/n-3) ratios were within recommended ranges, indicating their suitability for incorporation into ready-to-use food formulations. Owing to their high nutritional value, these powders may serve as an important dietary source for vulnerable groups, including infants as well as pregnant and lactating women. Furthermore, assessment based on Recommended Nutrient Intake (RNI) demonstrated that fish powders can substantially support food and nutrition security by helping to meet daily nutritional requirements. In addition, fish powders possess considerable potential

as functional raw materials for the development of nutritious value-added products targeted at consumers across different age groups (Mamun et al., 2022).

However, India has produced 175.45 lakh tonnes of fish during 2022–2023, including 131.13 lakh tonnes from inland fisheries and 44.32 lakh tonnes from marine sources, with an annual growth rate of 7.98%. Inland fisheries showed higher growth than marine fisheries, and India ranked second globally, contributing 8.92% of total world fish production. In Maharashtra, inland fish production reached 1.57 lakh tonnes, with the Vidarbha region contributing nearly 49.6%.13 (Department of Fisheries, Maharashtra, 2022). Among the freshwater fish species available in Nagpur markets, tilapia is one of the most accessible, affordable, and nutritionally valuable.

Considering the increasing fish production and the need for innovative nutritional products, converting tilapia into fish powder offers a practical way to improve fish utilization. Since high temperatures may reduce nutritional quality, this study aimed to prepare tilapia fish powder at low temperatures, evaluate its nutritional and functional quality attributes, and assess its suitability for developing fish-based snack product (Fish-Cracker).

MATERIALS AND METHODS

2.1 Preparation of Tilapia Fish Powder.

Fresh tilapia (*Oreochromis niloticus*) were procured from a local market of Nagpur, MH, India (21.0951° N, 79.0598° E) and transported under iced conditions to the laboratory of College of Fishery Science, Nagpur. Tilapia fish were cleaned, descaled, gutted and washed at 10 °C and fresh meat used for proximate composition and remaining meat immersed in 5% NaCl solution and boiled at 60 °C for 10 min. The flesh was manually separated from the boiled fish, the separated minced meat was pressed to remove excess moisture, and dried at 55 ± 5 °C for 10–12 h. The dried flakes of the separated minced meat were ground and sieved (1 mm) to obtain fine tilapia fish powder as shown in Flow chart 1.

2.2 Yield of tilapia fish powder (%)

The percentage yield of tilapia fish powder from whole tilapia (*Oreochromis niloticus*) which was cleaned, descaled, gutted and washed was calculated by the manual method using the following equation.

Yield of fish powder (%) = (Total weight of powder in Kg / Total weight of fish in Kg.)×100

2.3 Nutritional quality of tilapia fish powder

2.3.1 Proximate composition of tilapia fish powder

The proximate composition, moisture, lipids, protein and ash content of fish samples, was analyzed per the methods of AOAC (2005). The carbohydrate percentage was calculated as [100 - (sum of moisture, protein, lipids and ash%)].

2.3.2 Amino acids profiling of tilapia fish powder

The amino acid profiling of fish samples was assessed using High-Performance Liquid Chromatography (HPLC, Shimadzu LC-6A) (Herawati et al. 2018). The fish samples were digested in 6 N HCL for 20 hrs, incubated in an oven (110°C) under nitrogen gas, and neutralized with 4.8 mL of 10M NaOH. For assessment of free amino acids, 0.5 g of a sample was blended with acetic acid (3 mL: 3M) and mixed for 540 s in the bead beater at 4800 rpm, followed by centrifugation at 10,000 rpm for 5 min. Then, 1 ml of 100 mM Na₂EDTA was mixed with 0.5 ml of the supernatant. Finally, the samples were filtered using a 0.22-micron syringe filter and 20 µl sample was injected into HPLC, an analytical column of 300 x 7.8 mm. The mobile phase was 0.02 M H₂SO₄ at a flow rate of 0.4 ml/min and the retention time under this condition was 27.4 min for the standard. The wavelength for the detection of amino acids was 290 nm. The results were expressed in g per 100g of dried tilapia fish powder.

