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Note

Nutritional composition of tuna processing waste and its potential for human dietary applications

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Abstract

The tuna processing industry generates substantial quantities of waste in the form of head, red meat, bone and viscera. This study compared the proximate composition, fatty acid profile and lipid quality indices of head, visceral mass, bone and red meat of yellow fin tuna *Thunnus albacares*. Significant differences were observed among these components, particularly with respect to fat and ash content. The head exhibited the highest protein content, while bone had the highest fat content. Polyunsaturated fatty acids (PUFA) ranged from 35.65 to 50.80% of total fatty acids across the samples. The lipid quality indices including the Atherogenicity Index (AI) and Thrombogenicity Index (TI) were found to be notably lower in red meat. Principal component analysis (PCA) revealed positive correlations among the biochemical compositions of head, visceral mass, bone and red meat. The study also explored the various potential applications of tuna processing waste, highlighting its value in the development of nutritionally beneficial biomolecules.

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Fish is a vital source of nutrition in many developing countries and the fishing industry serves as a key economic driver for several nations (Halweil and Nierenberg, 2008). In the fiscal year 2022-23, India achieved a record fish production of 175.45 lakh t, making it the third-largest fish producer globally and accounting for around 8% of the global output. The sector contributes approximately 1.09% to the nation's Gross Value Added (GVA) and over 6.72% to the agricultural GVA (DoF, 2023). Approximately 75% of the total body weight of fish is converted into processing wastes during seafood processing (Panggat and Shindo, 2002). These processing wastes are either discarded, sold locally at minimal prices, or processed into low cost animal feed. According to FAO (2011), seafood ranks second globally in terms of food loss and waste. The disposal of such processing wastes poses significant environmental challenges and contributes to increased operational costs. However, the development and commercialisation of value-added products from these wastes offer a promising avenue to enhance revenue generation and to create employment opportunities within the seafood industry (Gates and Parker, 1992).

Fish waste is recognised as a significant source of bioactive compounds, including polyunsaturated fatty acids (PUFAs), polysaccharides, bioactive peptides, minerals, vitamins, antioxidants and enzymes (Kim and Wijesekara, 2010). Advances in extraction techniques for these bioactive compounds from fish waste represent a promising area of research. These biomolecules have applications in promoting human health, boosting economic value and mitigating environmental impacts. Tuna and its related products are particularly important in global trade, comprising approximately 9% of total export value (FAO, 2022), with Japan, the USA and several European nations serving as major importers of tuna products. The processing of tuna generates substantial waste, estimated at around 450,000 t annually (Sultanbawa and Aknes, 2006). Total landing of tuna and tuna like fish from Indian waters was estimated to be 2,08,928 t (IOTC, 2019). Major traded products of tuna include canned tuna, whole tuna as raw material for canning, sashimi tuna and frozen tuna. Speciality products from tuna processing wastes are gaining more and more niche markets in international fish trade (FAO, 2011). In general, tuna is traded as raw meat, with relatively low profit derived from loins and steaks. A global research group has projected the tuna market to reach a value of USD 47.6 billion by 2028, with an anticipated Compound Annual Growth Rate (CAGR) of 2.6%. Their findings, indicate that tuna is predominantly consumed in three forms *viz*., canned (68%), followed by fresh tuna and frozen tuna. Only about one third of the whole fish remains available for value addition after the canning process. The major wastes from tuna include tuna head, skin, bone, viscera and red meat. Tuna red meat, which is having less consumer preference, forms the major tuna discard generated from the processing sector. The characteristic colour of tuna meat is due to the presence of haemoglobin and myoglobin which is reported to be five times more in red meat than in white meat. The gut and gonads from tuna, together contribute to 8% of the total body weight followed by head, fin, mid-bone, tail and gills which together contribute to around 25% of the total body weight of the fish (Das *et al.,* 2011). It is a common practice to utilise tuna processing waste in food, feed and pharmaceutical applications. As profit margins in the traditional tuna business continue to decline, the industry is exploring opportunities to develop value added byproducts from tuna processing waste. In recent years, value addition and waste utilisation have emerged as key focus areas within the tuna industry.

