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Formulation of Chicken Nuggets Supplemented with Mutton and Fish Livers: Insights from Antioxidant and Textural Studies

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ABSTRACT: The use of byproducts from the food industry and the investigation of substitute sources are becoming progressively significant in fulfilling the consumer demand for animal-based protein. This study aimed to investigate the nutritional value of mutton and fish livers and their future application as a source of high-added-value proteins for supplement formulation. We performed compositional analysis (moisture, ash, crude protein, crude fat), free fatty acid (FFA) analysis, and 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay, and the color, peroxide value (POV), and total phenolic composition (TPC) were assessed to evaluate the nutritional value and shelf stability of mutton and fish livers. The optimized proximate and kinetics were later used to develop chicken nuggets with different percentages of mutton and fish liver added. The formulation was tested for the textural and organoleptic properties of value-added chicken nuggets that predict consumer acceptability. Comparative analysis of the variance between mutton and fish liver showed a highly significant ($P<0.01$) decrease in moisture, ash, protein, fat, DPPH, and TPC at different days and hours. The mutton liver had relatively high antioxidant potential (25.9% DPPH and 154-mg GAE/100 g TPC) compared with the fish liver. However, the fish liver's FFA and POV (2.4% for both) were higher than those of the mutton liver. The results showed that, after formulation, an increase in the amount of liver led to a highly significant ($P<0.01$) rise in the nutritional value of the nuggets, including a 1.5%~2.0% increase in protein content. This research indicates that valuing mutton and fish liver as a protein replacer in processed foods can be useful in developing healthy food products.

Keywords: antioxidant activity, fish liver, mutton liver, nuggets, nutritional value

INTRODUCTION

Meat processing plants and slaughterhouses produce nearly 150 million tons of liquid and solid byproducts every year (Limeneh et al., 2022). In addition, importers, renderers, and distributors produce a significant quantity of byproducts (Pame et al., 2023). Currently, processors produce a large amount of food that generates millions of tons of processing waste, whose disposal is a major issue for manufacturers (Gregson et al., 2015). Food waste and disposal rates worldwide are higher than 20%, with the cost of waste reaching as high as 2.5 trillion USD. Although most nations have established targets to eliminate the wastage of byproducts, very little change has been observed (FAO et al., 2020). The increasing global population demands an accessible, cheap, safe, nutritious, and sustainable source of protein for the human diet. Animal-based proteins account for 40% of total global protein consumption (Ribeiro et al., 2022). This percentage is expected to increase due to consumers' rising living standards and the demand for protein-rich foods (Lynch et al., 2018). Therefore, the constant increase in the global population demands a sustainable source of animal-based protein to fulfill consumer demands.

Meat byproducts, such as offal, bone, and fat, are an important source of protein and other nutrients and can be used in various food and nonfood products (Zaman et al., 2023). Using meat byproducts can help reduce waste and improve the sustainability of the meat industry. By using all parts of the animal, including those not traditionally used for human consumption, the industry can reduce the amount of waste generated and decrease its environmental impact. Many cultures consume meat byproducts or processed foods as part of their diet. Vitamins, proteins,

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vital amino acids, fats, minerals, and trace elements are abundant in such byproducts, giving them a high nutritional value (Alao et al., 2017). The liver, heart, kidneys, and other organs are rich in vitamins and minerals such as iron, zinc, and vitamin A, are a good source of protein, and can be consumed as part of a balanced diet (Rao et al., 2021). Moreover, they can be processed into various food products such as sausages, meatballs, burgers, and other processed food products. As a result, the ratio of food waste production to protein malnutrition worldwide can be reduced, and the sustainable development goal of zero hunger can be achieved (Byerlee and Fanzo, 2019). The liver is considered to be one of the most valuable and consumable byproducts that contain relatively high protein proportions, low levels of saturated fatty acids, and high levels of iron, creatine, taurine, and carnosine (Steen et al., 2016), although the liver's nutritional content varies from animal to animal. Liver is also abundant in vitamins A, B, C, and D and minerals such as copper, iron, and zinc. Liver is especially enriched in vitamins A and B12 and iron. The liver can be consumed directly or through processed food (Alao et al., 2017).

Beef liver (Soladoye et al., 2022), chicken liver (Henry et al., 2019), and pork liver (Mora et al., 2019) are utilized in many processed foods and have been studied extensively. However, the literature on mutton and fish livers is scarce. Because mutton and fish livers also have a high nutritional value, the present study focused on the valorization of these livers. We focused on characterizing mutton and fish livers under different storage periods and refrigeration temperatures. The sensory attributes, nutritional value, biochemical properties, and antioxidant potential of the developed chicken nuggets with added mutton and fish livers were evaluated.

MATERIALS AND METHODS

Materials

Fresh mutton and fish liver samples were purchased from a slaughterhouse. The samples were transported to the laboratory on dry ice. The samples were packaged in airtight containers and stored at 4°C. All chemicals used in the experiments were of analytical grade. The analytical reagents included copper sulfate, sulfuric acid, boric acid, sodium hydroxide, ethanol, n-hexane, Tris-base, sodium carbonate, gallic acid, 2,2-diphenyl-1-picrylhydrazyl (DPPH), Folin-Ciocalteu reagent, acetic acid, chloroform, potassium iodide, starch, sodium thiosulfate, and phenolphthalein were purchased from Sigma-Aldrich. Lean chicken meat, premium chicken skin, ice-cold water, vinegar, green chilies, premixed spices, and texturized vegetable protein were used to prepare the chicken nuggets.

