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Nutritional Composition of Skipjack Tuna *(Katsuwonus pelamis)* Caught from the Oceanic Waters around Sri Lankae

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Abstract Skipjack tuna samples (n= 44) were collected from representative fish landing sites around Sri Lanka. Proximate composition, fatty acid profile and major essential trace minerals were analyzed according to their respective standard methods, strictly adhering with quality control procedures. As per the results, Skipjack tuna is a rich source of protein (24.13±2.01%). It has low fat content and a majority of the fatty acid composition comprises with ω-3 type fatty acids which have more health benefits. In addition, skipjack tuna is rich with Fe, Cu, and Zn (24.05, 5.04, and 6.89 respectively in mg kg^{-1}) essential minerals in the human body.

Keywords: *skipjack tuna, Katsuwonus pelamis, proximate composition, protein, fatty acid profile, essential minerals*

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1. Introduction

Fish is consumed as a major source of food and essential nutrients to fulfill a broad range of nutritional requirements in most of the human population in the world. [1] Fish have been obtained a greater attraction as an excellent source of digestible protein, vitamins, essential minerals and polyunsaturated fatty acids (PUFA), which assist healthy life while providing a variety of diets to human. [2] Due to its high palatability, low harmful cholesterol levels and flesh with favorable tenderness, it is accepted as a delicacy all around the world. [3] Fish is considered as a choice for many since it is the cheapest source of animal protein and other essential nutrients for human health. As a human diet, fish contains a significantly low level of lipids and higher amount of water than other meat types such as beef and chicken. Hence, fish is greatly favored by the consumers over all the other red and white meat types. [4] Most of the well reputed health organizations advice general population to eat fish containing meals twice per week. [5,6]

Fish is an excellent source for proteins, whereas in nutritional concerns fish protein is ranked above casein. [7] Tissues of fish are a rich source of polyunsaturated fatty acids, ω-6 and especially ω-3 which have profound implications for health and disease prevention. [8] The uniqueness of fish lipids is the presence of long chain (LC) PUFA, namely eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA) and a low amount of docosapentaenoic acid (DPA). [9] These are important in the prevention and treatment of inflammatory disorders, cancers, hypertension and cardiovascular diseases. Fish contains most of the essential trace minerals for human metabolism, such as Fe, Cu and Zn. [10]

Tuna fishes are considered as the largest and most specialized commercially important group of species among all fish. [11] Tuna and tuna like marine fishes are important biological resources, which are dominant in the offshore fishery catch in Sri Lanka. [12] Among major tuna fisheries, skipjack tuna *Katsuwonus pelamis* (Linnaeus, 1758) is the largest fishery in all the oceans around the world and the largest marine fishery in Sri Lanka as well. [13] In the year 2013, skipjack tuna production in Sri Lanka was 73,350 Mt and it accounts 16% of total marine fishery production. [14] The other importance of skipjack tuna resource is that, its high productivity with compared to other tuna species. [15] Skipjack tuna is a major food commodity both regionally and internationally. [13] Hence, a comprehensive analysis of nutritional components of skipjack tuna is required to be performed, therefore this study was accomplished.

2. Materials and Methods

2.1. Sampling

Skipjack tuna samples were collected from representative fish landing sites around Sri Lanka during April-July 2014 (Figure 1). A total of 44 skipjack tuna samples (n) was used in this study.

Each sample was taken from individual skipjack tuna fish for analysis as an edible portion of one side of the body; the flesh part below the dorsal fin (from the left side of the body when it is on the measuring board). All the dissections were done using a stainless steel knife to avoid the metal contamination. Each sampled portion was then homogenized using a mixer grinder (Sonica domestic, India) and nearly 250 g of muscle portion was obtained for the study.