For the present study, yellow fin tuna waste was collected freshly from fish cleaning centres in Kochi, Kerala. The samples were immediately packed in ice and transported to the laboratory for analysis. Proximate composition was estimated according to AOAC (2023) standard procedures. Moisture content was estimated by drying the sample for 16 h at 105±2°C. The total nitrogen content was determined by Kjeldahl's method and percentage of crude protein was estimated. Fat content was estimated using petroleum ether in a Soxhlet apparatus, while ash content was determined by incinerating the sample at 550±2°C. Transesterification was done according to Sreelakshmi *et al.* (2015) and the resulting fatty acid methyl esters were analysed and fatty acid profiles were derived using gas liquid chromatography (Varian CP 3800, Palo Alto, USA). Lipid quality indices in terms of thrombogenicity index (TI), atherigenicity index (AI) and hypocholesterolemic/ hypercholesterolemic index were calculated using the following formulae:

$$AI = \frac{(C12{:}0+4C14{:}0+16{:}0)}{MUFA+PUFA}$$

$$TI = \frac{(C14{:}0 + C16{:}0 + C18{:}0)}{(0.5\sum MUFA + 0.5\sum n3PUFA + 3\sum n6PUFA + n3/n6)}$$

$$h/H = \frac{(C18{:}1n9 + C18{:}2n6 + C20{:}4n + C18{:}3n3 + C20{:}5n3 + C22{:}5n3 + C22{:}6n3)}{(C14{:}0+C16{:}0)}$$

where, C12:0 - Lauric acid; C14:0 - Myristic acid; C16:0 - Palmitic acid; MUFA - Monounsaturated fatty acids; PUFA - Polyunsaturated fatty acids; C18:0 - Stearic acid; n-3 PUFA - Omega-3 polyunsaturated fatty acids; n-6 PUFA-Omega-6 polyunsaturated fatty acids; n-3/n-6- Ratio of omega-3 to omega-6 PUFAs; C18:1n9 - Oleic acid; C18:2n6 -Linoleic acid; C20:4n - Arachidonic acid; C18:3n3 - Alpha-linolenic acid; C20:5n3 - EPA; C22:5n3 - DPA; C22:6n3 - DHA

Statistical analysis were performed using SPSS software (version 27, IBM, New York, USA) at a significance level of $p \leq 0.05$. Data were analysed by analysis of variance (ANOVA) and the results are presented as mean±standard deviation of triplicate samples. Principal component analysis was done using statistical software SAS (version 9.2) to assess the major variations in the fatty acid profiles of various parts of yellowfin tuna wastes in comparison with its nutritional composition.

The proximate composition analysis (Table 1) revealed significant variation among different body parts. The protein content was highest in the head (21.03%) and red meat (21.01%), which were statistically similar. Comparable observations were also reported by Karunarathna and Attygalle (2010), who investigated the nutritional composition of five tuna species. This is attributed to the predominance of muscle-rich tissues. In terms of fat content, bone exhibited the highest value (26.03%), followed by the head (16%). The visceral mass showed moderate fat content (5.37%), whereas red meat had the lowest (1.28). Moisture content was highest in red meat (72.24%) and visceral mass (71.49%), consistent with the high water retention typical of muscle and organ tissues. In contrast, the head (34%) showed moderate moisture and bone (15.97%) had the lowest, reflecting its dense, mineralised structure. This could be attributed to the relatively smaller size of yellowfin tuna, which is associated with a higher bone-to-flesh ratio and elevated mineral content, as reported by Rani *et al.* (2016). The ash content, representing the mineral fraction, was highest in bone (35.7%) and head (21.6%). This was in accordance with Karunarathna and Attygalle (2010). Red meat and visceral mass had comparatively lower ash values (0.98 and 4.03%, respectively). These findings underscore the nutritional diversity among body parts, which has implications for value addition, waste utilisation and targeted product development in the seafood sector.

These findings underscore the nutritional diversity among body parts, which has implications for value addition, waste utilisation, and targeted product development in the seafood sector. Given the distinct nutritional composition observed across tuna body parts, particularly the high protein and moisture content in red meat, this component holds significant potential for value-added applications. The red meat of tuna has been effectively utilised in the development of a wide range of innovative fish-based products, contributing to waste minimisation and valorisation in the tuna processing sector. Tuna red meat protein hydrolysate prepared from yellowfin tuna,

