Nutritional composition and fatty acid profile of Yellowfin Tuna (*Thunnus albacares*) by-products in Sri Lanka

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Abstract: The present study evaluated the nutritional composition and fatty acid profile of juvenile yellowfin tuna (n = 12, mean weight = 0.875 ± 0. 107 kg) heads, dorsal skins, and caudal muscles with fins. Fatty acid methyl esters (FAME) were separated by gas chromatography (Varian 3900 GC). The highest protein content was obtained in the caudal muscles with fins (23.80 ± 0.14 %) and the lowest (18.75 ± 0.21 %) as reported in the yellowfin tuna head. The highest moisture content was recorded in the caudal muscles with fins (77.06 ± 0.31%). The ash content was comparatively higher (8.65 ± 0.78%) in yellowfin tuna heads than in the dorsal and caudal muscles. The highest fat content was recorded in yellowfin tuna heads (4.18 ± 0.33%) which could be a potential source for fish oil extraction. The most abundant fatty acids in by-products were identified as docosahexaenoic poly-unsaturated fatty acid (DHA/PUFA) (head: 26.63 ± 0.19%, dorsal: 34.71 ± 0.72%, caudal: 31.27 ± 0.90%), followed by saturated fatty acids; palmitic acid (SFA) (head: 22.52 ± 0.22%, dorsal: 20.14 ± 0.47%, caudal: 20.72 ± 0.20%). The results of the present study indicate that omega-3 PUFAs ranged from 35.12% to 42.93% and were higher than omega-6 PUFAs ranging from 4.15% to 4.74% in yellowfin tuna heads, dorsal skin, and caudal muscles. The nutritional composition and fatty acid profile revealed that the yellowfin tuna by-products are excellent sources for extracting omega-3 fatty acids and protein for the food and pharmaceutical industries in Sri Lanka.

Keywords: by-products, fatty acid profile, nutritional composition, protein, PUFA

1. INTRODUCTION

Sri Lanka is one of the oldest and most important tuna-producing countries in the Indian Ocean. Tuna fisheries in Sri Lanka are developing rapidly with the expansion of offshore and high-sea fishing activities. The major tuna species are yellowfin tuna (*Thunnus albacares*), bigeye tuna (*Thunnus obesus*), skipjack tuna (*Katsuwonus pelamis*), frigate tuna (*Auxisathazard*), and bullet tuna (*Auxi srochei*). Among the major tuna fisheries, yellowfin tuna is the dominant commercial catch, and it is the backbone of the fish export industry in Sri Lanka (Jayasooriya and Bandara, 2013).

Yellowfin tuna is generally processed and exported as fresh, and frozen products of sashimi grade. However, most exported tuna products require processing that generates a large quantity of by-products that are not commonly used for further processing. The yellowfin tuna processing companies in Sri Lanka are using only 20% - 50% as edible portions consisting mainly of white muscles. According to the annual yellowfin tuna export volume, approximately, 4500 Mt of by-products are annually produced by seafood companies. Generally, 20% to 35% of solid waste and 20% to 35% of liquid waste (Sayana and Sirajudheen, 2017). The by-product consists of the head (17%), fins (2%), skin (8%), bones (4%), viscera (5%), scales (5%), and some damaged muscles. (Sayana and Sirajudheen, 2017). Discards of such by-products by fish processing companies are currently rising, driven by the increase in fish consumption.

Seafood possesses excellent sources of nutrients such as lipids, proteins, and minerals, which are important for human health. Fish heads, dorsal skins, dark muscles, and caudal muscles with caudal peduncle and fin represent around 35% of total off-cuts. Such waste consists of valuable compounds such as collagen, peptides, poly-

unsaturated fatty acids, chitin, enzymes, and minerals (Ferraro *et al.*, 2010). Those high-value added compounds which can be profitable owing to their beneficial role in human health joined the development of new products in the food and pharmaceutical industries in Sri Lanka. There are very few studies conducted on the characterization of the nutritional composition of yellowfin tuna muscles in Sri Lanka (Ampitiya *et al.*, 2022; Kumara *et al.*, 2011). Furthermore, there is a lack of information on the chemical composition of yellowfin tuna by-products. The aim of this study was to characterize the nutritional composition and fatty acid profile of yellowfin tuna by-products of heads, dorsal skin, and caudal muscle with some fin using highly sensitive analytical techniques.