2.3.3 Fatty acids profile of tilapia fish powder

The extraction of total lipids in the sample (5g) was performed using a chloroform: methanol mixture (2:1) (Folch et al. 1957). The fatty acids were obtained by the saponification of total lipids with NaOH and were converted into fatty acid methyl esters (FAMES) by methylation. The fatty acid methyl ester (FAME) was investigated by gas chromatography with FID (Model HP 6890, Hewlett-Packard) equipped with a DB-Wax column (25 9 25 mm; film thickness 0.25 mm) along with helium as a carrier gas. The sample was injected at a split mode injection port with a 1:15 split ratio at 250 °C, and the oven temperature was programmed to increase from 50 to 230°C in -1 steps of 10 °C min and then remain stable for 35 min. A suitable standard was applied for the identification and quantification of individual fatty acids and the values of fatty acids were expressed mg /100 g of fat (AOAC, 2005).

2.3.4 Mineral content of tilapia fish powder

The digestion method was followed for mineral (Ca, Mg, Na, K and Zn) analysis as per AOAC (2005). The tilapia fish powder sample (3 g) was incinerated in the muffle furnace for determination of ash content and finally, the resultant ash was digested with 2.5 ml of HNO and 60% perchloric acid for minerals estimation. The minerals were analyzed by Atomic Absorption Spectrophotometer (AAS) (Model No. novAA 350). Values of minerals were expressed in mg/ 100g.

2.4 Functional properties of tilapia fish powder

2.4.1 pH measurement

Precisely, 10 g product samples were mixed with 50 mL of distilled water in a homogeniser (Polytron system PT 2100, Germany) for 30 seconds and the pH value of the homogenates was measured using a digital pH meter (EQ-610, range 0-14) previously standardised by buffers of pH 4.8 and 9.2

2.4.2 Water and oil holding capacity (WHC/OHC)

WHC/OHC of samples was determined by the method described by Ofori et al. (2020). Accurately, 1 g of sample was mixed with 10 ml of distilled water in a centrifuge tube (20 ml), kept to stand for 30 min at ambient temperature ($30 \pm 2^\circ\text{C}$), and then centrifuged for 30 mins at 3000 rpm. WHC/OHC was examined in percentage by using the following formula.

$$\text{Water and Oil Holding Capacity (\%)} = \frac{\text{Bound Water or Oil}}{\text{Weight of Sample}} \times 100$$

2.4.3 Foaming capacity

Exactly 1 g of tilapia fish powder was transferred to 100 ml of distilled water and the mixture was homogenized for 1 min at high speed. Then, carefully transferred the mixture to a 250 ml calibrated beaker for volume measurement. Foam was calculated as the volume of the mixture after mixing compared to the original volume and expressed in percentage by using the following equation given by Obinna-Echem et al. (2020).

$$\text{Foaming Capacity (\%)} = \frac{\text{Final Volume of the foam} - \text{Initial Volume of the foam}}{\text{Initial Volume of the foam}} \times 100$$

2.4.4 Emulsifying Capacity

Emulsifying capacity was determined as per the method noted by Butt and Batool R (2010). Accurately, 1.8 g of tilapia fish powder was added to 25 ml of distilled water and introduced in a blender at high speed. 12.5 ml of edible oil was added and blended again for 1 min at high speed. The emulsion fashioned was transferred into two centrifuge tubes (12 ml) and centrifuged. The emulsion capacity was calculated using the following equation.

$$\text{Emulsion capacity (\%)} = \frac{\text{Height of emulsified layer}}{\text{Height of total content of the tube}} \times 100$$

2.5 Colour measurements

The color parameters of tilapia fish powder were measured using a Hunter Lab Colorimeter (Thiansilakul et al., 2007). The colorimeter was calibrated with the standard (No LX17376) using white ($X=79.81$, $Y=84.71$, $Z=90.95$) and black ($X=16.11$, $Y=21.94$, $Z=16.66$) tiles under “C” illuminate condition according to the CIE (Commission International de l'éclairage). The L^* variable represents lightness ($L^*=0$ (black), $L^*=100$ (white)), redness ($+a^*$) and yellowness ($+b^*$), or blueness ($-b^*$) were the color parameters evaluated for the samples. The color properties, L^* (lightness), a^* (redness/greenness), and b^* (yellowness/blueness), were determined by maintaining a distance from the sample of 3 cm height.