Table 1. Proximate composition of yellow fin tuna parts

Parameter (%)	Red meat	Bone	Visceral mass	Head
Protein	21.01±0.22^{b}	20.3±0.25^{ab}	19.5±0.47^{b}	21.03±0.51^{a}
Fat	1.28±0.23^{d}	26.03±1.33^{a}	5.37±0.38^{c}	16±0.62^{b}
Moisture	72.24±3.54^{ab}	15.97±0.93^{d}	71.49±1.85^{a}	34±1.31^{c}
Ash	0.98±2.54^{a}	35.7±1.91^{b}	4.03±0.68^{d}	21.6± 1.59^{c}

Data are presented as mean ± standard deviation from three independent replicates exhibited better functional properties when compared with tuna white meat protein hydrolysate (Parvathy *et al.,* 2018). The nutritive value of yellowfin tuna red meat was studied and reported to have higher total iron content in the form of haeme protein (73.45%) which increases its bioavailability (Elena *et al.,* 2011).

Kawa kawa tuna has been processed into fish ham (Siddappaji and Prabhu, 2002), demonstrating its suitability for ready-to-eat products. Various tuna species have also been used in the preparation of tuna crackers (Musa and Kadir, 2021), highlighting their potential in snack food formulations. Yellowfin tuna has shown promise in the preparation of dry artificial fish bait (Karunanithi *et al.,* 2018). Additionally, a health beverage incorporating peptides derived from tuna red meat was developed using yellowfin tuna (Unnikrishnan *et al.,* 2021). Beyond food applications, tuna red meat has also served as a low-cost substrate for biosurfactant production (Hu *et al.,* 2021) and as a raw material for fermented fish sauce (Moniharapon *et al.,* 2021).

While tuna red meat has been extensively explored for its versatility in both food and industrial applications, recent research has also turned attention towards tuna head discards, uncovering their potential as valuable raw materials for functional and bioactive ingredient development. Tuna head discards were employed in the extraction of gelatin with improved functional properties from bluefin tuna heads (Haddar *et al.,* 2011), while big eye tuna heads were transformed into tuna head soup (Qian *et al.,* 2019). Skipjack tuna heads served as a source for fish protein hydrolysate, from which antioxidant peptides were further characterised (Zhang *et al.,* 2019). Innovative applications also include the extraction of hydroxyapatite from the skull of bigeye tuna (Ma *et al.,* 2021) and skipjack tuna whole heads were utilised to extract sulphated polysaccharides and protein hydrolysates (Naghdi *et al.,* 2023). Collectively, these studies highlight the immense potential of tuna red meat and tuna heads as a rich source of bioactive molecules for both food and non-food applications.

The fatty acid profile of red meat, head, visceral mass and bone is presented in Table 2. The PUFA predominated in red meat and bone while saturated fractions predominated in visceral mass. EPA and DHA were present in all samples. In the present study, n-3 to n-6 ratio ranged from 3.4 to 13.71. Ratios higher than 0.2 are recommended to be more beneficial to human health (FAO/WHO, 1994). The relationship between pro-atherogenic fatty acids and anti-atherogenic fatty acids is represented as index of atherogenicity while the relationship between pro-thrombogenic fatty acids and anti-thrombogenic fatty acids is represented as index of thrombogenicity. Ulbricht and Southgate (1991) mentioned that the higher the values of AI and TI, the higher is the risk of heart disease. Both AI and TI values were found to be lower for red meat which proves its nutritional significance. Wu *et al.* (2012) suggested that higher h/H ratio shows better nutritional quality of the food products. In the yellowfin tuna samples studied, the ratio was higher in red meat and bone which shows that these parts can be better utilised for preparation of byproducts as food for human consumption.