2. MATERIALS AND METHODOLOGY

2.1 Raw material and sample pre-treatment

Figure 1: Yellowfin tuna by-products (Heads, dorsal skin with remaining flesh attached to the skin and caudal muscles with fins)

Juvenile yellowfin tuna (n = 12, mean weight = 0.875 ± 0. 107 kg) were purchased from Malabe, Colombo fish market in Sri Lanka. Whole frozen tuna were transported at 4^0C and stored at -18^0C in a freezer until further utilized. Each thawed yellowfin tuna was dissected longitudinally, and the head, dorsal skin with remaining flesh attached to the skin, and caudal muscles with fins were manually removed with a filleting knife (Figure 1). Then each sample was washed three times with cold distilled water to remove the surface dirt and minced using a laboratory grinder. Each by-product was vacuumed packed separately and stored at -18^0C until further transport. Then samples were packed in a styrofoam box with ice gel packets and transported to Matis, Iceland by air. The samples were then thawed and placed in polythene bags separately and stored at -20 ^{0}C until further use.

All other chemicals were an analytical grade from Sigma-Aldrich Corporation MO, USA.

2.2 Determination of protein content

Protein content was measured by the Dumas method (ISO 16634-1:2008) (ISO, 2008). All samples were analysed in triplicate. The crude protein content was calculated as:

Crude protein = Nitrogen content * 6.25

2.3 Determination of moisture content

Moisture content was determined by the ISO 6496:1999 method. All samples were analysed in triplicate. An empty porcelain bowl was weighed using an electronic balance (GR 200 semi-micro analytical scale, AANDD, Germany). Approximately 5 g of minced samples were placed in a bowl and weighed again. Then samples were oven dried at 102 -104 ^{0}C for 24 hours. The bowls were removed from the oven and allowed to cool to ambient temperature in a desiccator for about 30 minutes. Then the dried weight of each sample in the bawl was measured. The results were calculated as the weight loss during drying as a percentage of the wet muscle (% m/m) (ISO, 1999).

$$Water\ content\ (W) = 1 - \frac{m3-m1}{m2-m1} * 100(\%)$$

Where:

m_1 is the weight of the bowl (g)

m_2 is the weight of the bowl with wet sample (g)

m_3 is the weight of the bowl with dried sample (g)

2.4 Determination of ash content

Ash content was determined by the ISO 5984:2022 method. Approximately 3-5 g of the sample was heated at 550 ^{0}C for 12 -18 hours. Ash content was weighed, and the total ash content was calculated as a percentage of the sample mass (ISO, 2022).

$$Ash\ content\ (\%) = \frac{W2 - W0}{W1} * 100(\%)$$

Where, *W0* is the weight of the crucible, *W1* is the weight of the sample, and *W2* is the weight of the crucible + ash

2.5 Extraction and determination of total lipid content

Total lipid content was determined by Bligh and Dyer (1959) with some modifications. 25 g of sample (adapted to the quantity of water in the sample) were added into a 250/500 mL centrifuge bottle. 25 mL chloroform and 50 mL methanol were added and homogenized for 2 minutes using a homogenizer (T 25 digital ULTRA-TURRAX, IKA, Germany coupled with S 25 N -25G dispersing tool, IKA, Germany). Then 25 mL of chloroform was added and continued mixing for 1 minute. 25 mL of 0.88% of KCl was added and mixed for 1 minute. Then the lower chloroform phase was extracted using transfer pipettes. The chloroform phase was filtrated on a glass microfiber under suction. Then the suction flask content was poured into a 50 mL volumetric flask. The aqueous phase was removed using a pipette. The solution was diluted until 50 mL using chloroform.