2.6 Sensory analysis of tilapia fish powder fortified snack product (Crackers)

Tilapia fish powder fortified snack product was developed for evaluating the acceptance of consumers by sensory analysis. In the present study, Crackers fortified with tilapia fish powder were prepared as per the method described by Tiwari et al. (2020) with slight modification as Tapioca flour: Tilapia Fish Powder ratios as 90:10(T1), 80:20(T2), and 70:30(T3) showed in Table No. 1. The required quantities of tapioca, fish powder, and other ingredients were weighed accurately according to the respective formulation. The ingredients were thoroughly mixed, followed by the addition of the specified quantity of water to obtain a homogeneous dough. The dough was shaped into uniform cylindrical rolls and steamed at **100°C for 30 min**. After steaming, the rolls were cooled to room temperature and sliced into uniform pieces of approximately 1.5-2 mm. The slices were dried at **45°C for 12-16 h** to obtain the dried cracker pieces. Samples were air fried prior to evaluation. Sensory attributes including taste, colour, crispiness, texture, and overall acceptability were assessed. Sensory evaluation of the prepared formulations was conducted using 9-point hedonic scale by 10 panelists selected based on their willingness and ability to assess food products. The samples were prepared under identical conditions and assigned random three-digit codes before presentation. The coded samples were presented to the panelists in a randomized order to minimize order and identification bias. Panelists were not informed about the composition or treatment identity of the samples. Drinking water was provided for palate cleansing between samples. The evaluation was conducted in 10 independent sessions, and the sensory scores were recorded for the specified sensory attributes.

2.7 Statistical analysis

Data were analyzed using Microsoft Excel (MS Office 365) and IBM SPSS Statistics version 27.0. All analyses were performed on all samples were in triplicate. The data were subjected to one-way analysis of variance (ANOVA), followed by Tukey's post hoc test to determine significant differences among treatment means at a significance level of $p < 0.05$. The results are expressed as mean $\pm$ standard deviation (SD).

3. RESULTS AND DISCUSSION

3.1 Nutritional profile of Tilapia meat

The variation in the proximate composition of fish can be attributed both to interspecific differences and to the processing techniques employed, species-specific variations arise from inherent biological factors such as feeding ecology, metabolic rate, reproductive stage, and habitat, all of which influence the relative proportions of moisture, protein, lipid, and ash content in fish muscle. (Shaviklo et al. 2010).

The proximate profile of the tilapia used for fish-powder production exhibited as $77.36 \pm 0.12\%$, moisture, $17.73 \pm 0.06\%$, protein, $2.51 \pm 0.07\%$, lipid, $0.95 \pm 0.02\%$, ash and carbohydrate, $1.53 \pm 0.12\%$ and indicated as tilapia fish was a lean, protein-rich raw material that favours high protein powder yield, good functional properties, and

a lower risk of lipid oxidation during processing and storage. Multiple investigations on the proximate composition of tilapia meat/fillets aligned current with study results. (Jim et al. 2017; Sultana et al. 2023).

3.1.1 Tilapia fish powder yield (%)

Yield refers to the percentage ratio of the usable portion of a material to its total weight. The processing methods and the size of the fish head influence the overall meat yield and crucial metric for assessing the economic worth and efficiency of a product (Jankowska et al., 2007). In the present study, the yield of tilapia fish powder from whole fish was $11.31 \pm 0.63\%$ and comparable to fish powder prepared from tilapia (12.11%) and silver carp (12.69%) by Kabir et al., 2022. A quite closed value also found of anchovy fish powder yield 11.6 % (Mamun et. al., 2022).

3.2 Nutritional quality of tilapia fish powder

3.2.1 Proximate composition of tilapia fish powder

The proximate composition is the percentage combination of water, protein, lipid, ash and carbohydrate and shows the nutritional status of the product. In the present study, the proximate composition of tilapia fish powder, moisture was found to be $6.74 \pm 0.04\%$ after the completion of the drying process. However, the protein and lipid content at $68.29 \pm 1.06\%$ and $13.36 \pm 0.84\%$, respectively. The ash content was also observed to be as high as $7.86 \pm 0.56\%$ while carbohydrate content was noticed at $2.26 \pm 0.14\%$. The supportive proximate value of fish powder prepared from snakehead meat had a moisture percentage of 6.79, ash was 8.29 %, a carbohydrate 37.60 %, protein (50.70%) and fat was 3.48 % (Puteri et. al., 2024) and mentioned chemical composition of powder depending on proximate composition of fish muscle, physiological functions, dietary intake and metabolism of fish. Comparable proximate composition was revealed by Kabir et. al., 2022 during the preparation of tilapia and silver carp edible powder. The moisture, ash, protein, carbohydrate and energy values were 4.69 %, 6.94 %, 63.63 %, 2.37 %, and 465.48 Kcal/100g respectively with higher fat (22.38 %) was observed in tilapia fish powder. However, the highest moisture content was observed in whole sardine powder (10.32%) and anchovy muscle powder exhibited the lowest value (6.63%). Furthermore, highest protein found in anchovy muscle powder (72.55%) and sardine muscle powder displayed protein content (53.52%) which presented inverted relation of moisture and protein (Mamun et. al., 2022).

