INSIGHTS-JOURNAL OF
LIFE AND SOCIAL SCIENCES

DEVELOPMENT AND QUALITY EVALUATION OF CHICKEN NUGGETS USING FISH MEAT

Original Article

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Conflict of Interest: None
Grant Support & Financial Support: None

Acknowledgment: The authors acknowledge the technical support provided by the Department of Food Science and Technology.

ABSTRACT

Background: Chicken nuggets are widely consumed convenience meat products but are nutritionally limited in omega-3 long-chain polyunsaturated fatty acids, particularly eicosapentaenoic acid and docosahexaenoic acid. Fish meat is a rich source of omega-3 fatty acids, high-quality protein, essential lipids, and micronutrients that contribute to cardiovascular and metabolic health. Incorporating fish meat into chicken nuggets may therefore enhance their nutritional profile while maintaining acceptable quality and sensory characteristics.

Objective: The objective of this study was to develop fish-enriched chicken nuggets and to evaluate the effects of graded levels of fish meat incorporation on physicochemical, cooking, and sensory attributes during refrigerated storage.

Methods: Chicken nuggets were formulated by replacing chicken meat with fish meat at levels of 2%, 4%, 6%, 8%, and 10%, alongside a control formulation without fish meat. Standardized ingredients were weighed, mixed, blended, and molded into uniform shapes following partial freezing at −18 °C. Nuggets were coated with egg and breadcrumbs, packaged individually in polyethylene bags, and stored under refrigerated conditions for up to 45 days. Samples were evaluated at defined intervals for moisture, pH, ash, protein, fat content, cooking yield, cooking loss, shrinkage, water holding capacity, water retention, emulsion stability, and sensory attributes using a nine-point hedonic scale. Data were statistically analyzed to determine treatment and storage effects.

Results: Increasing fish meat levels and storage duration significantly influenced nugget quality. Moisture content increased from 62.30 ± 2.31 to 71.76 ± 2.07, pH from 6.03 ± 0.06 to 6.40 ± 0.03, ash from 1.59 ± 0.03 to 1.96 ± 0.03, protein from 17.11 ± 0.03 to 20.73 ± 0.53, and fat from 7.78 ± 0.03 to 9.28 ± 0.17. Cooking yield improved from 94.01 ± 0.05 to 97.70 ± 0.86, water holding capacity from 38.10 ± 0.96 to 50.43 ± 1.45, water retention from 84.13 ± 2.46 to 91.10 ± 2.66, and emulsion stability from 94.40 ± 1.06 to 99.13 ± 0.02, while cooking loss declined from 17.89 ± 0.57 to 9.73 ± 0.36. Shrinkage increased from 20.96 ± 0.69 to 27.85 ± 0.57. Sensory attributes differed significantly among treatments, with moderate fish incorporation achieving the highest acceptability scores.

Conclusion: The incorporation of fish meat substantially enhanced the nutritional quality and functional performance of chicken nuggets. A moderate level of fish meat provided the best balance between improved composition and sensory acceptance, supporting the development of healthier, consumer-acceptable meat products.

Keywords: Chicken nuggets, Food formulation, Omega-3 fatty acids, Protein enrichment, Sensory evaluation, Storage stability, Value-added meat products.

INTRODUCTION

Chicken nuggets are widely consumed convenience foods derived from boneless chicken meat that is minced, seasoned, coated, and fried to achieve a characteristic texture and flavor. The term "nugget," originating from "nug," meaning a compact lump or block, reflects their small, uniform form designed for ease of preparation and consumption. Typically formulated with chicken meat, breadcrumbs, eggs, and a blend of spices such as ginger, garlic, turmeric, cumin, onions, green chilies, coriander, lemon, salt, and pepper, chicken nuggets represent a value-added meat product with high consumer acceptance (1). Beyond their sensory appeal, these ingredients contribute functional and nutritional attributes, as spices are recognized for imparting color, aroma, and bioactive properties that may support health (2–4). Spices commonly used in nugget formulations possess documented biological effects. Ginger contains antioxidant compounds such as gingerol and shogaol that protect the gastric mucosa against ulcerogenic agents, while turmeric exhibits anti-inflammatory and antioxidant activities (2). Cumin enhances digestion by stimulating gastrointestinal alpha-amylase activity, onions have been associated with reduced risks of certain cancers and cardiovascular disorders, and garlic demonstrates antimicrobial, hypocholesterolemic, antiplatelet, and antitumor properties (3,4). These functional ingredients not only enhance flavor but also raise interest in optimizing nugget formulations to improve nutritional quality while maintaining consumer acceptability. Among the various nugget types, chicken, beef, mutton, and vegetable—chicken nuggets remain the most popular due to their relatively low fat content, affordability, ease of preparation, and broad market demand (4). Introduced in the 1950s by Robert C. Baker in the United States, chicken nuggets have evolved into globally recognized snack foods and are classified within the cutlet group (5). As ready-to-heat or ready-to-prepare products, they cater to modern dietary patterns by providing quick energy, short-term satiety, and sensory satisfaction, contributing to their rapidly increasing consumption worldwide (6).

Processing techniques play a critical role in determining nugget quality, with coating and frying being particularly influential. Coating serves as a form of value addition, improving product appearance, texture, and acceptability while acting as a barrier that reduces moisture loss and excessive oil absorption during frying (7,8). Edible coatings and enrobing techniques also provide mechanical protection and regulate gas and vapor exchange, thereby enhancing shelf life. Frying further modifies product characteristics by influencing porosity, oil uptake, color, flavor, and overall texture, all of which directly affect consumer perception (8,9). Additionally, cooking methods can alter the chemical composition and nutritional profile of meat products, underscoring the importance of optimizing processing conditions (10). From a nutritional perspective, chicken nuggets are calorie-dense products, with a standard nugget weighing approximately 14–16 g and providing around 54 calories per 15 g. A typical five-piece serving contributes notable amounts of protein and carbohydrates but also contains considerable fat, including saturated fat, raising concerns regarding frequent consumption (11). Nevertheless, chicken meat itself is widely regarded as an affordable and nutrient-dense "white meat," rich in high-quality protein and bioactive compounds such as anserine and creatine, while generally lower in fat compared to red meats (12,13). Global poultry consumption has increased markedly over recent decades, with chicken being the second most consumed meat worldwide and a major contributor to food security, including significant production growth in Pakistan (13,14).