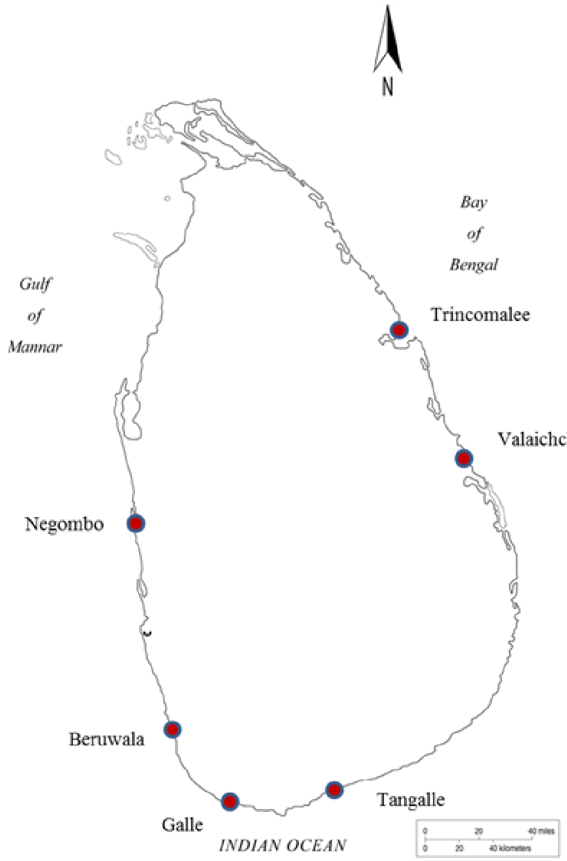

Figure 1. Map of sampling locations

All the samples were individually subjected essential trace mineral concentration determination, whereas all the other nutritional content analysis were carried out for composite muscle samples. The composite samples were prepared based on the length proportion and gender of each fish according its landing site.

2.2. Analysis of Protein Content

Protein content of composite samples was determined according to the AOAC official methods of analysis 928.08 (AOAC, 2000) using a UDK 132 semi-automated Kjeltec system (VELP Scientifica, Usmate, Italy).

2.3. Analysis of Moisture and Ash Contents

The moisture content of each composite sample was analyzed according to (AOAC method 950.46; AOAC, 2000) oven drying method (at 105 °C until it obtained a constant weight). The oven dried samples were further used to determine the ash content by the dry ashing method (AOAC method 920.153; AOAC, 2000). The samples were subjected to 550 °C in Carbolite furnace (Sheffield, UK) an overnight.

2.4. Analysis of Fat Content and Fatty Acid Composition

The muscle samples of skipjack tuna were analyzed for their fat content and fatty acid profile as composite samples. Total lipids in muscle tissue samples were extracted using the method described by Bligh and Dyer, 1959 [16]. Using the gravimetric method, the fat content of the each composite sample was determined as a percentage value (AOAC method 960.39; AOAC, 2000).

In accordance with the fat content of the each composite sample, the Bligh and Dyer extract was used for the Fatty Acid Methyl Ester (FAME) generation. Capillary Gas Chromatograph (GC) (GC-2014, Shimadzu, Kyoto, Japan) was used to determine the fatty acid profiles. The gas chromatograph was equipped with fused silica DB wax capillary column (30 m × 0.32 m, film 0.25 µm) and flame ionization detector (FID). Helium was used as the carrier gas at 14 psi. The initial temperature of the column was set at 160 °C and finally increased to 240 °C at a rate of 3 °C min^{-1}. The detector temperature was set at 270 °C, while the temperature at the injection port was maintained at 240 °C. Retention times of FAME standards were used to identify chromatographic peaks.

2.5. Analysis of Trace Metal Concentrations

Approximately 1 g portion from each homogenized and pre-prepared muscle samples were separated and separately weighed into a microwave digestion tube. Pre digestion of the sample was performed by adding 10 mL of 65% Conc. HNO_3 acid (AR, Sigma-Aldrich, USA) and allowing it to stand for 15 minutes in a fume hood. Each sample was analyzed in duplicates. A microwave accelerated system, CEM XP-1500 (CEM, Matthews, USA) was used to digest the sample further after the pre digestion. Atomic absorption spectrophotometer (AAS) (Varian240 FS, Varian Inc., Australia) was used to determine the trace metal concentrations in the prepared samples. Spectra AA Varian atomic absorption spectrometer with a flame (AAS-240 FS) was used for Zn, Cu and Fe determination. The calibration curves for the absorption of all the metals were performed with a series of standard solutions of particular metal at optimum wavelength. The reagent blank samples and spiked samples were aspirated into the AAS subsequent to the calibration and the readings were recorded. Each analytical batch was consisted of spiked samples and reagent blanks.