3.2.2 Amino acids content in tilapia fish powder

Tilapia fish powder enhances the quality and quantity of diets, supports child growth, and helps combat malnutrition disorders like Kwashiorkor in vulnerable under-five children (Vakily et al. 2012). In the present study, tilapia fish powder contained 17 amino acids, including 8 essential and 9 non-essential amino acids (Table 3). Total essential amino acids were found 29.66 g/100g, while non-essential amino acids were 32.43 g/100g. Lysine was the most abundant essential amino acid, followed by leucine and isoleucine. This is nutritionally significant because lysine is often the limiting amino acid in cereal-based diets, and inadequate lysine intake can impair physical growth and cognitive development. (Chapman et al., 2010). Methionine, phenylalanine, threonine, and valine were also present in adequate amounts. However, functional amino acids (FAAs), including arginine, methionine, leucine, tyrosine, cystine, proline, glycine, aspartate, and taurine, play crucial roles in regulating key metabolic pathways that support overall health, survival, growth, development, reproduction, and lactation. These amino acids are actively involved in physiological processes that maintain normal body functions. Nevertheless, among non-essential amino acids, glutamic acid (8.29 g/100g) was highest, followed by aspartic acid and arginine. These amino acids contribute to flavour enhancement and metabolic functions, with glutamic acid recognized for its role in palatability and as a major nitrogen donor along their health benefits (Lopez., 1975). On the other hand, similar values of amino acids content of hake powder were reported by Pires et al., 2012, where lysine was the dominant essential amino acid while glutamic acid and aspartic acid were the major non-essential amino acids. Nevertheless, less value of total essential amino acids was noted by Mamnun et.al., 2022 in sardine muscle powder, 23.16 mg/g and 12.54 mg/g respectively in sardine and anchovy muscle powder whereas, total non-essential amino acids found to be 3.54 mg/g in sardine muscle powder and 10.23 mg/g in anchovy muscle powder.

3.2.3 Fatty acids composition of fish powder

Fish is an abundant source of long-chain polyunsaturated fatty acids (PUFAs) and provides multiple health benefits. It plays a role in both the prevention and management of various health conditions, including reducing liver steatosis, supporting cardiovascular health, alleviating symptoms of rheumatoid arthritis, and promoting proper brain function (Zula and Desta, 2021). In present investigation, powder prepared from tilapia fish has found 31 fatty acids (Table 4). Total saturated fatty acids (SFA) were 2027.94 mg/100g, dominated by palmitic acid (1302.52 ± 0.03 mg/100g), followed by stearic acid (206.70 ± 0.03 mg/100g) and lignoceric acid (161.15 ± 0.08 mg/100g), while behenic acid was lowest (11.90 ± 0.03 mg/100g). Total monounsaturated fatty acids (MUFA) reached 2072.83 mg/100g, with oleic acid (894.96 ± 0.08 mg/100g) as the major component, followed by palmitoleic acid (393.20 ± 0.02 mg/100g) and nervonic acid (382.74 ± 0.06 mg/100g). Polyunsaturated fatty acids (PUFA) total 769.29 mg/100g, mainly cis-11,14,17-eicosatrienoic acid (340.32 ± 0.03 mg/100g), linolenic acid (234.92 ± 0.04 mg/100g), and linoleic acid (234.92 ± 0.04 mg/100g). The powder also contained EPA (6.64 ± 0.03 mg/100g), DHA (7.79 ± 0.03 mg/100g), total ω -3 fatty acids of 589.67 mg/100g, and ω -6 fatty acids of 179.62 mg/100g. Nevertheless, the PUFA/SFA ratio (0.379) observed in the present study is below the recommended value of 0.45 set by the UK Department of Health, suggesting potential cardiovascular health benefits to human

beings. This finding is further supported by the ω -6/ ω -3 ratio (0.3046), which remains well below the established threshold of 4, indicating a favorable fatty acid balance (Coskuntuna et al., 2015).