Despite their popularity, chicken meat products are highly perishable, necessitating effective preservation strategies to extend shelf life and ensure safety. Frying reduces water activity and microbial susceptibility, making nuggets a practical means of increasing chicken meat utilization while offering convenience to consumers. However, product quality remains highly dependent on raw material selection and processing methods, and there is growing demand for nuggets with improved nutritional profiles, lower fat content, and enhanced flavor without compromising safety or acceptability (15). In parallel, interest has grown in alternative protein sources such as fish, which is rich in high-quality proteins, long-chain omega-3 polyunsaturated fatty acids (EPA and DHA), and bioavailable minerals that support cardiovascular, immune, and neurological health (13-15). The recognized health benefits of fish components have prompted consideration of their incorporation or comparison with traditional meat products to address nutritional gaps and reduce diet-related disease risks. Against this background, there remains a need to systematically evaluate how ingredient selection and processing strategies influence the nutritional quality, sensory characteristics, and overall acceptability of nugget products. The present study is therefore designed to investigate whether modifications in raw material composition and processing can enhance the nutritional value and quality attributes of nuggets while maintaining consumer preference, with the objective of developing a more health-oriented, acceptable, and sustainable nugget product for contemporary dietary needs.

METHODS

Procurement of Raw Material

All raw materials required for nugget preparation, including fresh chicken meat, fish, ginger, garlic, salt, turmeric powder, black pepper powder, cumin powder, onions, green chilies, coriander leaves, lemon, breadcrumbs, and eggs, were procured from the local retail market of Bahawalpur, Pakistan. Ingredients were selected based on freshness, visual quality, and absence of spoilage to ensure uniformity and safety of the experimental formulations.

Preparation of Chicken Mince and Fish Mince

Boneless chicken meat and fish free from scales and visible impurities were thoroughly washed under running potable water. The cleaned meats were minced separately using an electric meat mincer under hygienic conditions. Following mincing, both chicken and fish mince were washed again to remove residual blood and connective tissue and were allowed to drain excess water prior to further processing.

Preparation of Chopped Onions

Fresh onions were washed, peeled, and cut into small pieces. The chopped onions were further processed using an electric chopper to obtain a uniform fine texture suitable for incorporation into the nugget formulation.

Preparation of Ginger Paste and Garlic Paste

Fresh ginger and garlic bulbs were peeled, cut into small pieces, washed thoroughly, and finely ground using an electric chopper to obtain homogeneous pastes. These pastes were prepared fresh to preserve their functional and sensory properties.

Preparation of Chicken Nuggets

Minced chicken meat was mixed thoroughly with all ingredients except fish meat, followed by marination for uniform distribution of spices and functional components. The marinated mixture was partially cooked in edible oil to stabilize the meat matrix. After cooling, the cooked mince was divided into six experimental groups: control (T_0, 0% fish meat) and treatments T_1, T_2, T_3, T_4, and T_5 containing 2%, 4%, 6%, 8%, and 10% fish meat, respectively, by replacing equivalent amounts of chicken meat. Each formulation was blended uniformly, frozen at −4 °C to facilitate shaping, molded into nugget shapes of uniform size, coated with egg, and breaded with breadcrumbs. The nuggets were individually packed in polyethylene bags and stored under refrigerated conditions at 8 °C. Chemical and sensory evaluations were carried out at 15-day intervals over a storage period of 45 days. The formulation composition for each treatment is presented in Table 01.

Chemical Analysis

All analyses were performed in triplicate, and results were expressed on a percentage basis. Standard laboratory procedures were followed to ensure reproducibility and accuracy.

Moisture Content

Moisture content was determined by using a hot air oven method. Samples were weighed before and after oven drying until constant weight was achieved. Moisture content was calculated using the formula:

$$\text{Moisture content (\%)} = \frac{\text{Initial weight} - \text{final weight}}{\text{Initial weight}} \times 100$$

pH

A 2 g nugget sample was crushed and homogenized with 25 mL of distilled water for 2 minutes. The pH of the homogenate was measured using a calibrated digital pH meter at room temperature.

Ash Content

Ash content was estimated using the muffle furnace method. Approximately 5 g of sample was weighed into pre-weighed crucibles and incinerated at 550 °C for 12–18 hours until white or light gray ash was obtained. Ash content was calculated as:

$$\text{Ash contents (\%)} = \frac{\text{weight of ash}}{\text{weight of sample}} \times 100$$

Protein Content

Protein content was determined using the Kjeldahl method. A 12 g sample was digested with concentrated H_2SO_4, K_2SO_4, and a boiling stone until a clear green solution was obtained. The digest was distilled with NaOH, and liberated ammonia was trapped in boric acid solution and titrated with 0.1 N HCl. Nitrogen content was calculated and multiplied by a conversion factor to obtain crude protein content.