Recoded data were statistically analyzed using MINITAB 17.0 software package.

3. Results and Discussion

3.1. Quality Control of Research Method

3.1.1. Proximate Analysis

All the proximate components were analyzed in triplicates according to the respective standard methods available in AOAC, 2000. All the reagents that used for analysis were analytical reagent grade. In order to determine the recovery percentage in crude protein analysis, spiked samples with $(NH4)_2SO_4$ were used and the recovery values were maintained within the acceptable range of 90 -110%.

3.1.2. Analysis of Fatty Acid Composition

Fatty acid composition was analyzed in duplicates. Internal Standards (IS) - (C17:0) heptadecanoic acid and standard sample 81-5550 Qualimix Fish S (Larodan fine chemicals, Malmo, Sweden) were used in order to control the quality of the analysis. All the reagents that used for analysis were analytical reagent grade.

3.1.3. Analysis of Essential Trace Minerals

All the reagents that used for trace metal analysis were analytical reagent grade and all the samples were analyzed in duplicates. The method of trace metal analysis was evaluated for its suitability in terms of their respective Limit Of Detection (LOD) and recovery levels using spiked samples. The detection limit was calculated as the 3-fold of the standard deviation of ten blanks. The calculated recovery values for all the trace metals were within the expected recovery range of 80%-120% (Table 1). For each trace metal, constructed calibration curves showed a good linearity over the entire range of concentrations with acceptable coefficients (r^2 = >0.99%).

Table 1. Obtained recovery percentages of spiked samples

Trace metal	% Recovery	Limit of Detection (mg kg^{-1})
Fe	99.12	0.15
Cu	89.30	0.01
Zn	83.80	0.43

3.2. Biological Parameters

The mean, standard length of the analyzed skipjack tuna fish samples was 47.4±3.9 cm and the range was 36-56 cm, whereas the mean total weight was 2.23±0.59 kg and it had a variation of 1.1- 4.2 kg. Among the analyzed samples 20 were female and 24 were male fish.

3.3. Nutritional Analysis

3.3.1. Proximate Composition Analysis

Table 2. Proximate composition (%) of the flesh of skipjack tuna and other major tuna species*

Component	Skipjack tuna [a]	Yellowfin tuna[b]	Bigeye tuna[b]
Crude protein	24.13±2.01	23.52±0.61	23.72±0.16
Crude fat	0.41±0.56	1.93±0.13	2.06±0.57
Moisture	73.28±0.89	73.57±0.55	72.89±0.63
Crude ash	1.43±0.22	1.54±0.06	1.77±0.13

* Data are expressed as mean±SD on a fresh weight basis
[a] The present study
[b] Peng *et al*., 2013 [17]

The results of analysis proximate components of skipjack tuna samples are given and (Table 2) Peng *et al.*, 2013 [17] have reported the proximate composition of the other two commercially important tuna species; yellowfin and big eye tuna (Table 2). Skipjack tuna contains a slightly higher amount of protein, considerably lower amount of fat as well as the same level of moisture and ash contents with compare to other major species in scombridae family; yellowfin and big eye tuna (Table 2). In general, the chemical composition of fish differs from one to another depending on environment, season, sex and age with the level of protein ranging from 16 to 25%, lipid from 0.1 to 25%, ash 0.4 to 1.5%, moisture content of 60 to 80% [18]. On average, moisture content of fish has been reported in the ranges of 65.88 to 78.62% [19] and 68.6 to 77.1% [20]. The values obtained in the present study for proximate composition were within the reported ranges for fish. These resulted values are in line with the findings of Balogun and Talabi, 1985 [21] and Karunarathna and Attygalle, 2010 [22] for skipjack tuna. However, Mumthaz *et al*., 2010 [23] have reported that skipjack tuna contains a lower level of moisture and higher level of protein, whereas reported values for crude fat and ash tally with the findings of this study. This might be due to the variation in protein content according to the seasonal changes as described by Clucas and Ward, 1996 [24]. In general, tuna species are considered as an excellent source of high quality protein to human. [25] The present study has confirmed that tuna contains a higher amount of protein when compared to other edible sea food. In addition, the results obtained in this study indicate that skipjack tuna is a good protein source as same as the majorly attracted other tuna species such as yellowfin and bigeye tuna by the fish consumers.