Physicochemical properties

***Proximate analysis*:** For the proximate analysis, we prepared the samples by finely mincing them. Within the storage period of 7 days, proximate analysis of the mutton and fish livers, including the analysis of the moisture, ash, crude fat, and crude protein contents, was performed as per Association of Analytical Chemists methods 930.15, 942.05, 920.39, and 984.13, respectively. These analyses were also performed for the supplemented chicken nuggets.

***Biochemical properties*:** The biochemical properties were determined by evaluating the peroxide value (POV) and free fatty acid (FFA), as described by Akhter et al. (2022). The POV and FFA of mutton and fish livers were determined within the storage period of 7 days. The POV and FFA of the supplemented chicken nuggets were also evaluated to determine the oxidation state of the product.

***Antioxidant potential*:** The antioxidant potential of the fish and mutton livers was determined by DPPH and total phenolic composition (TPC) assays (Wong-Paz et al., 2015). The same methods were used for the supplemented chicken nuggets.

For the DPPH assay, 25 μL of the homogenized sample was mixed with 1 mL of freshly prepared DPPH solution and 0.25 mL of Tris-HCl buffer, and the absorbance at 0 and 30 min was measured at 517 nm under dark conditions. The scavenging activity was calculated as the decrease in absorbance.

To determine the TPC, 0.5 mL of homogenized sample was mixed with 2.5 mL of 10% Folin-Ciocalteu reagent, and after a continual interval of 5 min, 2.5 mL of 7.5% sodium carbonate was added. The solution was then mixed thoroughly and incubated at 45°C for 45 min in a water bath. The absorbance was measured at 765 nm, and the reading was then compared with the standard curve of gallic acid.

Protein half-life determination in both types of liver

Protein content was the primary marker for the degradation studies to evaluate the shelf stability of the liver, and the analyses were performed on days 0, 1, 3, 5, and 7. The studies were performed at a storage temperature of 4°C.

Formulation of chicken nuggets

After nutritional profiling of mutton and fish livers, different treatments of supplemented chicken nuggets were prepared by the addition of whole liver. The treatments were named as follows: T_{+ve} (containing texturized soya protein), T_{-ve} (no texturized soya protein), T_1 (5% liver added), T_2 (10% liver added), and T_3 (15% liver added). Chicken nuggets were manufactured at Quick Foods Pvt. Ltd. according to the standard recipe presented in Table 1.

Table 1. Standard recipe for chicken nuggets

Ingredient	Negative control (%)	Positive control (%)	T_1	T_2	T_3
Chicken breast boneless	65	62	60	55	50
Chicken skin premium	10	10	10	10	10
Water/ice	20	20	20	20	20
Vinegar	0.5	0.5	0.5	0.5	0.5
Green chili	0.5	0.5	0.5	0.5	0.5
Premix	5	5	5	5	5
Liver (5%)			5		
Liver (10%)				10	
Liver (15%)					15
Texturized soy protein		3			
Total	100	100	100	100	100

T_1, 5% of liver addition; T_2, 10% of liver addition; T_3, 15% of liver addition.

Instrumental color analysis

The instrumental color analysis of the L^* a^* b^* values of the supplemented chicken nuggets was performed according to the method described by Abd-El-Aziz et al. (2022) with the help of a standardized colorimeter (CR-20, Konica Minolta). L^* values are a measure of the lightness, a^* values describe the measure of redness, and b^* values represent the measure of yellowness. A white background was used to avoid color reflection, and the instrument was placed on the sample's surface at three different points. All readings were taken in triplicate.

Texture profiling of the supplemented chicken nuggets

The texture analysis followed the methodology of Rubab et al. (2020). The following parameters were determined using a texture analyzer (FRTS-50N, IMADA Co., Ltd.): hardness, springiness, cohesiveness, chewiness, and gumminess. The texture analyzer was set at the same displacement (5 mm), compression speed (2.0 mm/sec), and probe diameter (20 mm) for all treatments. After applying the force on the supplemented chicken nuggets through the probe, a graph was constructed with the help of FRTS software.

Sensory evaluation of the supplemented chicken nuggets

The 9.0 hedonic scale was used to record the assessments of the supplemented chicken nuggets following the method of Wichchukit and O'Mahony (2015). A trained panel performed the sensory evaluation, and the sensory traits, including appearance, shape, texture, color, juiciness, flavor, aftertaste, and overall acceptability, were recorded.

Institutional review board statement

The Ethical Review Committee of the University of Management and Technology, Lahore, Pakistan, approved the sensory evaluation of the supplemented chicken nuggets. The approval number was UMT/IRB/PostGrad/Res/2022-01-R005. This study was conducted in accordance with the Declaration of Helsinki.

Statistical analysis

Analysis of variance tests were used to analyze the characterization data. The least significant difference test was used to compare the physicochemical properties of the two types of liver and the different treatments of supplemented chicken nuggets with a 95% confidence level.

RESULTS

Physicochemical properties

***Proximate analysis*:** Table 2 shows the mean moisture, ash, fat, and protein contents of the mutton and fish livers at different storage times. The mean moisture, ash, fat, and protein content of mutton and fish livers significantly ($P<0.05$) varied over the 7 days of storage. The moisture contents of the mutton and fish livers decreased from 72.6% to 69.8% and from 78.1% to 74.6%, respectively over the 7 days of storage. The high moisture loss led to a highly significant ($P<0.01$) decline in the amount of ash in the fish liver: from 1.5% to 1.1% during the 7 days of storage. The same trend was observed for the ash content of the mutton liver, which declined significantly ($P<0.01$) from 1.6% to 1.3% over the 7 days of storage. Similarly, a highly significant decrease ($P<0.01$) was observed in the fat content of both the mutton and fish livers, from 8.4% to 6.4% and from 14.4% to 6.6%, respectively. Moreover, the protein level in both livers significantly decreased ($P<0.01$) over the 7 days of storage: from 17.9% to 13.6% for the mutton liver and from 11.9% to 7.7% for the fish liver.