Fat Content

Fat content was estimated using solvent extraction. A 2 g dried sample was extracted using a Soxhlet apparatus with a chloroform–methanol mixture (2:1) for approximately 8 hours. The extracted sample was oven-dried and reweighed. Fat percentage was calculated as:

$$\text{Fat (\%)} = \frac{\text{Sample weight (initial)} - \text{Sample weight (final)}}{\text{Sample weight (final)}} \times 100$$

Cooking Yield

Nuggets were deep-fried at 180 °C for 5 minutes until a core temperature of 73 °C was achieved. After cooling for one hour, the fried nuggets were weighed. Cooking yield was calculated as:

$$\text{Cooking yield (\%)} = \frac{\text{Frying weight}}{\text{Weight before frying}} \times 100$$

Shrinkage

Shrinkage percentage was calculated according to the method of El-Magoli and Hansen (1996). Length, width, and thickness of nuggets were measured before and after cooking, and shrinkage was expressed as:

$$\text{Shrinkage (\%)} = \frac{\text{Thickness after cooking} + \text{Diameter after cooking}}{\text{Thickness before cooking} + \text{Diameter before cooking}} \times 100$$

Cooking Loss

Cooking loss was determined by recording the weight difference between raw and cooked nuggets. Cooking loss percentage was calculated as:

$$\text{Cooking loss (\%)} = \frac{\text{Initial weight} - \text{weight after cooking}}{\text{initial weight}} \times 100$$

Water Holding Capacity

Approximately 5 g of nugget sample was placed in centrifuge tubes and centrifuged at 1000 g for 15 minutes at 5 °C. Water holding capacity was calculated as:

$$\text{Water holding capacity (\%)} = \frac{\text{Centrifuge weight(initial)} - \text{Centrifuge weight(final)}}{\text{Centrifuge weight(initial)}} \times 100$$

Moisture Retention

Moisture retention was calculated using moisture content and cooking yield values of cooked samples as follows:

$$\text{Moisture retention (\%)} = \frac{(\text{\% Cooking yield} \times \text{\% Moisture in cooked product}}{100} \text{x} 100$$

Emulsion Stability

Emulsion stability was determined as an indicator of juiciness. Approximately 25 g of emulsion sample was sealed in polyethylene bags and heated in a thermostatically controlled water bath at 80 °C for 20 minutes. Emulsion stability was calculated using the formula:

$$\text{ES (g 100 g}^{-1}\text{ nugget)} = \frac{(W - W1)}{W} \times 100$$

Sensory Attributes

Sensory evaluation was conducted by a semi-trained panel comprising faculty members and students from the Department of Food Science and Technology, Faculty of Agriculture & Environment, Islamia University of Bahawalpur, Pakistan. Panelists evaluated appearance, aroma, flavor, texture, and overall acceptability using a 9-point hedonic scale, where 9 represented “extremely good” and 1 represented “extremely poor.” Prior to evaluation, panelists were briefed about the assessment procedure, and informed verbal consent was obtained.

Ethical Considerations and Data Analysis

The study involved food product development and sensory evaluation without clinical intervention. Ethical approval was obtained from the Departmental Research Ethics Committee, Faculty of Agriculture & Environment, Islamia University of Bahawalpur. Participation in sensory evaluation was voluntary, and all panelists were informed about the study objectives and product safety. Data obtained from chemical and sensory analyses were statistically analyzed using standard descriptive and inferential statistical methods, with mean values and standard deviations calculated to compare treatments.

Table: Composition for Formulation of Chicken Nuggets Using Fish Mince

Ingredients (g)	Treatments					
	T0	T1	T2	T3	T4	T5
Chicken Meat	500	490	480	470	460	450
Fish meat	-----	10	20	30	40	50
Ginger paste	2.77	2.77	2.77	2.77	2.77	2.77
Garlic Paste	7.33	7.33	7.33	7.33	7.33	7.33
Salt	7.50	7.50	7.50	7.50	7.50	7.50
Turmeric powder	2.73	2.73	2.73	2.73	2.73	2.73
Pepper powder	1.50	1.50	1.50	1.50	1.50	1.50
Cummin powder	1.17	1.17	1.17	1.17	1.17	1.17
Onion (chopped)	10.88	10.88	10.88	10.88	10.88	10.88
Green Chilies	0.63	0.63	0.63	0.63	0.63	0.63
Coriander leaves	0.17	0.17	0.17	0.17	0.17	0.17

RESULTS

Chicken nuggets were produced by progressively replacing chicken meat with fish meat across six formulations (T0–T5) and were evaluated at 0, 15, 30, and 45 days of storage for proximate composition, physicochemical attributes, cooking characteristics, emulsion stability, and sensory quality. Moisture content increased both with higher fish-meat inclusion and with storage time. At day 0, moisture ranged from 62.30±2.31 in T0 to 68.40±0.98 in T5, with intermediate values of 63.10±1.73 (T1), 64.60±0.87 (T2), 65.20±1.45 (T3), and 66.80±1.91 (T4). By day 45, moisture further increased across all treatments, reaching 66.72±2.24 (T0), 67.98±1.36 (T1), 68.59±2.03 (T2), 69.47±2.07 (T3), 70.97±2.38 (T4), and 71.76±2.07 (T5). Similarly, pH increased across treatments and storage duration. At day 0, pH ranged from 6.03±0.06 (T0) to 6.26±0.10 (T5), and at day 45 it ranged from 6.13±0.05 (T0) to 6.40±0.03 (T5), with a gradual stepwise rise from T0 through T5 at each storage point. Ash content increased with higher fish-meat incorporation but declined slightly over storage time within each treatment. At day 0, ash increased from 1.69±0.05 (T0) to 1.96±0.03 (T5). By day 45, ash values were 1.59±0.03 (T0), 1.65±0.05 (T1), 1.68±0.03 (T2), 1.73±0.05 (T3), 1.81±0.05 (T4), and 1.86±0.03 (T5). Protein content also increased with higher fish-meat inclusion and showed a small reduction across storage. At day 0, protein ranged from 17.23±0.35 (T0) to 20.73±0.53 (T5). At day 45, protein was 17.11±0.03 (T0), 17.76±0.04 (T1), 18.29±0.05 (T2), 19.01±0.03 (T3), 19.75±0.03 (T4), and 20.61±0.05 (T5). Fat content followed a similar pattern, increasing with fish-meat level and decreasing slightly during storage. At day 0, fat ranged from 7.85±0.29 (T0) to 9.28±0.17 (T5), and at day 45 it ranged from 7.78±0.03 (T0) to 9.17±0.03 (T5), with intermediate values decreasing marginally over time in all treatments. Cooking performance showed consistent treatment-related differences and storage-related shifts. Cooking yield increased as fish-meat level increased and declined modestly with storage time. At day 0, cooking yield rose from 94.50±2.32 (T0) to 97.70±0.86 (T5). At day 45, cooking yield remained highest in T5 (96.81±0.58) and lowest in T0 (94.01±0.05), with intermediate values of 94.56±0.05 (T1), 95.31±0.04 (T2), 95.78±0.05 (T3), and 96.01±0.04 (T4). Shrinkage increased with fish-meat incorporation and increased with storage time. At day 0, shrinkage ranged from 20.96±0.69 (T0) to 25.12±1.02 (T5), and by day 45 it ranged from 22.91±0.95 (T0) to 27.85±0.57 (T5). Cooking loss showed the reverse pattern: it decreased with increasing fish-meat inclusion but increased with storage time. At day 0, cooking loss declined from 14.56±0.50 (T0) to 9.73±0.36 (T5). By day 45, cooking loss increased within each treatment but remained lowest in T5 (12.09±0.23) and highest in T0 (17.89±0.57), with intermediate day-45 values of 16.87±0.39 (T1), 15.83±0.40 (T2), 14.60±0.55 (T3), and 13.76±0.28 (T4).