A screw cap glass tube without a cap was weighed using the electronic balance (GR 200 semi-micro analytical scale, AANDD, Germany). 2 mL of lipid extraction was added to a screw cap culture tube. The solvent contained in the lipid extract was removed at 55 ^{0}C using a nitrogen jet. The sample was allowed to cool and weighed. The weight difference in 2 mL was calculated and multiplied by the total volume of chloroform (50 mL) solution and divided by the initial weight of the sample used for lipid extraction.

$$Total\ lipid\ content\ (\%) = \frac{(W2-W1)*50*100}{2*W3}$$

Where:
W1: Initial weight of screw cap glass tube (g)
W2: Final weight of screw cap glass tube with lipid extract (g)
W3: Initial weight of raw sample used to extract lipids (g)

2.6 Determination of Fatty acid composition

Between 60-90 mg of extracted lipid was taken (the chloroform phase from the Bligh and Dyer extract was removed with a nitrogen jet). 1.5 mL of 0.5 NaOH in methanol was mixed with extracted lipid and heated in the oven for 7 minutes at 100 ^{0}C. 2 mL of BCl_3 12 % in methanol was added into each sample and heated in an oven for 30 minutes at 100 ^{0}C. Then the samples were allowed to cool and 1 mL of standard solution (C23:0 in isooctane) and 5 mL of concentrated NaCl were added. The solution was vortexed for 30 seconds. Then Isooctane layer was transferred into a small test tube with a small amount of natrium sulphate. 1 mL of clean isooctane was added and vortexed again for 30 seconds. The remaining isooctane layer was transferred into a small test tube. Then 1.5 mL of solution was transferred to small glass vials for gas chromatography. Fatty acid methyl esters (FAME) were separated on a Varian 3900 GC equipped with a fused silica capillary column (Omegawax 250, 30 m x 0.25 mm x 0.20 µm film), split injector, and flame ionization detector fitted with Galaxie Chromatography Data System, Version 1.9.3.2 software. Data for each fatty acid were expressed as g/100 g of extracted fish oil. Peak areas were determined using 1.9.3.2. software.

3. RESULTS

Table 1 shows the nutritional composition of yellowfin tuna heads, dorsal skin, and caudal muscles with fins. The protein content varied from 18.75% to 23.80%. The highest protein content was obtained in the caudal muscles with fins (23.80 ± 0.14 %) and the lowest (18.75 ± 0.21 %) in the yellowfin tuna head as reported in Table 1. The highest moisture content was recorded in the caudal muscles with fins (77.06 ± 0.31%) and the lowest was in the head (73.10 ± 0.01%). The ash content was comparatively higher (8.65 ± 0.78%) in yellowfin tuna heads than in the dorsal and caudal muscles. In terms of total lipid content, dorsal skin contained the lowest amount of fat 0.81 ± 0.06% while the

Table 1: Nutritional composition (mean ± SD) of yellowfin tuna by-products

By-products	Replicates (n)	*Protein (%)	*Moisture (%)	*Ash (%)	*Lipid (%)
Head	12	18.75 ± 0.21	73.10 ± 0.01	8.65 ± 0.78	4.18 ± 0.33
Dorsal	12	22.75 ± 0.64	75.85 ± 1.09	1.30 ± 0.28	0.81 ± 0.06
Caudal	12	23.80 ± 0.14	77.06 ± 0.31	5.60 ± 0.42	1.43 ± 0.16

* Uncertainty of the measurements themselves is the one causing the difference or something similar.