The moisture, ash, fat, and protein contents of chicken nuggets supplemented with different amounts of mutton and fish liver, along with their positive and negative controls are also presented in Table 2. There was a highly significant ($P<0.01$) increase in the moisture content of the chicken nuggets, from 59.5% to 63.5%, with an incremental increase in liver concentration. Moreover, the moisture content of the supplemented chicken nuggets was

Table 2. Proximate composition of both livers and supplemented chicken nuggets

Sample	Day/treatment	Moisture	Ash	Crude fat	Crude protein
Mutton liver	Day 0	72.6±0.50^{a}	1.61±0.02^{a}	8.41±0.10^{a}	17.9±0.21^{a}
	Day 1	72.0±0.32^{ab}	1.60±0.04^{a}	8.10±0.51^{ab}	17.0±0.32^{b}
	Day 3	71.5±0.90^{b}	1.50±0.02^{b}	7.71±0.32^{bc}	15.9±0.21^{c}
	Day 5	71.3±0.52^{b}	1.41±0.03^{c}	7.01±0.51^{cd}	14.8±0.32^{d}
	Day 7	69.8±0.31^{c}	1.32±0.02^{d}	6.42±0.31^{d}	13.6±0.31^{e}
Fish liver	Day 0	78.0±0.30^{a}	1.51±0.01^{a}	14.4±0.51^{a}	11.9±0.05^{a}
	Day 1	77.2±0.31^{ab}	1.51±0.03^{b}	13.2±0.40^{b}	10.9±0.04^{b}
	Day 3	76.5±0.82^{bc}	1.42±0.02^{c}	11.6±0.22^{c}	9.80±0.07^{c}
	Day 5	75.5±0.91^{cd}	1.31±0.01^{d}	9.50±0.53^{d}	8.90±0.04^{d}
	Day 7	74.6±0.93^{d}	1.10±0.02^{e}	6.60±0.31^{e}	7.71±0.10^{e}
CN-ML	Negative control	57.3±0.31^{a}	1.61±0.01^{a}	13.2±0.21^{a}	11.8±0.21^{a}
	Positive control	53.4±0.50^{b}	1.64±0.11^{ab}	12.6±0.40^{b}	11.9±0.11^{a}
	T_1	59.5±0.30^{c}	1.80±0.01^{b}	14.5±0.30^{c}	11.9±0.02^{c}
	T_2	61.2±0.21^{d}	1.83±0.01^{c}	15.4±0.41^{d}	12.6±0.04^{c}
	T_3	63.5±0.32^{e}	1.85±0.01^{d}	16.6±0.20^{d}	13.9±0.04^{c}
CN-FL	Negative control	57.3±0.31^{a}	1.61±0.01^{a}	13.2±0.21^{a}	11.8±0.21^{a}
	Positive control	53.4±0.51^{b}	1.64±0.04^{b}	12.6±0.41^{b}	11.9±0.11^{a}
	T_1	62.3±0.80^{c}	1.71±0.01^{c}	19.0±0.07^{c}	10.5±0.30^{b}
	T_2	65.0±0.60^{d}	1.74±0.01^{d}	20.1±0.21^{d}	11.8±0.11^{b}
	T_3	67.4±0.51^{e}	1.79±0.01^{e}	21.1±0.31^{e}	12.6±0.20^{c}

Values are presented as mean±SD.
Different notations (a-e) show the significant differences in the proximate composition of both livers and supplemented nuggets. CN-ML, chicken nuggets supplemented with mutton liver; CN-FL, chicken nuggets supplemented with fish liver; T_1, 5% of liver addition; T_2, 10% of liver addition; T_3, 15% of liver addition.

higher than that of the positive and negative controls, which had moisture contents of 53.4% and 57.3%, respectively. Likewise, in chicken nuggets supplemented with fish liver, the moisture content was increased significantly (P<0.01), from 62.3% to 67.4%, as the proportion of added fish liver was increased from 5% to 15%.

The ash contents of the positive and negative controls were 1.61% and 1.64%, respectively. However, the ash content was significantly (P<0.01) increased in the supplemented chicken nuggets (from 1.80% to 1.85%) as the proportion of mutton liver was increased. Similarly, a highly significant (P<0.01) increase in the ash content was observed from 1.71% to 1.79% with the addition of 5%～15% of fish liver.

The fat contents of the positive and negative controls were 12.6% and 13.2%, respectively. However, a significant (P<0.01) trend was observed in the fat contents (from 14.5% to 16.6% in the mutton-liver-added nuggets and from 19.0% to 21.1% in the fish-liver-added nuggets) as the mutton and fish liver fractions increased in the treatments.

The protein contents of the positive and negative controls were 11.9% and 11.8%, respectively. However, the protein content significantly (P<0.01) increased (from 11.9% to 13.9% in the mutton-liver-added nuggets and from 10.5% to 12.6% in the fish-liver-added nuggets) as the mutton and fish liver fraction increased in the supplemented chicken nuggets.