Water holding capacity increased with higher fish-meat levels but declined with storage time. At day 0, values ranged from 44.66±1.42 (T0) to 50.43±1.45 (T5). At day 45, water holding capacity reduced to 38.10±0.96 (T0), 39.12±0.90 (T1), 41.07±0.92 (T2), 42.983±1.40 (T3), 43.35±1.51 (T4), and 44.92±1.57 (T5). Water retention showed comparatively smaller separation among treatments but tended to be higher in fish-enriched formulations and declined with storage. At day 0, water retention ranged from 87.80±2.13 (T0) to 91.10±2.66 (T5), and at day 45 from 84.13±2.46 (T0) to 88.98±1.84 (T5). Emulsion stability increased with higher fish-meat inclusion and increased slightly with storage time. At day 0, emulsion stability ranged from 94.40±1.06 (T0) to 97.90±0.97 (T5), and at day 45 from 95.89±0.02 (T0) to 99.13±0.02 (T5). Sensory scores declined with storage time for all attributes, while the best-performing formulation consistently remained T3 across the full storage period. For appearance, day-0 scores ranged from 6.78±0.17 (T5) to 8.40±0.02 (T3), and at day 45 from 6.59±0.11 (T5) to 8.21±0.08 (T3). Aroma followed a similar pattern: day 0 ranged from 7.69±0.07 (T0) to 8.52±0.02 (T3), and day 45 ranged from 7.46±0.04 (T0) to 8.25±0.10 (T3). Flavor scores were highest in T3 at every time point, with day-0 values ranging from 7.23±0.10 (T5) to 8.74±0.06 (T3) and day-45 values ranging from 6.91±0.26 (T5) to 8.56±0.21 (T3). Texture results similarly favored T3, with day-0 values ranging from 7.23±0.12 (T5) to 8.68±0.03 (T3) and day-45 values ranging from 6.59±0.15 (T5) to 8.41±0.15 (T3). Overall acceptability remained highest in T3 throughout storage, with day-0 values ranging from 7.44±0.32 (T5) to 8.55±0.03 (T3) and day-45 values ranging from 7.01±0.15 (T5) to 8.30±0.07 (T3), while all treatments showed gradual score reductions over time.

Table 1: Effect of Treatments and Storage Time on Proximate Composition (%) of Chicken Nuggets

Treatment	Days	Moisture (%)	Ash (%)	Protein (%)	Fat (%)
T0	0	$62.30±2.31^{h}$	$1.69±0.05^{jklmn}$	$17.23±0.35^{klm}$	$7.85±0.29^{jkl}$
	15	$63.42±1.88^{fgh}$	$1.66±0.03^{klmn}$	$17.19±0.03^{lm}$	$7.83±0.03^{kl}$
	30	$65.41±2.14^{defgh}$	$1.62±0.03^{mn}$	$17.16±0.03^{lm}$	$7.81±0.03^{kl}$
	45	$66.72±2.24^{abcdefg}$	$1.59±0.03^{n}$	$17.11±0.03^{m}$	$7.78±0.03^{l}$
T1	0	$63.10±1.73^{gh}$	$1.73±0.05^{ghijklm}$	$17.89±0.73^{ijk}$	$8.21±0.17^{i}$
	15	$64.87±2.25^{efgh}$	$1.71±0.03^{ijklm}$	$17.86±0.04^{ijk}$	$8.19±0.02^{i}$
	30	$66.87±1.49^{bcdefgh}$	$1.67±0.05^{jklmn}$	$17.81±0.04^{ijkl}$	$8.18±0.03^{ij}$
	45	$67.98±1.36^{abcdef}$	$1.65±0.05^{lmn}$	$17.76±0.04^{jklm}$	$8.13±0.04^{ijk}$
T2	0	$64.60±0.87^{efgh}$	$1.78±0.04^{defghij}$	$18.43±0.46^{fghi}$	$8.43±0.23^{ghi}$
	15	$65.91±1.08^{cdefgh}$	$1.75±0.05^{fghijkl}$	$18.39±0.03^{ghij}$	$8.41±0.02^{ghi}$
	30	$67.95±1.82^{abcdef}$	$1.72±0.03^{hijklm}$	$18.35±0.03^{hij}$	$8.38±0.03^{ghi}$
	45	$68.59±2.03^{abcde}$	$1.68±0.03^{jklmn}$	$18.29±0.05^{ij}$	$8.35±0.03^{hi}$
T3	0	$65.20±1.45^{defgh}$	$1.84±0.05^{bcdefg}$	$19.13±0.17^{cde}$	$8.69±0.29^{efg}$