The findings of the present study are consistent with those reported by Mamun et al. (2022), who observed that total saturated fatty acids (SFA) were highest in whole sardine powder (4957.29 mg/100 g) and lowest in anchovy muscle powder (1192.29 mg/100 g). Among SFAs, myristic acid (14:0; 104.68–1058.64 mg/100 g), palmitic acid (16:0; 715.97–2969.02 mg/100 g), and stearic acid (18:0; 256.77–657.92 mg/100 g) were predominant across all developed fish powders. Similarly, total monounsaturated fatty acids (MUFA) were highest in whole sardine powder (2916.94 mg/100 g) and lowest in anchovy muscle powder (533.46 mg/100 g), with palmitoleic acid (16:1n-7; 196.78–1574.82 mg/100 g), oleic acid (18:1n-9; 203.74–786.19 mg/100 g), cis-vaccenic acid (18:1n-7; 83.11–429.29 mg/100 g), and nervonic acid (24:1n-9; 17.91–28.45 mg/100 g) being the major contributors.

In terms of polyunsaturated fatty acids (PUFA), the highest levels were also recorded in whole sardine powder (2619.79 mg/100 g), while anchovy muscle powder exhibited the lowest values (841.73 mg/100 g). Notably, whole sardine powder contained the greatest concentrations of both n-6 PUFA (468.42 mg/100 g) and n-3 PUFA (1718.56 mg/100 g), whereas anchovy muscle powder showed comparatively lower amounts (170.83 mg/100 g and 647.26 mg/100 g, respectively). These observations align with previous reports on punti, carp, anchovy, and sardine powders, where palmitic and oleic acids were dominant, accompanied by favorable n-6/n-3 ratios and appreciable levels of EPA and DHA.

3.2.4 Minerals content of tilapia powder

Minerals are essential indicators of nutritional status and may reveal hidden metabolic disorders. However, their concentration in fish varies with environmental conditions, species, processing methods, and drying techniques. Nevertheless, adequate dietary sodium (Na) is important for maintaining extracellular fluid volume and regulating water balance, acid–base equilibrium, and electrolyte homeostasis in the body. A sufficient intake of magnesium (Mg), contributes to bone and tooth development, supports muscle relaxation, and may help lower the risk of chronic degenerative conditions. Potassium (K) consumption in the range of 4500–4700 mg per day is considered beneficial for mitigating increases in blood pressure, particularly in the context of high sodium intake. Calcium (Ca), is essential for skeletal formation, transmission of nerve impulses, intracellular signalling, and proper blood clotting mechanisms (Nahid et al., 2017). In the present study, tilapia fish powder contained valuable macro-minerals such as calcium (84.67 ± 1.2 mg/100g), potassium (140.51 ± 0.92 mg/100g), and sodium (61.56 ± 0.89 mg/100g), along with micro-minerals including magnesium (7.42 ± 0.19 mg/100g), zinc (1.78 ± 0.06 mg/100g), and iron (0.72 ± 0.02 mg/100g) as shown in Fig.1.

Comparable findings were reported by Kabir et al., 2022 and found potassium, calcium, magnesium, and phosphorus as predominant minerals in tilapia and silver carp powders. However, higher mineral values than the present study found by Mamun et al. 2022 may be due to species differences, processing methods, sampling time, and season.

3.3 Functional properties of tilapia fish powder

Functional properties determine protein behaviour in food systems and directly influence product quality and sensory characteristics. In the present study, functional properties of tilapia fish shows The pH a near-neutral (6.26 ± 0.03), similar to tilapia and silver carp powders reported by 30 Kabir et al., 2022 (6.40 and 6.32), indicating good stability. Neutral pH stability is associated with active stabilizing compounds (Tungadi and Imran, 2018). Whilst, the water holding capacity (WHC) and oil holding capacity (OHC) of tilapia fish powder were $106.22 \pm 1.95\%$ and $126.95 \pm 2.31\%$, respectively. These values reflect the amphoteric nature of fish proteins, enabling binding of both water and oil, with higher oil retention due to nonpolar amino acids (Kabir et al., 2022). Similar WHC and OHC values were also observed in small fish flours (Tiwari et al., 2020).

On the other hand, foaming capacity was $7.22 \pm 0.22\%$ and emulsifying activity was $10.66 \pm 0.60\%$, which was close to tilapia powder (Kabir et al., 2022). These properties support the use of fish powder as an emulsifier and stabilizer in food formulations, though they may vary with processing methods.