***Biochemical properties*:** The estimation of FFA and POV verified the results of the fat analyses on different days. Fig. 1 shows the highly significant (P<0.01) increase in FFAs in the mutton and fish livers, from 0.1% to 0.7% and from 0.9% to 2.4%, respectively. Fig. 1 also shows that the POV of the mutton and fish livers significantly (P< 0.01) increased from 0.4% to 0.9% and from 0.9% to 2.4%, respectively, over the 7 days of storage time.

The oxidative stability of the supplemented chicken nuggets was also evaluated by performing FFA and POV analysis. Fig. 1 shows the significant (P<0.01) increasing trend of FFA content in the chicken nuggets supplemented with mutton and fish liver, from 1.3% to 1.5% and from 1.2% to 1.9%, respectively, as the fraction of liver increased in the treatments. The FFA content of the positive and negative controls was 1%, with no significant (P>0.05) difference. Fig. 1 also shows the highly significant (P<0.01) increase in the POV of the chicken nuggets supplemented with mutton liver (0.5～0.7 meq/kg) with the increase in the fraction of added liver. The POV of the positive and negative controls was 0.3 meq/kg, and there was no significant (P>0.05) difference. Similarly, a highly significant (P<0.01) increase in the POV of the chicken nuggets supplemented with fish liver was observed (0.5～0.7 meq/kg) as the proportion of added fish liver increased.

Antioxidant potential

The antioxidant activity of both livers was evaluated using DPPH and TPC assays. Fig. 2 shows the scavenging

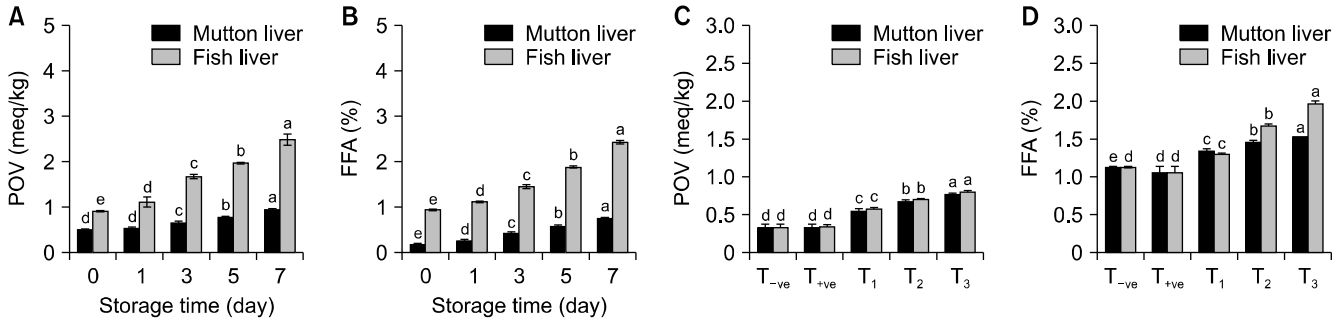

Fig. 1. Biochemical properties of mutton and fish livers and supplemented chicken nuggets. (A) Peroxide value (POV) of mutton and fish livers during a storage period of 7 days. (B) Free fatty acid (FFA) content of mutton and fish livers during a storage period of 7 days. (C) POV of supplemented chicken nuggets compared with the controls. (D) FFA content of supplemented chicken nuggets. Values are presented as mean±SD. The letters (a–e) indicate a significant difference at a 95% probability level. T_{+ve}, containing texturized soya protein; T_{-ve}, no texturized soya protein; T_1, 5% of liver addition; T_2, 10% of liver addition; T_3, 15% of liver addition.

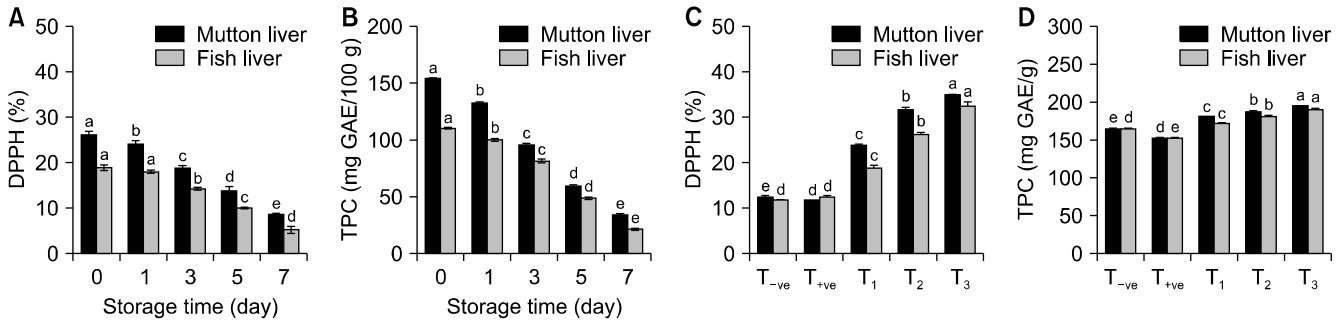

Fig. 2. Antioxidant potential of mutton and fish livers and supplemented chicken nuggets. (A) Antioxidant activity [by 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay] of mutton and fish livers during a storage period of 7 days. (B) Total phenolic composition (TPC) of mutton and fish livers during a storage period of 7 days. (C) Antioxidant activity of the supplemented chicken nuggets. (D) TPC of the supplemented chicken nuggets. Values are presented as mean±SD. The letters (a–e) indicate a significant difference at a 95% probability level. T_{+ve}, containing texturized soya protein; T_{-ve}, no texturized soya protein; T_1, 5% of liver addition; T_2, 10% of liver addition; T_3, 15% of liver addition.

potential of antioxidants (by DPPH assay) in the mutton and fish livers, which significantly (P<0.01) decreased from 25.9% to 8.6% and from 18.6% to 5.2%, respectively, during the 7 days of storage time. The TPC of the mutton and fish livers also significantly (P<0.01) decreased from 154 mg GAE/100 g to 34.3 mg GAE/100 g, and from 21.7 mg GAE/100 g to 110 mg GAE/100 g, respectively, over the 7 days of storage time.