The PCA biplot (Fig. 1) demonstrates a robust data reduction, capturing 98.05% of the total variance, with Principal Component 1 (PC1) contributing 84.01% and Principal Component 2 (PC2) accounting for 14.04%. These high eigen values, as detailed in Table 3, indicate that the two principal components effectively represent the original multidimensional dataset, allowing meaningful interpretation of variable relationships. In the biplot, the composition of different tuna discards *viz.,* head, bone, visceral mass, and red meat, are observed to cluster in the same quadrant, indicating a strong positive correlation among these tissue types. This spatial association suggests that they share similar compositional traits, particularly in terms of protein, fat and monounsaturated fatty acid (MUFA) contents, highlighting their collective potential as sources of nutritional or functional ingredients. A distinct cluster of lipid quality indices, specifically Atherogenic Index (AI) and Thrombogenic Index (TI), is seen along with various fatty acids such as C22:0, C17:1, C16:1, C18:2, C18:3, C17:0, C20:4, C18:5, and C15:0, all occupying the negative region of PC1. Their close proximity suggests a positive interrelationship, forming a distinct compositional profile potentially less favourable for cardiovascular health. Notably, EPA (C20:5n3) and DHA (C22:6n3) are positioned in the opposite direction of AI and TI along PC1, demonstrating a negative correlation with the lipid indices. This inverse relationship underscores the nutritional significance of EPA and DHA, which are known for their cardioprotective effects and play a key role in enhancing the overall lipid quality of fish-derived ingredients. Along PC2, a more defined correlation is observed between the head and bone, in contrast to the relatively lower association with red meat and visceral mass, which are located farther along this axis. This differentiation supports the concept of component-specific compositional profiles, which can guide targeted utilisation strategies. From a practical standpoint, this PCA-based clustering facilitates a more strategic and efficient approach to tuna byproduct valorisation. For instance, parts like the head and bone, being richer in protein and structural lipids, could be prioritised for protein hydrolysate or gelatin extraction, whereas red meat and viscera,

Table 2. Fatty acid profile and lipid quality indices of yellow fin tuna parts

Fatty acids	Red meat	Bone	Visceral mass	Head
C14:0	8.84	5.53	5.74	7
C15:0	3.67	2.54	2.33	2.1
C16:0	11.8	15.5	22.67	17.5
C16:1	1.1	4.13	5.61	3.3
C17:0	0.47	0.65	1.34	0.34
C17:1	2.66	0	1.6	0
C18:0	7.1	12.84	12.42	10.58
C18:1	6.4	18.96	10.16	14.1
C18:2	6.8	2.77	0.65	2.8
C18:3	5.27	1.3	0.34	1.6
C20:4	4.6	0	4.33	0
C20:5	13.3	15.2	12.2	13.3
C22:0		0.73	0	4.6
C22:6	20.828	20.21	18.13	23.5
SFA	31.88	37.79	44.5	42.12
MUFA	10.16	23.09	17.37	17.4
PUFA	50.80	39.48	35.65	41.2
n3/n6	3.46	13.25	6.16	13.71
AI	0.34	0.34	0.54	0.42
TI	0.57	0.66	1.27	0.70
H/H	2.77	2.78	1.61	2.26

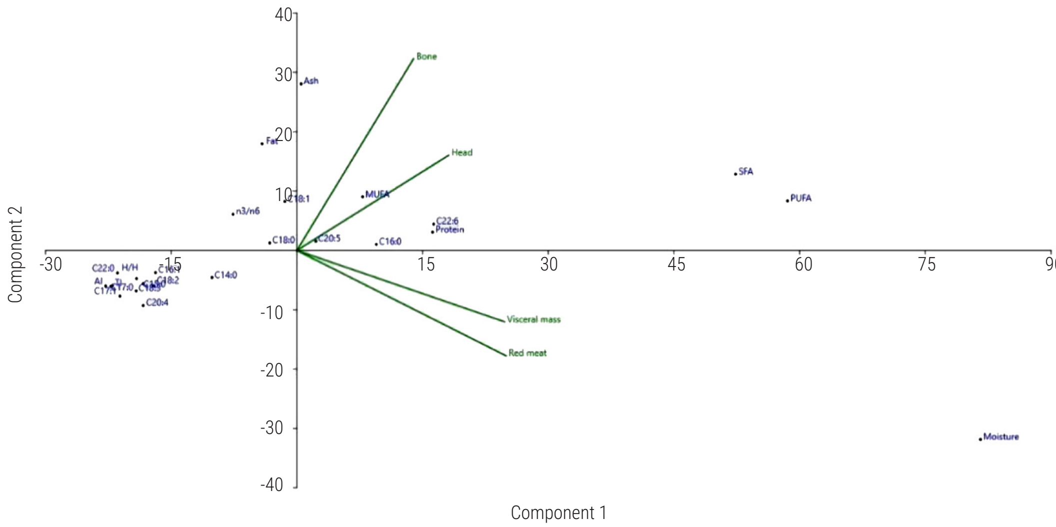

Fig. 1. PCA correlation matrix of tuna discard composition and lipid quality indices

Table 3. Eigen value scale for principal components

PC	Eigenvalue	% Variance
1	744.387	83.697
2	118.875	13.366
3	20.8318	2.3423
4	5.28771	0.59454

having higher PUFA and enzyme content, may be better suited for nutraceutical or enzymatic applications. This informed segregation reduces processing complexity and cost, enhancing the economic viability of product development from tuna processing waste while supporting sustainability.