Table 2: Full fatty acid composition (%) of yellowfin tuna by-products

Fatty Acid formula	Name	Head	Dorsal	Caudal
14:0	Myristic acid	2.87 ± 0.09	1.21 ± 0.16	1.79 ± 0.11
15:0	Pentadecanoic acid	0.95 ± 0.02	0.56 ± 0.04	0.71 ± 0.03
16:0	Palmitic acid	22.52 ± 0.22	20.14 ± 0.47	20.72 ± 0.20
16:1n7	Palmitoleic acid	2.92 ± 0.07	1.59 ± 0.12	2.03 ± 0.16
16:2n4	9,12-hexadecadienoic acid	0.60 ± 0.10	0.55 ± 0.06	0.59 ± 0.01
17:0	Heptadecanoic acid	1.42 ± 0.04	1.02 ± 0.05	1.27 ± 0.02
16:3n4	6,9,12-hexadecatrienoic acid	0.43 ± 0.01	0.32 ± 0.01	0.37 ± 0.02
18:0	Stearic acid	7.75 ± 0.18	7.66 ± 0.04	8.51 ± 0.22
18:1n9	Oleic acid	10.07 ± 0.17	7.77 ± 0.12	8.82 ± 0.28
18:1n7	Vaccenic acid	1.68 ± 0.02	1.43 ± 0.02	1.58 ± 0.02
18:2n6	Linoleic acid	1.22 ± 0.08	0.84 ± 0.01	0.92 ± 0.04
18:3n6	y-linolenic acid	0.31 ± 0.01	0.26 ± 0.00	0.32 ± 0.00
18:3n3	Linolenic acid	0.41 ± 0.04	0.22 ± 0.01	0.27 ± 0.02
18:4n3	Stearidonic acid	0.43 ± 0.01	0.21 ± 0.00	0.27 ± 0.03
20:0	Arachidic acid	0.37 ± 0.003	0.23 ± 0.01	0.31 ± 0.01
20:1(n11+n9)	Eicosenoic acid	1.47 ± 0.06	0.79 ± 0.11	1.26 ± 0.01
20:2	cis-11,14-Eicosadienoic acid	0.38 ± 0.007	0.33 ± 0.01	0.37 ± 0.01
21:0	Henicosanoic acid	2.65 ± 0.04	4.08 ± 0.18	3.37 ± 0.02
20:3n3	cis-11,14,17-Eicosatrienoic acid	0.39 ± 0.01		
20:4n6	Arachidonic acid	0.35 ± 0.03	0.25 ± 0.02	0.34 ± 0.02
20:4n3	Eicosatetraenoic acid	0.34 ± 0.003	1.54 ± 2.61	0.26 ± 0.02
20:5n3	Eicosapentaenoic acid (EPA)	6.15 ± 0.03	5.31 ± 0.04	5.49 ± 0.03
22:00	Behenic acid	0.28 ± 0.01	0.20 ± 0.00	0.25 ± 0.01
22:4n6	Docosatetraenoic acid	2.26 ± 0.04	3.39 ± 0.13	3.08 ± 0.08
22:5n3	Docosapentaenoic acid	0.76 ± 0.49	0.94 ± 0.02	1.02 ± 0.01
24:0	Lignoceric acid	1.06 ± 0.01	0.22 ± 0.01	0.21 ± 0.01
22:6n3	Docosahexaenoic acid (DHA)	26.63 ± 0.19	34.71 ± 0.72	31.27 ± 0.90
24:1n9	Nervonic acid	0.79 ± 0.09	1.00 ± 0.32	1.06 ± 0.02
SFA		39.87	35.31	37.14
MUFA		16.94	12.58	14.76
PUFA		40.67	48.86	44.55
EPA+DHA		32.78	40.02	36.75
Omega 3		35.12	42.93	38.57
Omega 6		4.15	4.74	4.65

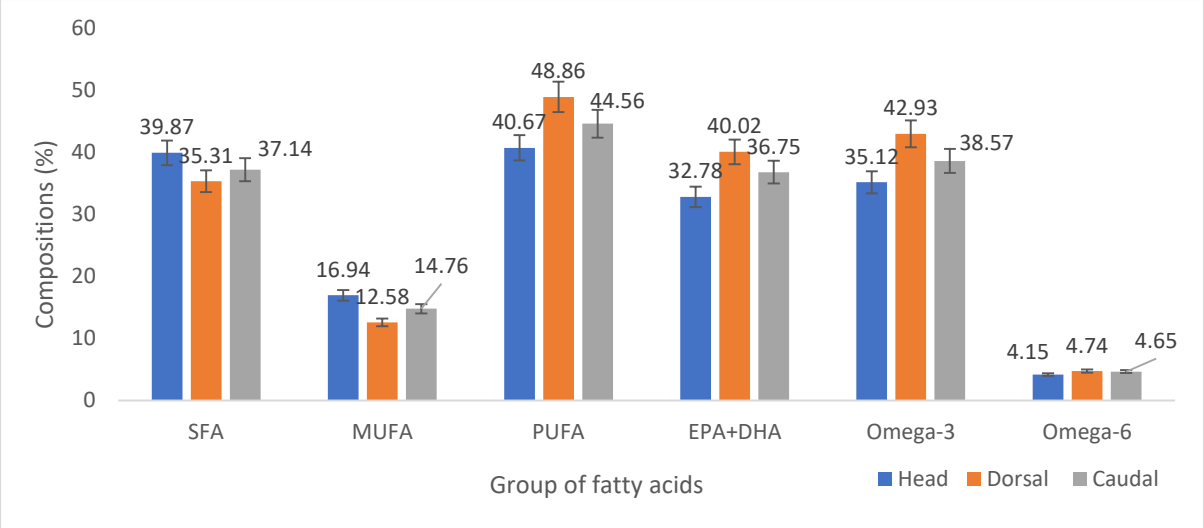

Figure 2: Fatty acid composition of main fatty acid groups of yellowfin tuna by-products

highest fat content was determined in heads (4.18 ± 0.33%) followed by the caudal muscles (1.43 ± 0.16%).