The fat and protein content of a fish is a crucial factor to evaluate the nutritional condition. [20] In general, tuna is considered as a low fat and calorie containing food, which can be a great substitute for meat and dairy products that contain a higher content of saturated fatty acids and trans-fatty acids. As described by Bligh *et al.*, 1988 [26] the fat content in fish body can be influenced by place of life, season, source of food, activity, growth phase, spawning and the muscle type. Fishes that contain more than 2% fat content are grouped under fatty fish. [24] According to the results obtained in this study as well as previous studies, skipjack tuna contains a fat content below 2% in their body composition. Therefore, it can be concluded that, although tuna fishes are considered as fatty fishes in general, the skipjack tuna is not exactly a fatty fish.

3.3.2. Fatty Acid Profile

In general, 50-60 different fatty acids can be identified in fish, but only 14 fatty acids are important in terms of nutrition. [27] Fourteen fatty acids in skipjack tuna fish flesh were identified in the present study. The predominant fatty acids of skipjack tuna muscle were C22:6 (docosahexaenoic acid - DHA), C16:0 (palmitic acid) and C18:0 (stearic acid). With compare to other fatty acids, level of C22:6 (DHA) was very high (Table 3).

The obtained values for saturated fatty acids (SFA) and monounsaturated fatty acids (MUFA) in this study were higher while PUFA, EPA and DHA were lower than those values reported by Mumthaz *et al*., 2010 [23]. Karunarathna and Attygalle, 2010 [22] have reported the different values as they have studied the fatty acid profiles separately for white and red muscles of skipjack tuna. They have recorded a lower value of SFA and PUFA as well as the higher value of MUFA in white muscle while a higher value of SFA and PUFA as well as lower MUFA in red muscle. Furthermore, the obtained value of this study for the PUFA/ SFA ratio was lower than the recorded values for red and white muscles in the above study while the obtained ω-6/ ω-3 ratio was lower than the previously recorded values. The major SFA were palmitic (C16:0) and stearic (C18:0) acids. These findings are in line with the findings of Stephen *et al.*, 2010 [28] for skipjack tuna.

The palmitic acid (C16:0) has been reported as the major fatty acid in marine fish followed by stearic acid (C18:0) by many authors. [29,30,31,32,33] The major MUFA were oleic acid (C18:1) followed by vaccenic acid (C18:1 ω-7) and palmitoleic acid (C16:1). Ackman *et al.*, 1982 [34] and Bandarra *et al.*, 1997 [33] also have reported a high level of vaccenic acid C18:1 as a MUFA in marine fish. According to this study the dominant ω-3 PUFA was DHA, which this result agrees well with the findings of Bandarra *et al.*, 1997 [33] and Stephen *et al.*, 2010 [28]. As explained by Ackman, 1989 [35]; Nettleton and Exler, 1992 [36] and Saito *et al.*, 1999 [37] the levels of each type of fatty acid vary majorly with the diet of the fish. In addition, it could be influenced by the factors such as geographic location, season, age as well as reproductive status. These might be the reasons for the differences in the obtained values in this study compared with the previously recorded values.

Table 3. Fatty acid profile of skipjack tuna

Fatty acid	% value
Tetradecanoic acid (Myristic acid, C14:0)	2.02±0.61
Pentadecanoic acid (C15:0)	0.66±0.09
Hexadecanoic acid (Palmitic acid, C16:0)	21.88±1.53
Hexadecenoic acid (Palmitoleic acid, C16:1)	2.49±0.78
Octadecanoic acid (Stearic acid, C18:0)	11.69±0.67
Octadecenoic acid (Oleic acid, C18:1 ω-9)	10.03±0.72
(*E*)-11-octadecenoic acid (Vaccenic acid, C18:1 ω-7)	2.14±0.43
Octadecadienoic acid (Linoleic acid, C18:2 ω-6)	1.38±0.13
Octadecatrienoic acid (Linolenic acid, C18:3 ω-3)	0.13±0.00
Eicosatetraenoic acid (Arachidonic acid, C20:4 ω-6)	0.32±0.37
Eicosapentaenoic acid (EPA) (Timnodonic acid, C20:5 ω-3)	4.74±0.39
Docosatetraenoic acid (Adrenic acid, C22:4 ω-6)	6.04±0.39
Docosapentaenoic acid (DPA) (Clupanodonic acid, C22:5 ω-3)	1.13±0.25
Docosahexaenoic acid (DHA) (C22:6 ω-3)	35.66±0.23
SFA	36.25
MUFA	14.67
PUFA	49.40
ω-3	41.67
ω-6	7.74
EPA	4.74
DHA	35.66
PUFA/ SFA	1.36
ω-6/ ω-3	0.19
EPA+DHA	40.39