The antioxidant potential of the developed chicken nuggets was also evaluated. The DPPH assay estimated the scavenging activity and potential for oxidative stability of the chicken nuggets supplemented with mutton and fish liver, along with their positive and negative controls. The results of the DPPH assays are presented in Fig. 2, and show a highly significant (P<0.01) increase in the scavenging activity of the chicken nuggets supplemented with mutton and fish liver (from 23.8% to 34.9% and from 18.7% to 32.5%, respectively) as the fraction of liver increased. The scavenging activity of the positive and negative controls was 11.6% and 12.3%, respectively. The phenolic content of the chicken nuggets supplemented with mutton and fish liver also increased significantly (P<0.01) from 180.6 mg GAE/g to 194.7 mg GAE/g and from 171.8 mg GAE/g to 189.6 mg GAE/g, respectively, with the addition of greater proportions of added liver content (Fig. 2). The phenolic compositions of the positive and negative controls were 152 mg GAE/g and 164 mg GAE/g, respectively.

Degradation kinetics of proteins in both livers

The degradation kinetics results are presented in Fig. 3, where A/A_o denotes the amount of leftover protein in both livers, A represents the protein content after storage at different days and hours, and A_o represents the initial protein content at day 0. The rate constant of the first-order kinetics was evaluated using the best-fit experimental results obtained by the regression function. The estimated coefficients of determination (R^2) for mutton and fish liver were >0.95, indicating that the appropriate application of first-order kinetics is rational (Khalid et al., 2013). The rate constants and half-lives of protein degradation from different liver sources on different days are presented in Table 3. A significant difference (P<0.01) was observed in the degradation kinetics of the proteins in the two livers. The observed half-life at 4°C for mutton liver was >18 days and, for fish liver, it was >11

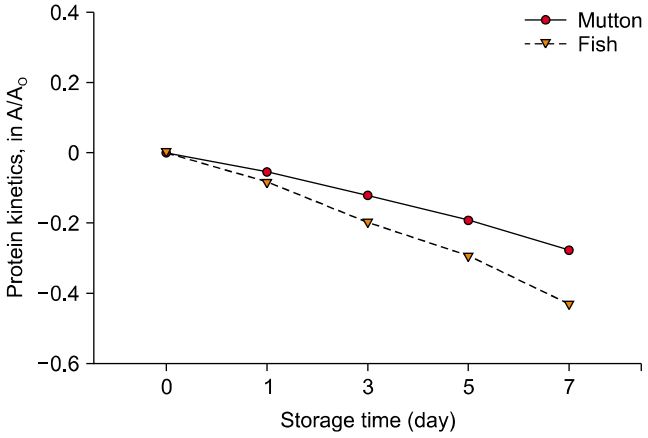

Fig. 3. Degradation kinetics of proteins in mutton and fish livers stored at 4°C for 7 days. The rate constants, coefficients of determination, and half-lives are presented in Table 3. A, the protein content after storage at different days and hours; A_o, the initial protein content at day 0.

days (Table 3). The half-life values for the mutton liver stored at 4°C showed better stability than the fish liver.

Color analysis of the supplemented chicken nuggets

Instrumental color analysis can indicate the quality and consumer acceptability of the final product. The lightness (L^*), redness (a^*), and yellowness (b^*) values of the chicken nuggets supplemented with mutton liver showed significant differences between the treatments and controls (Table 4). The final product's lightness values were observed to decrease as the fraction of mutton liver increased; likewise, the lightness values of chicken nuggets supplemented with fish liver also decreased significantly ($P<0.05$). Meanwhile, there were no significant differences in the redness (a^*) and yellowness (b^*) values among the treatments.

Texture analysis of the supplemented chicken nuggets

Texture analysis of the supplemented chicken nuggets was also conducted, and the results are presented in Table 5 and 6. All texture parameters underwent significant changes as the fraction of liver increased in the treatments. Generally, all treatments and control samples showed highly significant differences ($P<0.05$) for texture parameters such as hardness, springiness, cohesiveness, chewiness, and gumminess. With regard to adding mutton and fish liver, the T_3 (15% liver) nuggets had lower hardness, chewiness, and springiness than the T_1, T_2 (Table 6), and controls. This may have been due to the increased moisture content of the developed chicken nuggets. However, the gumminess and cohesiveness were higher in the T_3 nuggets than in the T_1, T_2, and control nuggets. It was observed that the addition of liver enhanced the eating quality of the supplemented chicken nuggets to a certain extent.