3.2 Fatty acid profile in yellowfin tuna by-products

The fatty acid profile of the main fatty acid groups of yellowfin tuna by-products is presented in Figure 2 and the full fatty acid composition is presented in Table 2. According to the fatty-acid profile of the by-products, the most abundant fatty acids in by-products were identified in docosahexaenoic acid (DHA/PUFA) (head: 26.63 ± 0.19%, dorsal: 34.71 ± 0.72%, caudal: 31.27 ± 0.90%), followed by palmitic acid (SFA) (head: 22.52 ± 0.22%, dorsal: 20.14 ± 0.47%, caudal: 20.72±0.20%), oleic acid (MUFA) (head: 10.07 ± 0.17%, dorsal: 7.77 ± 0.12%, caudal: 8.82 ± 0.28%) and eicosapentaenoic acid (EPA/PUFA) (head: 6.15 ± 0.03%, dorsal: 5.31 ± 0.04%, caudal: 5.49 ± 0.03%). Lower frequency fatty acids included eicosenoic acid, linoleic acid, vaccenic acid, heptadecanoic acid, palmitoleic acid, and myristic acid while the rest were ≤ 1.0% at all sampling points. Furthermore, the results indicate that Omega-3 PUFAs ranging from 35.12% to 42.93% were higher than omega-6 PUFAs ranging from 4.15% to 4.74%.

4. DISCUSSION

The fish used for this study were juvenile yellowfin tuna weighing less than 1 kg each. As commercial-size tuna ranged from 20 kg to 90kg, their proximate composition could therefore be significantly different from this study, mainly from the head which is smaller and contains more bones when the fish are juveniles than when they are adults.

Table 1 summarizes the proximate composition of yellowfin tuna by-products. Accordingly, the protein content of by-products varied from 18.75% to 23.80%. The highest protein content was obtained in the caudal muscles with fins. This might be related to some muscles remaining with the caudal peduncle that contained high proteins. Similar results were reported in a study conducted for yellowfin tuna muscle (23.52%) (Peng *et al.*, 2013). Generally, the level of protein content in fish varied from 16% to 25% depending on species, season, sex, and size as shown in the study. According to Karunarathna and Attaygalle (2010), the average protein content of marine and freshwater fish muscles was 18.5 %. In the present study, the protein content in the caudal muscles with fins was higher than this average value. Moreover, tuna species are known as an excellent source of high-quality protein for

humans. Therefore, the caudal muscles with fins containing the highest amount of protein could be utilized to extract the protein isolate for human consumption.

The moisture contents in heads, dorsal skin, and caudal muscles with fins of yellowfin tuna were in line with other studies done for yellowfin tuna muscle tissue (73.57 ± 0.55%), head (71.93 ± 0.71%), and red muscle (70.83 ± 0.70%) (Garofalo and Tommasi, 2023; Karunarathna and Attaygalle, 2010; Peng *et.al.,* 2013). The same trend was observed due to the low-fat content in juvenile yellowfin tuna used in the present study (Peng *et.al.,* 2013).

The ash content in dorsal skin (1.30 ± 0.28%) was similar to the value reported for yellowfin tuna muscle tissue (1.54 ± 0.06%) by Peng *et.al.,* (2013). However, Karunarathna and Attaygalle, (2010) have reported lower ash content of yellowfin tuna head (1.00 ± 0.06%) than the present value. Ash content indicates the mineral concentration and trace elements in fish and depends on body parts, size, feeding behavior, environment, and season. In the present study, the ash content of by-products accumulated more than in previous studies (Karunarathna and Attaygalle, 2010; Peng *et.al.,* 2013). This might be due to the smaller size of yellowfin tuna containing higher mineral content and a high bone-to-flesh ratio described by Rani *et.al.,* (2016).