Treatment	Days	Moisture (%)	Ash (%)	Protein (%)	Fat (%)
	15	66.69±1.53^{bcdefgh}	1.81±0.03^{cdefghi}	19.09±0.05^{def}	8.66±0.03^{efgh}
	30	68.49±1.74^{abcde}	1.77±0.03^{efghijk}	19.04±0.03^{efg}	8.61±0.02^{efgh}
	45	69.47±2.07^{abcd}	1.73±0.05^{ghijklm}	19.01±0.03^{efgh}	8.57±0.05^{fgh}
T4	0	66.80±1.91^{bcdefgh}	1.91±0.02^{abc}	19.89±0.61^{b}	8.93±0.17^{bcde}
	15	67.98±0.87^{abcdef}	1.87±0.05^{abcde}	19.85±0.04^{b}	8.91±0.03^{cde}
	30	69.75±1.72^{abcd}	1.83±0.03^{bcdefgh}	19.79±0.05^{bc}	8.88±0.03^{cdef}
	45	70.97±2.38^{ab}	1.81±0.05^{cdefghi}	19.75±0.03^{bcd}	8.84±0.03^{def}
T5	0	68.40±0.98^{abcde}	1.96±0.03^{a}	20.73±0.53^{a}	9.28±0.17^{a}
	15	68.86±1.10^{abcde}	1.93±0.03^{ab}	20.69±0.03^{a}	9.25±0.03^{ab}
	30	70.34±1.86^{abc}	1.89±0.05^{abcd}	20.65±0.04^{a}	9.21±0.05^{abc}
	45	71.76±2.07^{a}	1.86±0.03^{abcdef}	20.61±0.05^{a}	9.17±0.0^{3abcd}

Values are mean ± S.E (n = 3). Different superscript letters within a column indicate significant differences ($p < 0.05$).

Table 2: Effect of Treatments and Storage Time on Cooking Characteristics (%) of Chicken Nuggets

Treatment	Days	Cooking Yield (%)	Shrinkage (%)	Cooking Loss (%)
T0	0	94.50±2.32^{ghi}	20.96±0.69^{j}	14.56±0.50^{efg}
	15	94.47±0.58^{hi}	21.12±0.72^{ij}	15.51±0.47^{cde}
	30	94.37±0.03^{hi}	22.01±0.77^{hij}	16.32±0.50^{bc}
	45	94.01±0.05^{i}	22.91±0.95^{fghij}	17.89±0.57^{a}
T1	0	95.10±1.10^{defghi}	21.22±1.13^{ij}	13.71±0.43^{ghi}
	15	94.98±0.05^{efghi}	22.29±0.58^{ghij}	14.71±0.42^{defg}
	30	94.76±0.05^{fghi}	23.29±0.62^{efghij}	15.59±0.45^{cde}
	45	94.56±0.05^{ghi}	23.87±0.83^{defgh}	16.87±0.39^{ab}
T2	0	95.80±1.69^{abcdefghi}	22.12±0.87^{hij}	12.97±0.44^{hij}
	15	95.62±0.05^{abcdefghi}	23.35±0.96^{efghi}	13.97±0.44^{fgh}
	30	95.48±0.05^{bcdefghi}	24.32±0.65^{defgh}	14.98±0.57^{def}
	45	95.31±0.04^{cdefghi}	24.65±0.70^{cdefg}	15.83±0.40^{bcd}
T3	0	96.40±1.29^{abcdefgh}	23.32±0.94^{efghij}	11.76±0.49^{jklm}
	15	96.22±0.04^{abcdefgh}	24.23±0.61^{bcdef}	12.56±0.57^{ijk}
	30	95.99±0.05^{abcdefghi}	25.13±0.87^{bcdef}	13.97±0.31^{fgh}
	45	95.78±0.05^{abcdefghi}	25.83±0.79^{abcd}	14.60±0.55^{defg}
T4	0	97.10±0.55^{abcd}	24.11±0.98^{defgh}	10.98±0.56^{lm}

Treatment	Days	Cooking Yield (%)	Shrinkage (%)	Cooking Loss (%)
	15	96.88 ± 0.60^{abcde}	25.31 ± 1.06^{bcde}	11.98 ± 0.44^{jklm}
	30	96.58 ± 0.05^{abcdefg}	26.11 ± 0.62^{abcd}	12.94 ± 0.38^{hij}
	45	96.01 ± 0.04^{abcdefghi}	26.91 ± 0.51^{abc}	13.76 ± 0.28^{fghi}
T5	0	97.70 ± 0.86^{a}	25.12 ± 1.02^{bcdef}	9.73 ± 0.36^{n}
	15	97.56 ± 0.05^{ab}	26.15 ± 1.08^{abcd}	10.79 ± 0.29^{mn}
	30	97.26 ± 0.05^{abc}	27.05 ± 0.69^{ab}	11.56 ± 0.32^{klm}
	45	96.81 ± 0.58^{abcdef}	27.85 ± 0.57^{a}	12.09 ± 0.23^{jkl}

Values are mean ± S.E. (n = 3). Different superscript letters within a column indicate significant differences ($p < 0.05$).

Table 3: Effect Of Treatments and Storage Time on Ph of Chicken Nuggets

Treatments	Days			
	0	15	30	45
T0	6.03 ± 0.06^{i}	6.06 ± 0.07^{hi}	6.10 ± 0.05^{fghi}	6.13 ± 0.05^{efghi}
T1	6.07 ± 0.07^{ghi}	6.11 ± 0.09^{cdfghi}	6.15 ± 0.06^{fghi}	6.19 ± 0.04^{bcdefghi}
T2	6.13 ± 0.05^{efghi}	6.17 ± 0.05^{cdefghi}	6.21 ± 0.05^{bcdefgh}	6.24 ± 0.06^{abcdefg}
T3	6.18 ± 0.08^{cdefghi}	6.23 ± 0.05^{abcdefgh}	6.27 ± 0.05^{abcdef}	6.32 ± 0.05^{abcd}
T4	6.21 ± 0.10^{bcdefgh}	6.25 ± 0.04^{abcdef}	6.31 ± 0.04^{abcd}	6.36 ± 0.07^{ab}
T5	6.26 ± 0.10^{abcdef}	6.30 ± 0.05^{abcde}	6.34 ± 0.03^{abc}	6.40 ± 0.03^{a}

*Each value is mean of 3± S.E

Table 4: Effect of Treatments and Storage Time on Water Binding Properties and Emulsion Stability (%) of Chicken Nuggets