Sensory evaluation of the supplemented chicken nuggets

Sensory evaluation of the supplemented chicken nuggets was performed to determine the consumer acceptability and perception. The parameters evaluated were color, aroma, texture, flavor, tenderness, juiciness, aftertaste, appearance, and overall acceptability. The sensory parame-

Table 3. Rate constants and half-life of protein degradation in mutton and fish livers

Source	Treatment	Rate equation	R^2	Rate constant (k)	Average value (k)	Standard deviation	Half life (0.693/k)
Mutton liver	R1	y = −0.0369× + 0.0053	0.9979	0.0369	0.04	0.001	18.09
	R2	y = −0.0378× + 0.0063	0.9957	0.0378			
	R3	y = −0.0402× + 0.0072	0.9966	0.0402			
Fish liver	R1	y = −0.0586× + 0.0126	0.9954	0.0586	0.05	0.001	11.71
	R2	y = −0.0603× + 0.0103	0.9932	0.0603			
	R3	y = −0.0585× + 0.012	0.9951	0.0585			

R1, R2, and R3 represent replication 1, 2, and 3.

Table 4. The effect of storage on color profiles of chicken nuggets supplemented with mutton and fish liver

Color	Treatment	Negative control	Positive control	T_1	T_2	T_3
L^*	CN-ML	39.3±0.31^{b}	40.6±0.51^{a}	37.4±0.40^{c}	35.8±0.41^{d}	33.7±0.60^{e}
	CN-FL	40.4±0.20^{a}	39.4±0.42^{b}	32.3±0.32^{c}	31.4±0.31^{d}	30.5±0.10^{e}
a^*	CN-ML	5.50±0.21^{ab}	5.71±0.21^{a}	5.40±0.10^{ab}	5.20±0.10^{bc}	5.11±0.11^{c}
	CN-FL	5.80±0.30^{a}	5.50±0.31^{a}	4.71±0.10^{b}	4.61±0.10^{b}	4.60±0.05^{b}
b^*	CN-ML	12.02±0.11^{b}	12.2±0.11^{a}	11.7±0.10^{c}	11.4±0.05^{d}	11.3±0.05^{d}
	CN-FL	12.2±0.30^{a}	12.0±0.40^{a}	11.3±0.20^{b}	11.4±0.30^{b}	11.4±0.10^{b}

Values are presented as mean±SD.
Different notations (a-e) show significant differences.
CN-ML, chicken nuggets supplemented with mutton liver; CN-FL, chicken nuggets supplemented with fish liver; T_1, 5% of liver addition; T_2, 10% of liver addition; T_3, 15% of liver addition.

Table 5. Texture profile analysis of chicken nuggets supplemented with mutton liver

Treatment	Positive control	Negative control	T_1	T_2	T_3
Hardness (N/m^2)	$3.01\times10^4\pm0.02^c$	$2.70\times10^4\pm0.04^d$	$4.90\times10^4\pm0.01^a$	$3.50\times10^4\pm0.01^b$	$2.10\times10^5\pm0.01^e$
Springiness	0.97 ± 0.01^a	0.90 ± 0.04^b	0.90 ± 0.01^c	0.90 ± 0.03^c	0.90 ± 0.01^c
Cohesiveness	1.17 ± 0.02^a	1.04 ± 0.02^b	0.90 ± 0.02^c	0.90 ± 0.02^c	1.00 ± 0.01^b
Chewiness (N/m^2)	$3.40\times10^4\pm0.03^b$	$2.70\times10^4\pm0.02^d$	$4.50\times10^4\pm0.03^a$	$3.10\times10^4\pm0.02^c$	$2.10\times10^5\pm0.07^e$
Gumminess (N/m^2)	$3.50\times10^4\pm0.02^b$	$2.80\times10^4\pm0.02^d$	$2.80\times10^4\pm0.01^e$	$3.40\times10^4\pm0.03^c$	$4.10\times10^5\pm0.03^a$

Values are presented as mean±SD.
Each parameter's value sharing the same letter (a–e) in a row indicates a nonsignificant difference at a 95% probability level. T_1, 5% of liver addition; T_2, 10% of liver addition; T_3, 15% of liver addition.

Table 6. Texture profile analysis of chicken nuggets supplemented with fish liver

Treatment	Positive control	Negative control	T_1	T_2	T_3
Hardness (N/m^2)	$3.01\times10^4\pm0.02^b$	$2.70\times10^4\pm0.04^c$	$3.20\times10^4\pm0.01^a$	$2.30\times10^4\pm0.05^d$	$1.40\times10^5\pm0.01^e$
Springiness	0.97 ± 0.01^a	0.94 ± 0.04^b	0.80 ± 0.01^c	0.80 ± 0.01^d	0.80 ± 0.05^e
Cohesiveness	1.10 ± 0.02^b	1.00 ± 0.02^d	1.10 ± 0.04^c	1.40 ± 0.06^a	1.40 ± 0.01^a
Chewiness (N/m^2)	$3.40\times10^4\pm0.03^a$	$2.70\times10^4\pm0.02^c$	$3.30\times10^4\pm0.01^b$	$2.10\times10^4\pm0.05^d$	$1.70\times10^4\pm0.09^e$
Gumminess (N/m^2)	$3.50\times10^4\pm0.02^a$	$2.80\times10^4\pm0.02^c$	$1.90\times10^5\pm0.06^e$	$2.20\times10^4\pm0.01^d$	$3.30\times10^4\pm0.05^b$

Values are presented as mean±SD.
Each parameter's value sharing the same letter (a–e) in a row indicates a nonsignificant difference at a 95% probability level. T_1, 5% of liver addition; T_2, 10% of liver addition; T_3, 15% of liver addition.