The fat content is inversely related to the moisture content. In this study, the moisture content of yellowfin tuna was high therefore, the fat content was considerably low. But the value obtained for yellowfin tuna head was higher than the values reported in previous studies done for yellowfin tuna head (0.98 ± 0.13%), skipjack tuna head (0.72 ± 0.23%) and little tuna head (0.67 ± 0.32%) (Karunarathna and Attaygalle, 2010). Therefore, this could be an indication that the yellowfin tuna heads are a potential source to produce fish oil as their fatty acid composition is also of interest for human consumption. As described by Mahaliyana *et al.,* (2015), lipid content can be fluctuated by habitat, growth phase, season, feeding behavior, muscle type, and spawning season. Fish that contain more than 2% fat can be considered fatty fish. In this study, juvenile yellowfin tunas (mean weight: 0.875 ± 0. 107 kg) which were smaller sized were used. Although tuna fish are considered fatty fish, this juvenile fish contains less fat and can be affected by growth phase and size. Therefore, it might be expected that high-fat content in commercial-size yellowfin tuna by-products (25kg -90kg).

Fatty acids are considered important nutrients for human health and are used to regulate cellular activities in the human body (Peng *et.al.,* 2013). In general, docosahexaenoic acid DHA positively impacts human health including the prevention of some diseases (Jafarpour *et. al.,* 2020). Referring to the fatty acid composition of extracted yellowfin tuna oil, the major fatty acids were DHA (26.83%, 26.11%) followed by palmitic acid (23.13 %, 23.32%), and oleic acid (10.0%, 9.85%). This result is in agreement line with the study reported for neritic tuna species (*Thunnus tonggo* and *Euthynnus affinis*) with slight differences in composition (Ferdosh *et al.,* 2015).

In terms of fatty acid classes, the most prominent fatty acid class was Polyunsaturated fatty acids (PUFAs) followed by Monounsaturated fatty acids (MUFA) and Saturated fatty acids (SFA) in this study. PUFAs are important derivatives from fish by-products that have gained interest from the pharmaceutical and food industries. PUFA can be either omega-3 or omega-6 PUFA (Ferraro *et al.,* 2010). Among the PUFA, DHA was dominant and attributed to the highest percentage of the others in all samples. Yellowfin tuna oil has a higher amount of DHA than the oil extracted from the head of *T. tonggo* (19.9%) and *E. affinis* (18.0%) (Ferdosh *et al.,* 2015). Abdullahi and Undeland (2020) reported that salmon (1.47%) and herring (3.37%) contain comparatively lower DHA than yellowfin tuna oil. Although salmon and herring are known as an important source of PUFA, these results revealed that yellowfin tuna had a higher PUFA level (35.56%) than salmon (25.31

%), herring (11.94%), and mackerel (18.10%) (Abdollahai and Undeland, 2020; Ferraro *et al.*, 2010). The PUFA levels of extracted oil from yellowfin tuna by-products exceeded 30%, which makes them commercially interesting raw materials for ω-3 PUFA extraction (Ferraro *et al.*, 2010). SFAs were the second most abundant fatty acid group in extracted oil from yellowfin tuna heads, caudal fin, and dorsal skins which were higher than the SFA in salmon (13.46%) and herring oil (17.95%) (Abdollahai and Undeland, 2020). These changes in fatty acids between different species were observed due to the species variation, habitat, feeding habits, nature of migration, and differences in extraction methods (Ferdosh *et al.*, 2015).

5. CONCLUSION

In this present study, the nutritional composition and fatty acid profiles of juvenile yellowfin tuna head, dorsal skin, and caudal muscles were evaluated. The high protein content of juvenile yellowfin tuna by-products including caudal and dorsal indicates an excellent source to extract high-quality protein. The value obtained for yellowfin tuna head was reported as high lipid content among other by-products of yellowfin tuna. The most abundant fatty acids in by-products were identified as docosahexaenoic acid (DHA/PUFA) (head: 26.63%, dorsal: 34.71%, caudal: 31.27%) which is the most important nutrient for human health concerns. The nutritional composition of juvenile yellowfin tuna heads, dorsal skin, and caudal muscles revealed that these solid wastes could be ideal sources for the recovery of oil and protein which may boost the Sri Lankan seafood industry to the next level through promoting the value-adding market and may help in the sustainable use of yellowfin tuna resources.