3.4 Colour measurement:

Colour attributes of tilapia fish powder (L^* 67.98 ± 1.07 , a^* 14.90 ± 0.50 , b^* 37.34 ± 0.58) indicate a light powder with strong red–yellow tones, which are important for the appearance, browning, and acceptability of fortified snacks. These values help predict colour changes during product formulation, confirming its suitability for snack fortification. Colour is a key sensory trait influencing consumer acceptance, and the high protein content of tilapia powder may enhance Maillard reactions (Kabir et al., 2022).

3.5 Sensory attributes performed for standardization of Tilapia fish powder fortified snack foods (Crackers).

Sensory trials were performed to standardize tilapia fish powder (TFP) fortified crackers using tapioca flours at 90:10 (T1), 80:20 (T2), and 70:30 (T3) flour: TFP ratios. Among these, the tapioca-based formulation (T2) scored significantly higher in most sensory attributes, indicating that 20% TFP integrates effectively into the starch matrix while improving sensory and textural quality (Table 2 and Fig.2). The reason behind this tapioca's neutral flavour and high crisping ability likely masked fishy notes and enhanced crispiness and mouthfeel (Tokarczyk et al., 2025). This 80:20 ratio also improved nutritional value without affecting processing behaviour, while the functional properties of tilapia powder supported good dispersion, moisture retention, and acceptable texture (Kabir et al., 2022).

4. CONCLUSION:

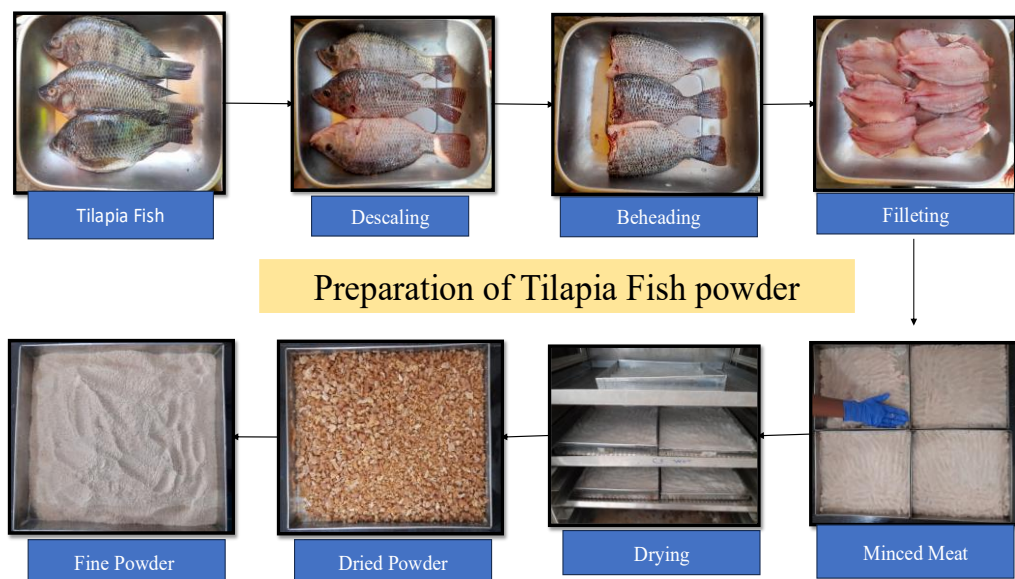
The tilapia fish powder demonstrates strong potential as a nutrient-dense functional ingredient for food fortification, particularly in snack products. Its rich protein content, well-balanced amino acid profile, beneficial fatty acid composition, and significant mineral levels contribute to improving the overall nutritional value of commonly consumed cereal-based foods. This makes it especially relevant for addressing protein and micronutrient deficiencies among vulnerable populations.

Furthermore, the functional and colour characteristics of the powder support its suitability in product development without compromising quality. Sensory evaluation findings highlight that 20% incorporation level especially in tapioca-based crackers achieves optimal consumer acceptability, balancing nutrition and palatability. Given its affordability and accessibility, tilapia fish powder presents a solution for enhancing dietary quality in both urban and rural settings where economic limitations often restrict food diversity. Its inclusion in widely consumed snack items offers a promising strategy to combat malnutrition and improve public health outcomes.