Treatment	Days	Water Holding Capacity (%)	Water Retention (%)	Emulsion Stability (%)
T0	0	44.66 ± 1.42^{cdefg}	87.80 ± 2.13^{ab}	94.40 ± 1.06^{c}
	15	42.51 ± 1.59^{fghi}	86.43 ± 2.44^{ab}	95.11 ± 2.00^{bc}
	30	40.11 ± 0.86^{ijk}	85.01 ± 2.70^{ab}	95.37 ± 1.44^{bc}
	45	38.10 ± 0.96^{k}	84.13 ± 2.46^{b}	95.89 ± 0.02^{abc}
T1	0	45.23 ± 0.72^{cdefg}	88.20 ± 2.30^{ab}	95.10 ± 1.86^{bc}
	15	43.12 ± 0.93^{efghi}	87.02 ± 2.26^{ab}	95.87 ± 2.25^{abc}
	30	41.11 ± 0.50^{hijk}	86.52 ± 2.25^{ab}	96.11 ± 1.86^{abc}
	45	39.12 ± 0.90^{jk}	85.32 ± 2.49^{ab}	96.99 ± 1.13^{abc}

Treatment	Days	Water Holding Capacity (%)	Water Retention (%)	Emulsion Stability (%)
T2	0	46.07±1.98^{bcde}	88.90±1.88^{ab}	95.80±1.06^{abc}
	15	44.07±0.82^{defgh}	87.91±1.96^{ab}	96.01±1.80^{abc}
	30	42.07±1.40^{ghij}	86.97±3.09^{ab}	96.96±1.74^{abc}
	45	41.07±0.92^{hijk}	86.21±1.31^{ab}	97.52±0.05^{abc}
T3	0	47.78±1.42^{abc}	89.50±1.96^{ab}	96.30±0.82^{abc}
	15	45.98±1.14^{bcde}	88.15±1.30^{ab}	96.99±1.66^{abc}
	30	43.98±0.79^{defgh}	87.01±0.65^{ab}	97.23±1.21^{abc}
	45	42.983±1.40^{efghi}	86.94±2.13^{ab}	98.29±0.05^{abc}
T4	0	48.98±1.35^{ab}	90.30±3.51^{ab}	97.10±1.66^{abc}
	15	47.35±0.72^{abc}	89.01±2.95^{ab}	97.54±1.21^{abc}
	30	45.35±1.13^{cdef}	88.45±2.87^{ab}	97.87±0.98^{abc}
	45	43.35±1.51^{efghi}	87.21±1.86^{ab}	99.01±0.02^{ab}
T5	0	50.43±1.45^{a}	91.10±2.66^{a}	97.90±0.97^{abc}
	15	48.92±1.06^{ab}	90.31±1.14^{ab}	98.01±0.93^{abc}
	30	46.92±0.86^{bcd}	89.21±2.24^{ab}	98.23±0.66^{abc}
	45	44.92±1.57^{cdefg}	88.98±1.84^{ab}	99.13±0.02^{a}

Values are mean ± S.E. (n = 3). Different superscript letters within a column indicate significant differences ($p < 0.05$).

Table 5: Effect of Treatments and Storage Time on Appearance of Chicken Nuggets

Treatment	Days			
	0	15	30	45
T0	7.81±0.30^{b}	7.73±0.12^{b}	7.65±0.14^{b}	7.59±0.15^{b}
T1	7.87±0.28^{b}	7.81±0.07^{b}	7.72±0.09^{b}	7.65±0.21^{b}
T2	7.92±0.14^{b}	7.86±0.06^{b}	7.76±0.09^{b}	7.69±0.11^{b}
T3	8.40±0.02^{a}	8.30±0.09^{a}	8.25±0.13^{a}	8.21±0.08^{a}
T4	6.98±0.44^{cd}	6.91±0.01^{cd}	6.85±0.12^{cd}	6.79±0.07^{cd}
T5	6.78±0.17^{cd}	6.72±0.12^{cd}	6.66±0.12^{cd}	6.59±0.11^{cd}

*Each value is mean of 5± S.E

Table 6: Effect of Treatments and Storage Time on Sensory Attributes of Chicken Nuggets

Treatment	Days	Aroma	Flavor	Texture	Overall Acceptability
T0	0	7.69±0.07^{defgh}	7.59±0.05^{cdefg}	7.78±0.13^{bcd}	7.79±0.09^{bcd}
	15	7.61±0.12^{fghi}	7.52±1.30^{defgh}	7.71±0.14^{bcde}	7.59±0.04^{cdefg}