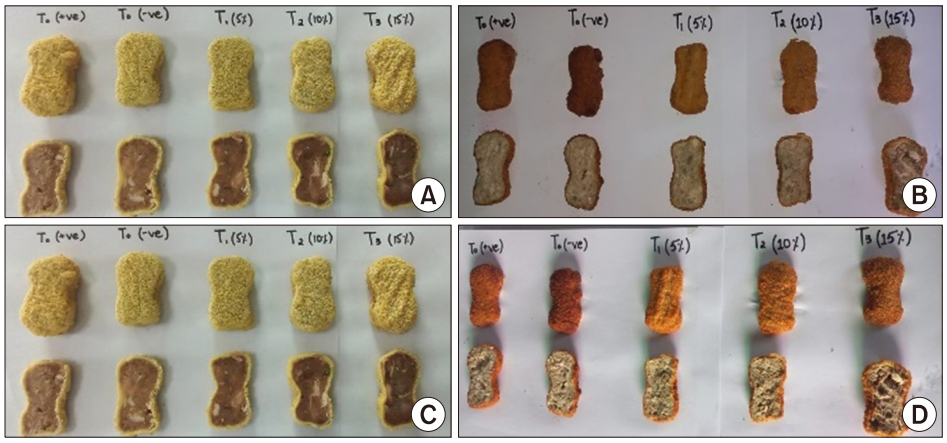

Fig. 4. Pictorial presentation of chicken nuggets. (A) Uncooked chicken nuggets supplemented with mutton liver. (B) Cooked chicken nuggets supplemented with mutton liver. (C) Uncooked chicken nuggets supplemented with fish liver. (D) Cooked chicken nuggets supplemented with fish liver. T_{+ve}, containing texturized soya protein; T_{-ve}, no texturized soya protein; T_1, 5% of liver addition; T_2, 10% of liver addition; T_3, 15% of liver addition.

ters were scored within an acceptable range for all types of treatments. Moreover, no difference was observed among the various treatments for uncooked and cooked items (Fig. 4).

Fig. 5A presents the overall sensory evaluation of the chicken nuggets supplemented with mutton liver. It was observed that the overall acceptability of T_3 was lower than that of the other treatments and the controls. Likewise, other parameters such as color, aroma, texture, flavor, tenderness, juiciness, aftertaste, and appearance had lower acceptability for T_3 than the other nuggets.

Fig. 5B shows the sensory evaluation of the chicken nuggets supplemented with fish liver. The results depict that the overall sensory characteristics declined as the fish liver level increased in the chicken nuggets. T_3 had the lowest overall acceptability, except for juiciness and tenderness. T_1 scored better than the other treatments for all sensory characteristics, but scored lower than the controls. The reason for this could be the fish liver's specific texture and smell.

DISCUSSION

In this study, different quantities of mutton and fish liver were added to the formulation of chicken nuggets to improve the nutritional value and health perspectives of the developed product. The nuggets were characterized by their physicochemical, functional, and sensory characteristics.

The supplemented chicken nuggets showed a decrease in moisture and ash contents over time, which may be due to a loss in water-holding capacity (Akhter et al., 2022). A possible reason for the high moisture loss in

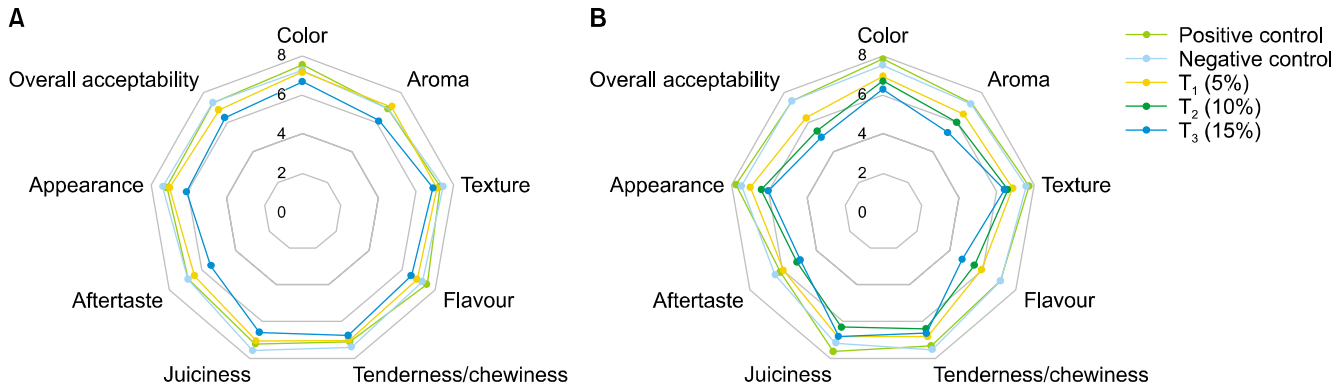

Fig. 5. Sensory evaluation of supplemented chicken nuggets. (A) Evaluated sensory parameters of chicken nuggets supplemented with mutton liver. (B) Evaluated sensory parameters of chicken nuggets supplemented with fish liver. T_1, 5% of liver addition; T_2, 10% of liver addition; T_3, 15% of liver addition.

the fish liver might be its cold-blooded nature and pathological differentiation in the liver. The moisture and fat contents of the fish liver were relatively high, making it more susceptible to unstable environmental conditions such as oxygen availability, temperature changes, and storage time that lead to fat content oxidation and the release of more FFAs (Abraha et al., 2018). Additionally, protein degradation can be caused by the oxidation of proteins when exposed to the environment; moreover, the enzymatic activity of endogenous enzymes causes protein degradation (Yasmin et al., 2022).