This study has shown that skipjack tuna can be recommended in diet for obtaining the essential fatty acids since it contain approximately 50% of polyunsaturated fatty acids which the majority consist with ω-3 type fatty acids. Based on this study, the limiting fatty acid types in skipjack tuna would be the linolenic acid (C18:3) and arachidonic acid (C20:4).

3.3.3. Essential trace Minerals

The highest mean concentration was recorded for Fe whereas Cu was recorded for the lowest concentration (Table 4). The trend of the essential trace metal concentrations was Fe > Zn > Cu in skipjack tuna muscle. A higher Fe content in skipjack is presumably related to the presence of the dark muscles in the body since dark muscles are characterized by higher Fe concentrations than light muscles. [38] In contrary to the findings of Kojadinovic *et al.*, 2007 [39], the present study has obtained a higher Fe level as well as lower Zn and Cu levels. The trend of these reported essential trace metal concentrations also differs from the present study.

Table 4. Essential trace mineral concentrations (mg kg^{-1} fresh weight basis) in skipjack tuna muscle

Essential trace mineral	Mean±SD
Fe	24.05±4.81
Zn	6.89±3.42
Cu	5.04±7.35

However, the standard deviations of Fe and Zn were high in both studies, which indicate that the resulted values for individual specimens have a wider distribution. Unlike this study, Kojadinovic *et al.*, 2007 [39] have reported a lower standard deviation for Cu. Karunarathna and Attygalle, 2009 [40] have studied Fe, Zn and Cu separately in white as well as red muscles of skipjack tuna in Sri Lankan oceanic waters. The reported results of the trend of these essential trace metals are in line with the present study. However, the present data differ from the reported mean values for each trace metals as higher Fe and Cu as well as lower Zn in white muscle whereas lower Fe, Zn and Cu values in red muscle. The high level of concentrations of Fe, Zn and Cu could be explained by their specific structural and functional roles in living organisms. Essential trace metals such as Fe, Cu and Zn have main functions in skeletal structure, maintenance of colloidal system and regulation of acid-base equilibrium. They are essential constituents of hormones, enzymes and enzyme activators. [38,41,42]

4. Conclusion

Skipjack tuna is a good source of protein which is similar to the protein content of other commercially important tuna species such as yellowfin and big eye. Skipjack tuna has low fat content and the majority of the fatty acid composition comprises with ω-3 type fatty acids which have more health benefits. In addition, skipjack tuna is rich with Fe, Cu and Zn essential minerals in the human body.

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Statement of Competing Interests

The authors have no competing interests.

References

[1] James, D, *Risks and benefits of seafood consumption*. Globefish Research Programme, Rome, Italy: FAO. 2013.

[2] Carvalho, M. L., Santiago, S. and Nunes, M. L, "Assessment of the essential element and heavy metal content of edible fish muscle". *Analytical and Bioanalytical Chemistry*, 382(2), 426-432. 2005.

[3] Eyo, A. A, *Fish processing technology in the tropics*. New Bussa, Nigeria: National Institute for Freshwater Fisheries Research (NIFFR). 2001.

[4] Nestel, P. J, "Fish oil and cardiovascular disease: lipids and arterial function". *The American Journal of Clinical Nutrition*, 1, 228-231. 2000.

[5] Kris-Etherton, P. M., Harris, W. S. and Appel, L. J, "Fish consumption, fish oil, omega-3 fatty acids, and cardiovascular disease".*Circulation*, 106(21), 2747-2757. 2002.

[6] Harris, W. S, "Are omega-3 fatty acids the most important nutritional modulators of coronary heart disease risk?". *Current Atherosclerosis Reports*, 6(6), 447-452. 2004.