Treatment	Days	Aroma	Flavor	Texture	Overall Acceptability
	30	7.53 ± 0.18^{ghi}	7.41 ± 0.22^{efghi}	7.71 ± 0.13^{bcde}	7.39 ± 0.05^{efgh}
	45	7.46 ± 0.04^{i}	7.26 ± 0.12^{ghijk}	7.59 ± 0.18^{cdef}	7.19 ± 0.25^{hi}
T1	0	7.78 ± 0.06^{bcdef}	7.71 ± 0.06^{bcde}	7.87 ± 0.28^{bc}	7.88 ± 0.01^{bc}
	15	7.68 ± 0.12^{defgh}	7.65 ± 0.09^{bcdef}	7.79 ± 0.08^{bcd}	7.68 ± 0.19^{bcde}
	30	7.59 ± 0.17^{fghi}	7.53 ± 0.15^{defgh}	7.79 ± 0.05^{bcd}	7.48 ± 0.13^{defgh}
	45	7.51 ± 0.13^{hi}	7.42 ± 0.20^{efghi}	7.65 ± 0.17^{bcde}	7.28 ± 0.18^{ghi}
T2	0	7.94 ± 0.02^{b}	7.98 ± 0.09^{b}	7.99 ± 0.25^{b}	7.99 ± 0.06^{bcd}
	15	7.71 ± 0.11^{cdefg}	7.93 ± 0.10^{bc}	7.81 ± 0.07^{bcd}	7.79 ± 0.14^{b}
	30	7.73 ± 0.06^{cdef}	7.86 ± 0.27^{bcd}	7.81 ± 0.10^{bcd}	7.59 ± 0.18^{cdefg}
	45	7.65 ± 0.09^{efghi}	7.76 ± 0.17^{bcde}	7.69 ± 0.19^{bcde}	7.39 ± 0.11^{efgh}
T3	0	8.52 ± 0.02^{a}	8.74 ± 0.06^{a}	8.68 ± 0.03^{a}	8.55 ± 0.03^{a}
	15	8.37 ± 0.05^{a}	8.61 ± 0.05^{a}	8.60 ± 0.04^{a}	8.49 ± 0.08^{a}
	30	8.31 ± 0.04^{a}	8.60 ± 0.21^{a}	8.53 ± 0.09^{a}	8.41 ± 0.14^{a}
	45	8.25 ± 0.10^{a}	8.56 ± 0.21^{a}	8.41 ± 0.15^{a}	8.30 ± 0.07^{a}
T4	0	7.86 ± 0.11^{bcd}	7.45 ± 0.20^{efgh}	7.47 ± 0.24^{defg}	7.66 ± 0.11^{defgh}
	15	7.81 ± 0.04^{bcde}	7.32 ± 0.31^{fghij}	7.39 ± 0.28^{efg}	7.46 ± 0.09^{bcdef}
	30	7.76 ± 0.05^{bcdef}	7.24 ± 0.12^{ghijk}	7.39 ± 0.24^{efg}	7.29 ± 0.14^{ghi}
	45	7.69 ± 0.10^{defgh}	7.09 ± 0.28^{ijk}	6.79 ± 0.22^{hi}	7.15 ± 0.28^{hi}
T5	0	7.89 ± 0.09^{bc}	7.23 ± 0.10^{hijk}	7.23 ± 0.12^{fg}	7.44 ± 0.32^{efgh}
	15	7.76 ± 0.04^{bcdef}	7.19 ± 0.08^{hijk}	7.15 ± 0.16^{gh}	7.32 ± 0.24^{fghi}
	30	7.69 ± 0.07^{defgh}	7.03 ± 0.18^{jk}	7.15 ± 0.18^{gh}	7.21 ± 0.16^{hi}
	45	7.59 ± 0.11^{fghi}	6.91 ± 0.26^{k}	6.59 ± 0.15^{i}	7.01 ± 0.15^{i}

Values are mean ± S.E. (n = 5). Different superscript letters within a column indicate significant differences ($p < 0.05$).

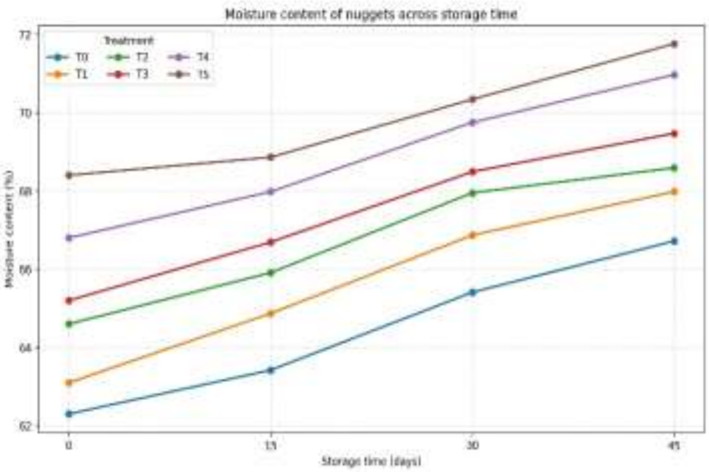

Figure 2 Moisture Content of Nuggets Across Storage Time

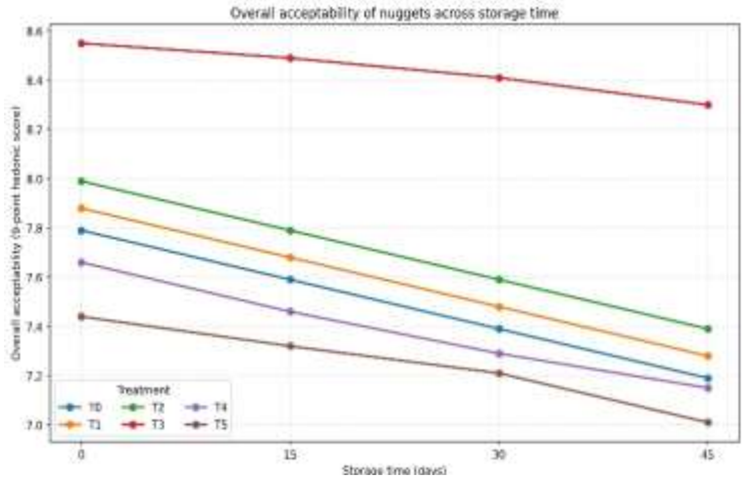

Figure 2 Overall Acceptability of Nuggets Across Storage Time

DISCUSSION

The present findings indicated that partial replacement of chicken meat with fish meat consistently shifted the nuggets toward a more moisture- and nutrient-dense profile, while storage time exerted a separate, progressive influence on stability-related attributes. Across treatments, higher fish inclusion produced higher moisture, protein, ash, and fat values, alongside higher pH, improved cooking yield, greater water holding capacity, and stronger emulsion stability. These directional changes were biologically plausible because fish muscle typically contains highly functional myofibrillar proteins with strong water-binding behavior and an emulsifying capacity that can improve batter–meat matrix integrity during heating and frying. Comparable improvements in water binding and cooking performance have been reported when functional ingredients or reformulation strategies were used to enhance nugget matrices, supporting the interpretation that protein–water interactions were central to the improved yields and reduced losses observed in fish-enriched samples (15,16). A consistent increase in pH with both increasing fish proportion and longer storage suggested progressive accumulation of alkaline nitrogenous compounds during refrigerated holding, a phenomenon widely linked to seafood and mixed-meat systems where trimethylamine and related volatiles may rise over time. Even though the absolute pH values remained within the expected range for comminuted poultry products, the upward drift over 45 days was aligned with earlier reports in nugget systems where quality changes during cold storage were tracked alongside chemical stability indices (17). From a product-quality standpoint, the increase in moisture content during storage observed here was notable because many fried, breaded products tend to lose free water over time; however, if packaging limited dehydration while protein matrices continued to relax or redistribute bound water, an apparent rise in measured moisture could occur. This pattern strengthened the case for adding objective shelf-life markers (microbial load and oxidation indices) in future work to ensure that compositional shifts did not mask deterioration.