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7. REFERENCES

[1]. Abdollahai, M. and Undeland, I., (2020). A novel cold biorefinery approach for isolation of high-quality fish oil in parallel with gel-forming protein. *Food chemistry*, 332, 1272-1282.

[2]. Ampitiya, A. G., Gonapinuwala, S. T., Fernando, C. A. and De Croos, M. D., (2022). Extraction and characterisation of type I collagen from the skin off-cuts generated at the commercial fish processing centres. *Journal of Food science Technology*, 60(2), 192-203.

[3]. Ferdosh, S., Sarker, Z. I., Norulaini, N., Oliveira, A. and Yunus, K., (2015). Quality of tuna fish oils extracted from processing the by-products of three species of neritic tuna using supercritical carbon dioxide. *Journal of food processing and preservation*, 39(4), 432-441.

[4]. Ferraro, V., Cruz, I. B., Jorge, R. F., Malcata, F. X., Pintado, M. E. and Castro, P. M., (2010). Valorisation of natural extracts from marine source focused on marine by-products: A review. *Food Research International*, 43(9), 2221-2233.

[5]. Garofalo, S. F. and Tommasi, T., (2023). From tuna viscera to added-value products: A circular approach for fish-waste recovery by green enzymatic hydrolysis. *Food and bioproducts processing*, 137, 155-167.

[6]. ISO., (1999, 08). *ISO 6496:1999*. Retrieved from ISO: www.iso.org/standard/12871.html

[7]. ISO., (2008). *ISO 16634-1:2008.* Retrieved from ISO: www.iso.org/standard/46328.html#:~:text=ISO%2016634%2D1%3A2008%20specifies,nitrogen%20and%20non%2Dprotein%20nitrogen

[8]. ISO., (2022). *ISO 5984:2022.* Retrieved from ISO: https://www.iso.org/standard/37272.html

[9]. Jafarpour, A., Gomes, R. M., Gregersen, S., Sloth, J. J., Jacobsen, C. and Sorensen, A.D. M., (2020). Characterization of cod (Gadus morhua) frame composition and its valorization by enzymatic hydrolysis. *Journal of food composition and analysis*, 89, 103469.

[10]. Jayasooriya, J. and Bandara, H., (2013). *Analysis of catch assessment of tuna fisheries in Sri Lanka.* Colombo: Ministry of Fisheries and Aquatic Resource Development Sri Lanka.

[11]. Karunarathna, K. A. and Attaygalle, M. V., (2010). Nutritional evaluation in five species of tuna. *Vidyodaya Journal of Science*, 7-16.

[12]. Kumara, M. S., Rajapakshe, G. and Jayamanne, C. S., (2011). Production of tuna fish oil by utilizing tuna (Thunnus albacares) processing by-products. *Proceedings of the research symposium of Uva Wellassa University Badulla: University of Uva Wellassa*, 154-156.

[13]. Mahaliyana, A. S., Jinadasa, B., Liyanage, N. P., Jayasinghe, G. D. and Jayamanne, S. C., (2015). Nutritional composition of skipjack tuna (Katsuwonus pelamis) caught from oceanic waters around Sri Lanka. *American journal of food and nutrition*, 3(4), 106-111.

[14]. Peng, S., Chen, C., ShiZhaohong, and Wang , L., (2013). Amino acid and fatty acid composition of the muscle tissue of yellowfin tuna (Thunnus albacares) and bigeye tuna (Thunnus obesus). *Journal of food and nutrition research*, 1(4), 42-45.

[15]. Rani, P. S., Kumar, P. V., Rao, K. R. and Shameem, U., (2016). Seasonal variation of proximate composition of tuna fishes from Visakhapatnam fishing harbor, East coast of India. *International journal of fisheries and aquatic studies*, 4(6), 308-313.

[16]. Sayana, K. and Sirajudheen, T., (2017). By-products from tuna processing waste - an economic approach to coastal waste management. *Proceedings of the International seminar on coastal biodiversity assessment, Kerala: COBIA*, 411-313