[7] Johnson, B. L., Hicks, H. E., Jones, D. E., Cibulas, W., Wargo, A. and De Rosa, C. T, "Public health implication of persistent toxic substance in the Great Lakes and St. Lawrence Basins". *Journal of Great Lakes research*, 24(2), 698-722. 1998.

[8] Uauy-Dagach, R. and Valenzuela, A. L. F. O. N. S. O, "Marine oils as a source of omega-3 fatty acids in the diet: how to optimize the health benefits". *Progress in Food and Nutrition Science*, 16(3), 199-243. 1991.

[9] Guzmán-Maldonado, S. H., Paredes-López, O. and Mazza, G, *Functional Foods: Biochemical and processing aspects*. Chicago: CRC Press. 1998.

[10] Le, Q. D., Shirai, K., Nguyen, D. C., Miyazaki, N. and Arai, T, "Heavy metals in a tropical eel *Anguilla marmorata* from the central part of Vietnam". *Water, air, and soil pollution*, 204, 69-78. 2009.

[11] Collette, B. and Nauen, C, FAO species volume 2. Scombrids of the world. An annotated and illustrated catalogue of tunas, mackerels, bonitos and related species known to date. FAO Fisheries Synopsis. 1983.

[12] Hasarangi, D. G. N., Haputhantri, S. S. K. and Maldeniya, R, *A Review on Shark Fishery Resources in Sri Lanka*. IOTC-2012-WPEB08-15. 2012.

[13] Acharige, D., Terrence, S., Chand, V. and Mather, P. B, "Development and characterisation of tri-and tetra-nucleotide polymorphic microsatellite markers for skipjack tuna *(Katsuwonus pelamis)"*. *Ceylon Journal of Science (Biological Science)*, 41(1), 11-17. 2012.

[14] Ministry of fisheries and aquatic resources (MFAR), "Fisheries Statistics 2015". Available: http://www.fisheries.gov.lk/content.php?cnid=ststc. [Accessed Oct. 29, 2015]

[15] Indian Ocean Tuna Commission (IOTC). *Executive summary of the status of the skipjack tuna resource*. IOTC-2005-SC-08[EN]. 2005.

[16] Bligh, E. G. and Dyer, W. J, "A rapid method for total lipid extraction and purification". *Canadian Journal of Biochemistry and Physiology*, 37, 911-917. 1959.

[17] Peng, S., Chen, C., Shi, Z. and Wang, L, "Amino acid and fatty acid composition of the muscle tissue of yellowfin tuna (*Thunnus albacares*) and bigeye tuna (*Thunnus obesus*)". *Nature*, 1(4), 42-45. 2013.

[18] Muraleedharan, V., Antony, K. P., Perigreen, P. A. and Gopakumar, K, "Utilization of unconventional fish resources for surimi preparation". *Proceedings of the second workshop on scientific results of FORV SAGAR*, (pp. 539-543). Sampada. New Delhi: Department of Ocean development. 1996.

[19] Mazumder, M. S. A., Rahman, M. M., Ahmed, A. T. A., Begum, M. and Hossain, M. A, "Proximate composition of some small indigenous fish species (sis) in Bangladesh". *International Journal of Sustainable Crop Production*, 3(4), 18 -23. 2008.

[20] Aberoumad, A. and Pourshafi, K, "Chemical and proximate composition properties of different fish species obtained from Iran". *World Journal of Fish and Marine Sciences*, 2(3), 237-239. 2010.

[21] Balogun, A. M. and Talabi, S. O, "Proximate analysis of the flesh and anatomical weight composition of skipjack tuna (*Katsuwonus pelamis*)". *Food Chemistry*, 17(2), 117-123. 1985.

[22] Karunarathna, K. A. A. U. and Attygalle, M. V. E, "Nutritional evaluation in five species of tuna". *Vidyodaya Journal of Sri Lanka*, 15(1), 7-16. 2010.

[23] Mumthaz, V. R., Yathavamoorthi, R., Thomas, A., James, R. and Gopal, T. K. S, "A comparative evaluation of the biochemical composition of three tuna species". *Proceedings of the National Seminar on Conservation and Sustainability of Coastal Living Resources of India*, (pp. 742-753). 2010.

[24] Clucas, C. J. and Ward, A. R, *Post-harvest Fisheries Development - A Guide to Handling Preservation Process and Quality*. Natural Resources Institute, Kent: NRI publication. 1996.