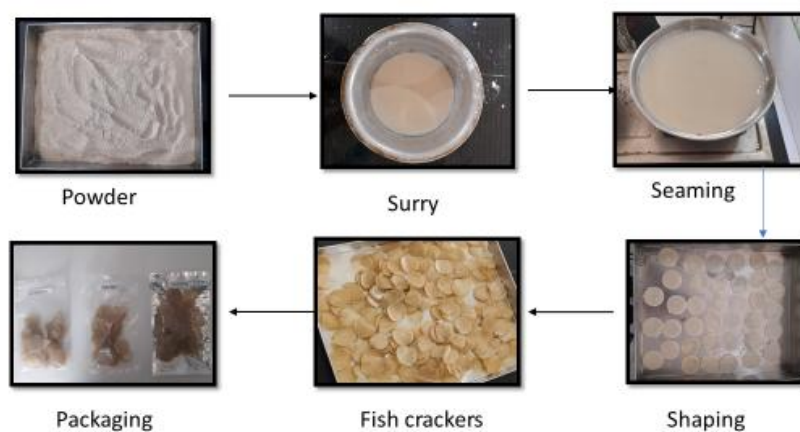
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Flow chart 1. Preparation of Tilapia Fish Powder



Flow Chart 2 Preparation of Fish Crackers by using Tapioca flour

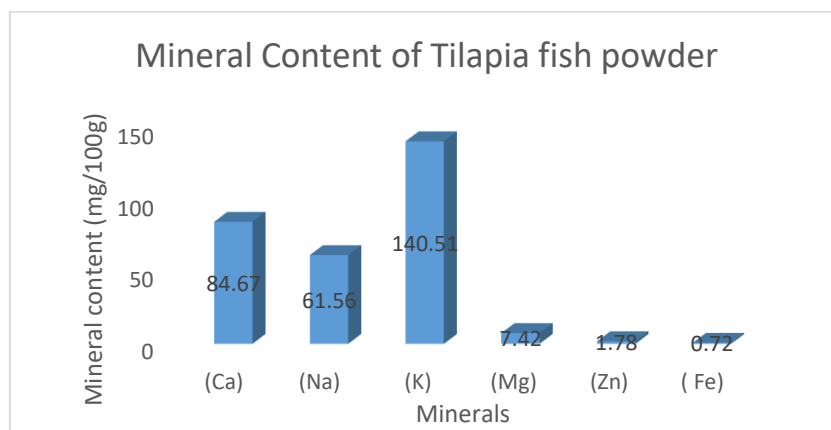


Fig. 1 Mineral Content of Tilapia Fish Powder

Table 1 Optimization of the concentration of tilapia fish powder in fish wafers prepared using tapioca flour

Sr. No	Ingredients	T1	T2	T3
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1.	Tapioca flour	90g	80g	70 g
2.	Fish powder	10g	20g	30g
3.	Salt	2g	2g	2g
4.	Water	100 ml	100 ml	100 ml

Table No. 2 Organoleptic characteristics of fish wafers prepared from Tapioca flour

Sr. No.	Characteristics	(Tapioca) T1 90:10	(Tapioca) T2 80:20	(Tapioca) T3 70:30
1	Appearance	6.2±1.03 ^a	8.85±0.24 ^b	5.75±0.42 ^a
2	Colour	6.05±0.96 ^a	8.80±0.26 ^b	5.82±0.90 ^a
3	Odour	5.90±0.88 ^a	8.9±0.21 ^b	5.4±0.45 ^a
4	Texture	6.20±0.48 ^a	8.8±0.21 ^b	6.0±0.78 ^a
5	Crispiness	6.30±0.53 ^b	8.9±0.22 ^c	5.60±0.70 ^a
6	Taste	6.65±0.58 ^b	8.85±0.24 ^c	5.95±0.69 ^a
7	Overall Acceptability	6.45±0.49 ^b	8.9±0.21 ^c	5.9±0.46 ^a

Data (n=10) are expressed as the mean ± SD. According to Tukey's test, different superscripts in the same row signify statistical difference ($P < 0.05$).