Among the various tuna discards identified for targeted valorisation through PCA, the visceral mass stands out not only for its compositional profile but also for its enzymatic richness, offering immense potential for bioactive compound production. Tuna viscera, a major processing discard, is a rich source of enzymes like pepsin, trypsin, chymotrypsin and collagenase. These enzymes are highly sought after for their excellent catalytic properties, effective activity at low temperatures, reduced substrate sensitivity and remarkable stability across a wide pH range (Zhou *et al.,* 2011). The proteases generated from fish viscera has several applications in food processing industries (Haard, 1992). Inclusion of proteolytic enzymes for hydrolysis yield biologically active peptides having antioxidant, functional and antimicrobial properties. Bioactive attributes especially antioxidant characteristics as well as better functional properties were exhibited by tuna visceral hydrolysate prepared from skipjack tuna by employing Alcalase 2.4 L (Klomklao and Benjakul, 2018). Antimicrobial activity was exhibited by the peptides derived from viscera of yellow fin tuna after hydrolysis with protamex, especially against certain food borne pathogens and fish spoilage bacteria (Pezeshk *et al.,* 2019). Anti-hypertensive properties were depicted by the peptides produced after the hydrolysis of tuna visceral mass especially liver by Flavourzyme, Alcalase, Protamex and Neutrase (Je *et al.,* 2009). Type of enzyme, enzyme to substrate ratio, temperature, pH and hydrolysis time are the major factors that influence the bioactive properties of hydrolysates (Ko *et al.,* 2013).

In addition to the enzymatic potential of tuna viscera, other discards such as tuna bones also offer substantial opportunities for valorisation, particularly in the development of mineral rich nutraceuticals and bio-functional materials. Tuna bones, can be effectively utilised for the extraction of calcium and the production of value added products such as tuna bone meal, bone powder, and hydroxyapatite. Extraction of hydroxyapatite from tuna bone is reported to be partially exhibiting the properties as a bio-ceramic material (Lee *et al.,* 1997). Another implication is the presence of oligophosphopeptide which is reported to have better calcium affinity. This product is having better application as a nutraceutical product (Jung *et al.,* 2005). A steam explosion pre-treatment method was developed which produces microscale tuna bone powder by ultra-speed pulverisation which improves the properties of tuna bone powder (Cui *et al.,* 2021). A study was conducted on the comparison of the nutritional quality of tuna frame and tuna bone powder which demonstrated that tuna bone powder of yellowfin tuna can be a healthy alternative for calcium supplement for the population suffering from lactose intolerance (Nemati *et al.,* 2017). The nutritional study conducted on yellowfin tuna bone powder showed the presence of protein, useful fat, calcium and phosphorous as possible agents for fortification (Murthy *et al.,* 2014). Precooked skipjack tuna bone was utilised for the production of bio-calcium powder which were crystalline, rich in HA-consisting of both calcium and phosphorous with collagenous protein which exhibited odorous compounds (Benjakul *et al.,* 2017).

Till recent past, the left-over materials generated during primary fish processing were regarded as waste, despite its nutritional richness. Tuna, one of the main fishery resources generate huge quantity of secondary raw material which has immense scope for utilisation in food and various allied sectors. This study focused on different aspects of biochemical composition of tuna wastes that can aid in production of various value added products. All samples were found to be good sources of protein. Also the PUFA content was found to be higher in the samples studied. The lipid quality indices were also studied to ensure the quality of the lipid present. Various tuna by products such as tuna meal, oil, bone powder, silage and sauces already exist in the market.

The study highlights the nutritional, nutraceutical and pharmaceutical potential of various tuna waste components, emphasising their value in the development of health-promoting byproducts. Effective utilisation of these processing wastes not only adds economic value but also addresses the environmental challenges associated with waste disposal in the fish processing industry. Therefore, promoting such value addition initiatives at the grassroot level is recommended to reduce environmental pollution and enhance the economic sustainability of tuna fisheries.

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