[25] Gopakumar, K, *Biochemical Composition of Indian Food Fish*. Cochin, India: Central Institute of Fish Technology. 1997.

[26] Bligh, E. G., Shaw, S. J. and Woyewoda, A. D, "Effect of drying and smoking on Lipids of fish". In J. R. Burt (Eds.). *Fish Smoking and Drying*. (pp. 41- 52). New York: Elsevier Science Publishers Ltd. 1988.

[27] Ackman, R. G, Marine lipids and fatty acids in human nutrition, In *Fishery Products*, (pp.113-131). Fishing News Ltd. 1974.

[28] Stephen, N. M., Shakila, R. J., Jeyasekaran, G. and Sukumar, D, "Effect of different types of heat processing on chemical changes in tuna". *Journal of Food Science and Technology*, 47(2), 174-181. 2010.

[29] Gopakumar, K. and Nair, M. R, "Fatty acid composition of eight species of Indian marine fish". *Journal of the Science of Food and Agriculture*, 23, 493–496. 1972.

[30] Bhuiyan, A. K. M. A., Ratnayake, W. M. N. and Ackman, R. G, "Stability of lipids and polyunsaturated fatty acids during smoking of Atlantic mackerel (*Scomber scombrus* L.)". *Journal of the American Chemical Society*, 63, 324-328. 1986.

[31] Beltran, A. and Moral, A, "Gas chromatographic estimation of oxidative deterioration in sardines during frozen storage". *Lebensmittel-Wissenschaft und-Technologie*, 23, 499-504. 1990.

[32] Sanchez-Muniz, F. J., Viejo, J. M. and Medina, R, "Deep- frying of sardines in different culinary fats changes in the fatty acid composition of sardines and frying fats". *Journal of Agricultural and Food Chemistry*, 40, 2252-2256. 1992.

[33] Bandarra, N. M., Batista, I., Nunes, M. L., Empis, J. M. and Christie, W. W, "Seasonal changes in lipid composition of sardine (*Sardina pilcharchus*)". *Journal of Food Science*, 62, 40-41. 1997.

[34] Ackman, R. G, Fatty acid composition of fish oils. In S.M. Barlow, & M.E. Stansby (Eds.) *Nutritional evaluations of long chain fatty acids in fish oils*, (pp. 25). London: Academic Press. 1982.

[35] Ackman, R. G, "Nutritional composition of fats in sea food". *Progress Food Nutritional Science*, 13, 161-289. 1989.

[36] Nettleton, J. A. and Exler, J, "Nutrient in wild and farmed fish and shellfish". *Journal of Food Science*, 57, 257-260. 1992.

[37] Saito, H., Yamashiro, R., Alasalvar, C. and Konno, T, "Influence of diet on fatty acids of three subtropical fish, subfamily caesioninae (*Caesio digrumna* and C. *tile*) and family siganidae (*Siganus canaliculatus*)". *Lipids*, 34, 1073-1082. 1999.

[38] Lal, S. P, Macro and Trace Elements in Fish and Shellfish. In A. Ruiter, (Eds.), *Fish and Fishery Products: Composition, Nutritive Properties and Stability*, (pp. 187-214). Wallingford, UK: CAB International. 1995.

[39] Kojadinovic, J., Potier, M., Le Corre, M., Cosson, R. P. and Bustamante, P, "Bioaccumulation of trace elements in pelagic fish from the Western Indian Ocean". *Environmental Pollution*, 146(2), 548-566. 2007.

[40] Karunarathna, K. A. A. U. and Attygalle, M. V. E, "Mineral spectrum in different body parts of five species of tuna consumed in Sri Lanka". *Vidyodaya Journal of Sri Lanka*, 14(11), 103-111. 2009.

[41] Kirkpatrick, D. C. and Coffin, D. E, "The trace metal content of representative Canadian diets in 1970 and 1971".*Canadian Institute of Food Science and Technology Journal*, 7, 56–58. 1974.

[42] Khan, A. H., Ali, M., Biaswas, S. K. and Hadi, D. A, "Trace elements in marine fish from the Bay of Bengal". *The Science of the Total Environment*, 61, 121-130. 1987.