The cooking characteristics showed a coherent pattern: higher fish substitution was associated with higher cooking yield and lower cooking loss, while storage time reduced yield and increased loss. These results were consistent with a mechanism in which fish-derived proteins and lipids improved water and fat retention during frying, reducing exudation and drip loss. Similar relationships between formulation strategies, reduced cooking loss, and improved structural integrity have been demonstrated in recent nugget-oriented preservation and reformulation work, including ingredient systems designed to stabilize the matrix during frozen or chilled storage (18). At the same time, shrinkage increased with fish level and storage duration. This apparent contradiction—higher yields alongside higher shrinkage—was still physiologically reasonable because shrinkage reflects dimensional change (protein contraction and matrix tightening) rather than mass loss alone; a tighter gel network may contract yet still retain more moisture internally, particularly when emulsions remain stable. The emulsion stability increased with fish inclusion and rose slightly over storage, suggesting that the fat–protein matrix remained cohesive and may have strengthened as the system equilibrated. Related literature on fish-oil enrichment and encapsulation in nuggets emphasized that lipid phase management can strongly influence stability, oxidation, and sensory outcomes, particularly under cold storage (19). Importantly, the present study did not quantify oxidation (e.g., TBARS, peroxide value) or microbial dynamics, which are critical in products containing fish lipids that may oxidize readily. Studies that incorporated fish oil into nuggets typically included oxidation and microbiology precisely because sensory declines can be driven by rancidity and spoilage volatiles even when basic proximate metrics appear acceptable (19).

Sensory outcomes added an important practical dimension. The mid-level fish formulation (T3) repeatedly achieved the highest scores for appearance, aroma, flavor, texture, and overall acceptability across storage, while higher fish levels (T4–T5) tended to score lower. This pattern supported a common product-development trade-off: nutritional enhancement and functional gains can be achieved with greater fish inclusion, but sensory penalties may emerge due to stronger fishy notes, altered color, or changes in mouthfeel. Modern stabilization strategies (antioxidant coatings, essential oil systems, or encapsulation approaches) have been used to maintain sensory quality in nugget products during storage and could be tested to preserve the advantages of higher fish incorporation without compromising acceptability, Different cooking techniques can also alter the chemical composition, texture, flavor, and overall acceptability of meat products. The nutritional quality of animal-based foods is highly affected by sex, parities, enzymes and hormonal changes (20,21). The study had several strengths. It used graded substitution levels, evaluated multiple physicochemical and cooking-performance metrics alongside sensory testing, and monitored changes at regular storage intervals, allowing a clear separation of formulation effects from time-dependent trends. However, key limitations constrained interpretation of shelf-life and safety. Storage at 8 °C was higher than standard refrigeration practice for meat products, which could accelerate microbial growth and biochemical changes; this temperature choice therefore limited direct generalization to typical cold-chain conditions. Additionally, the absence of microbial counts, lipid oxidation indices, instrumental color, and objective texture profiling reduced the ability to explain why sensory scores declined and to validate stability in fish-enriched formulations. Panel composition was limited to a single academic setting, which may not reflect broader consumer preferences, and the work did not report fatty-acid profiling, which would be central to substantiating omega-3–related nutritional claims. Future research could strengthen the evidence base by storing products at ≤4 °C under standardized packaging (vacuum or modified-atmosphere systems), and by integrating microbial (TPC, psychrotrophs), oxidative (TBARS/peroxide value), and instrumental quality (L*a*b* color, texture profile analysis) endpoints. Incorporating antioxidants or encapsulation strategies specifically designed for marine lipids may further reduce off-flavor development and extend sensory shelf-life (23). Collectively, the present data supported a practical formulation window in which moderate fish substitution optimized acceptability while still improving functional quality, and they established a clear foundation for more comprehensive shelf-life and nutritional validation in subsequent studies.

CONCLUSION

The findings of this study demonstrated that the incorporation of fish meat into chicken nuggets is a practical and effective approach to enhancing their overall nutritional and functional quality without compromising consumer acceptability. The formulation of chicken nuggets with varying proportions of fish meat influenced key quality attributes, including physicochemical characteristics, cooking performance, and sensory perception. Notably, a moderate level of fish meat addition achieved an optimal balance between improved nutritional value and desirable sensory properties, resulting in the highest consumer preference. These outcomes highlight the potential of fish meat as a functional ingredient in the development of healthier, value-added meat products and support its application in the formulation of nutritionally enriched chicken nuggets that align with contemporary consumer demands for both quality and healthfulness.

AUTHOR CONTRIBUTIONS

Author	Contribution
Sehar Zafar	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Jahanzaib Khaliq*	Substantial Contribution to study design, acquisition and interpretation of Data

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	Critical Review and Manuscript Writing Has given Final Approval of the version to be published
Muhammad Ismail	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Tayyab Ahmad	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Ikram Ullah	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Abdur Rahman	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published
Talal Maqbool	Contributed to study concept and Data collection Has given Final Approval of the version to be published
Masroor Ali	Writing - Review & Editing, Assistance with Data Curation
Zia ur Rehman	Writing - Review & Editing, Assistance with Data Curation
Muhammad Umar Farooq	Writing - Review & Editing, Assistance with Data Curation
Muhammad Abbas	Writing - Review & Editing, Assistance with Data Curation
Muhammad Sadiq	Writing - Review & Editing, Assistance with Data Curation

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