Since liver is a perishable commodity with a high moisture and mineral content, its addition to chicken nuggets may cause an increase in the overall moisture and mineral content as the fraction of liver increases. Various similar studies have been conducted, including adding dehydrated shellfish to chicken nuggets to increase their mineral content (Abd-El-Aziz et al., 2022). The addition of green banana and soybean hull flour to chicken nuggets led to an increase in their ash content (Kumar et al., 2013). In another study, chicken nuggets were developed with chickpea flour to increase their ash content (Sharima-Abdullah et al., 2018).

The liver also contains various saturated and polyunsaturated fatty acids (Biel et al., 2019). However, fish liver is rich in polyunsaturated and ω-3 fatty acids, which have various health benefits (Pateiro et al., 2020). Recently, a study was conducted to increase the nutritional value of chicken nuggets by meat breading, increasing the overall fat content (Amorim et al., 2022).

Similarly, several other research studies have been conducted to increase the protein content of chicken nuggets. For example, dehydrated shellfish have been added to chicken nuggets to increase their protein content (Abd-El-Aziz et al., 2022), and pea and rice protein isolates have been added to chicken nuggets, causing a sharp increase in the protein content (Shoaib et al., 2018).

The fish liver's FFA and POV were relatively high, possibly due to the higher fat content that oxidizes when exposed to the environment. However, storage studies on FFA and POV of fish liver have not yet been conducted. However, the increase in FFA and POV of both livers might be due to the oxidation of fats, which leads to the release of fatty acids and a rise in POV (Akhter et al., 2022). The increased fat content in the developed chicken nuggets due to the addition of liver (Vanathi et al., 2020) may be a reason for the observed increase in FFA and POV (Kumar et al., 2013).

A high scavenging potential may be due to good phenolic content and stable feeding practices (Kumar et al., 2015). The decrease in the antioxidant potential of both livers might be due to the exposure of perishable commodities to the environment, which leads to radical oxidation and formation (Echegaray et al., 2021). However, no storage studies have been reported that are related to the antioxidant potential of animal livers. The liver has a high antioxidant potential that leads to oxidative stability. One study showed that porcine liver-extracted hydrolysates have a high scavenging potential for free radicals (Verma et al., 2017). Therefore, the addition of mutton or fish liver to the chicken nuggets might explain the high antioxidant potential of the supplemented chicken nuggets. Similarly, several attempts have been made in previous studies to increase the antioxidant potential of chicken nuggets for their oxidative stability. For example, a pomegranate peel-based edible coating has been applied to chicken nuggets and was found to increase their antioxidant potential, phenolic content, and other antimicrobial characteristics (Bashir et al., 2022). Chicken nuggets have also been developed with different levels of frozen white cauliflower, which was found to increase the scavenging activity, phenolics, and flavonoids (El-Anany et al., 2020).

Protein stability is an important parameter for designing new food products. The results showed the first-order kinetics for both types of liver over a storage time of 7 days. The main reason for estimating degradation kinetics at different hours is that sensitive proteins show degrada-

tion due to environmental factors. The better stability of the mutton liver-supplemented chicken nuggets was due to the fact that mutton liver proteins have a higher half-life than fish liver proteins (Bester et al., 2018).

The decrease in the lightness values of supplemented chicken nuggets was due to the addition of liver, whose increasing amount in the treatments resulted in the darkness of the final product. Because the liver contains more myoglobin than meat and stores different pigments, it is darker than meat (Llauger et al., 2023; Poveda-Arteaga et al., 2023). Texture is another key factor in determining the perceived value of a food product in terms of its exterior appearance. Hardness and tenderness emerge among the several qualities of texture as the most important factors in addressing the needs of consumers. The degree of force required to cause a given deformation or puncture in the food product reflects its hardness or tenderness. When evaluating the quality of a food product, cohesiveness, gumminess, springiness, and chewiness are considered in addition to hardness (Rubab et al., 2020). In sensory evaluation, texture is an important parameter that determines the tenderness of the meat and its palatability (Abd-El-Aziz et al., 2022). The findings of sensory evaluation revealed that the mutton liver-supplemented nuggets were superior to the control in terms of juiciness, texture, tenderness, and aroma. Incorporating mutton liver into chicken nuggets therefore positively impacted the overall sensory characteristics. These results are supported by previous findings, which state that adding plant proteins (frozen cauliflower) positively impacts the sensory characteristics of chicken nuggets (El-Anany et al., 2020).

This study reflects the value of using mutton and fish liver in processed food products. It was observed that the nutritional value, shelf stability, antioxidant potential, and oxidative stability of livers decreased significantly with storage time. Furthermore, the study of the degradation kinetics of proteins in the liver predicted their stability and usage within an appropriate time frame. In the developed chicken nuggets, the texturized vegetable protein was replaced, and we increased the protein content in the treatments. The overall moisture, ash, fat, and protein content increased significantly along with the antioxidant potential. Moreover, the texture analysis and sensory evaluation of the formulated chicken nuggets gave positive results that reflected their eating quality and acceptability. This study provides a baseline for developing value-added chicken-based products through the incorporation of liver, improving the final product's nutritional profile and overall functionality with additional proteins, vitamin C, and iron. Moreover, these products can be indigenously introduced to reduce the risk of iron deficiency in children.

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AUTHOR DISCLOSURE STATEMENT

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Concept and design: NK. Analysis and interpretation: LM, SA, SAM. Data collection: SA, SAM. Writing the article: LM, SA, SAM, HUR, NK. Critical revision of the article: NK, HUR. Final approval of the article: all authors. Statistical analysis: SA. Overall responsibility: NK.

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