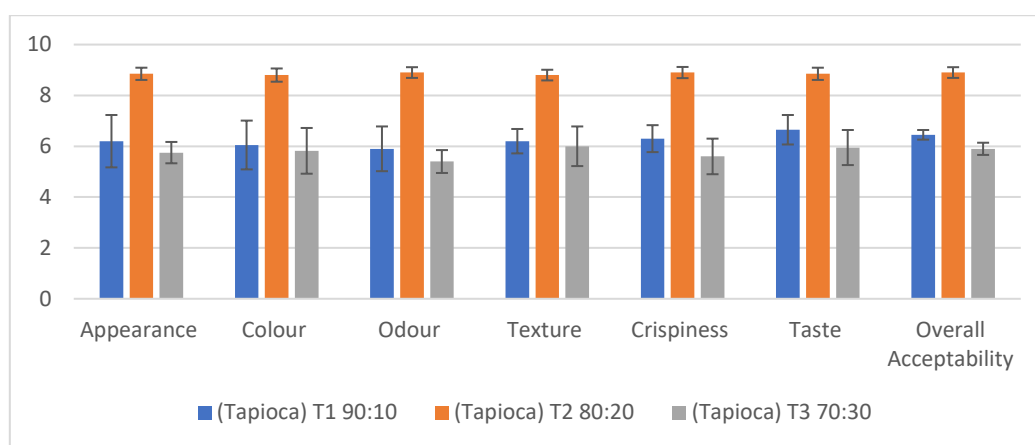


Fig. 2 Organoleptic score of Tapioca based fish crackers

Table No. 3 Amino acid (AA) composition (g/100g) of tilapia fish powder

S. N.	Amino Acids	Tilapia Powder	Fish
Essential amino acid			
1	Lysine	6.31±0.05	
2	Isoleucine	3.46±0.04	
3	Leucine	4.85±0.02	
4	Histidine	1.69±0.06	
5	Methionine	2.88±0.03	
6	Phenylalanine	2.98±0.04	
7	Threonine	3.85±0.05	
8	Valine	3.64±0.04	
	Total EAA	29.66	
Non-essential amino acid			
9	Alanine	4.07±0.07	
10	Arginine	3.60±0.08	
11	Aspartate	3.65±0.05	
12	Cysteine	0.98±0.02	
13	Glutamate	8.29±0.03	
14	Glycine	4.26±0.02	
15	Proline	2.56±0.07	
16	Serine	2.89±0.05	
17	Tyrosine	2.13±0.03	
	Total NEAA	32.43	

Note- Values represent the Mean± Standard deviation where n=3 .

Table No. 4 Fatty Acid composition of tilapia fish powder (mg/100g)

S. N.	Fatty acids	
Saturated Fatty Acids (SFA)		
1	Lauric acid (C12:0)	6.52±0.03
2	Tridecanoic acid (C13:0)	-
3	Myristic acid (C14:0)	132.42±0.05
4	Pentadecanoic acid (C15:0)	37.50±0.08
5	Palmitic acid (C16:0)	1302.52±0.03
6	Heptadecanoic acid (C17:0)	75.38±0.02
7	Stearic acid (C18:0)	206.70±0.03
8	Arachidic acid (C20:0)	68.54±0.03
9	Heneicosanoic acid (C21:0)	12.88±0.02
10	Behenic acid (C22:0)	11.90±0.03
11	Tricosanoic acid (C23:0)	12.43±0.04
12	Lingnoceric acid (C24:0)	161.15±0.08
Monounsaturated Fatty Acids (MUFA)		
13	Myristoleic acid (C14:1)	13.90±0.03
14	cis-10-Pentadecenoic acid (C15:1)	16.87±0.02
15	Palmitoleic acid (C16:1)	393.20±0.02
16	cis-10-Heptadecanoic acid (C17:1)	21.61±0.04
17	Elaidic acid (C18:1)	173.93±0.03
18	Oleic acid (C18:1)	894.96±0.08
19	cis-11-Ecosenic Acid (C20:1)	5.39±0.03
20	Erucic acid (C22:1)	170.23±0.03
21	Nervonic acid (C24:1)	382.74±0.06
Polyunsaturated fatty acids (PUFA)		
22	Linolelaidic acid (C18:2)	4.09±0.02
23	Linoleic acid (C18:2)	96.02±0.04
24	α-Linolenic acid (C18:3)	234.92±0.04
25	cis-11,14 Eicosadienoic acid (C20:2)	30.55±0.03
26	8,11,14-Eicosadienoic acid (C20:3)	8.33±0.03
27	Arachidonic acid (C20:4)	32.78±0.02
28	cis-11,14,17-Eicsatrienoic acid (C20:3)	340.32±0.03
29	Eicosapentaenoic acid (EPA; C20:5)	6.64±0.03
30	cis-13,16-Docosadienoic Acid (C22:2)	7.85±0.02
31	Docosahexaenoic acid (DHA; C22:6)	7.79±0.03
	ΣSFA	2027.94
	ΣMUFA	2072.83
	ΣPUFA	769.29
	Σ ω-6	179.62
	Σ ω-3	589.67
	PUFA/SFA	0.379
	ω-6/ ω-3	0.3046

Note- Values represent the Mean± Standard deviation where n=3.