

Fatty acid profiles and mineral contents of selected freshwater fishes of Maharashtra, India: A comparative analysis

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Abstract

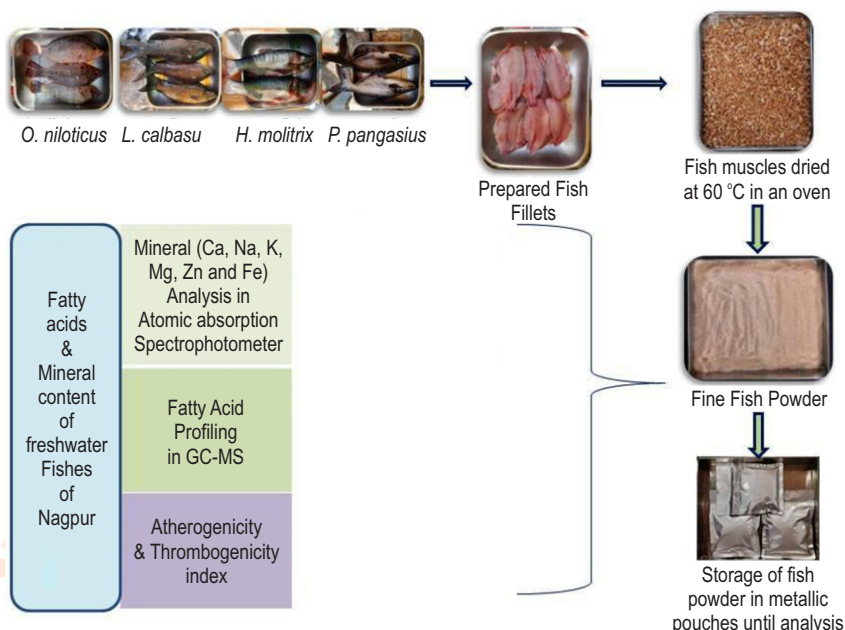
Aim: The study aimed to evaluate fatty acids and mineral content of four selected freshwater fish species.

Methodology: Fresh fish, *Labeo calbasu*, *Hypophthalmichthys molitrix*, *Oreochromis niloticus* and *Pangasianodon pangassius* were processed for preparation of fish powder. The fish powder was analyzed for fatty acids content in gas chromatography. Lipid health indices were calculated. The mineral analysis was performed using an Atomic Absorption Spectrophotometer.

Results: Among fatty acids, total saturated fatty acids (SFA) varied between 1039.09 mg 100 g⁻¹ in silver carp and 4669.58 mg 100 g⁻¹ in pangassius. Total monounsaturated fatty acids (MUFA) ranged from 1343.4 mg 100 g⁻¹ to 2419.51 mg 100 g⁻¹. Palmitic acid and Oleic acid were found to be the most dominant individual SFA and MUFA respectively in fishes. Polyunsaturated fatty acids (PUFA) content varied from 446.72 mg 100 g⁻¹ to 1221.14 mg 100 g⁻¹. Docosahexaenoic acid (5.67 mg 100 g⁻¹) and eicosapentaenoic acid (6.58 mg 100 g⁻¹) contents were found highest in tilapia. All fishes were characterized by high levels of ω-3 fatty acids than ω-6 fatty acids. Minerals such as Ca, Na, K, Mg, Zn and Fe were observed in appreciable quantities.

Interpretation: The results of the present study revealed that selected fish species have high and nutritious fatty acids and mineral composition for offering positive health benefits upon consumption.

Key words: Atherogenicity index, Freshwater fish, Fatty acids, Minerals, Thrombogenicity index



Introduction

Globally fish is considered an essential part of a healthy diet. It has been acknowledged that consuming fish is important for maintaining a healthy lifestyle. Fish contains highly digestible protein, and presence of unsaturated fatty acids, vitamins and minerals made the fish an indispensable commodity of trade in today's world. Therefore, fish food quality and its nutritional value plays a significant role in deciding market value of fish and ultimately their probable benefits on human health upon consumption. The need of healthy and nutraceutical food seems more conspicuous after effects of Covid pandemic around the world and therefore food scientists are striving hard to meet these challenges to protect human health through food intervention. In recent years, unsaturated nature of lipids found in fish has gained tremendous importance in medical science due to their functional and positive health effects on the body. Docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA) are the main active ingredients of fish lipids along with other essential fatty acids have proven immense helpful in alleviating or preventing certain types of diseases and improving the health as well. Eicosapentaenoic acid like fatty acids have been reported to exert positive effects on the cardiovascular and nervous system of children, alleviated or slowed down metabolic disorders, etc. (Dyall, 2015).

Reduction in low density lipoprotein (cholesterol), improvement in blood flow and circulation are the effects of EPA on human body (Fitria et al., 2020). On the other hand, DHA has been reported to restore brain health and optic nerves in human body. Another important category of polyunsaturated fatty acids (PUFA) includes ω -3 and ω -6 fatty acids of fishes. Antithrombotic, antiarrhythmic and anti-inflammatory activities of ω -3 fatty acids (Oppedisano et al., 2020) and thrombotic and inflammatory properties of ω -6 fatty acids was observed in human studies (Innes and Calder, 2018). In the light of dietary guidelines issued from various health organization of the world, it is recommended to upsurge the intake of ω -3 fatty acids although letting down the intake of ω -6 fatty acids through diet to promote health. Nevertheless the consumption of ω -6 fatty acids is more due to use of vegetable and animal fat (Yamashima et al., 2020) which has adversely affected human health. Thus, the antagonistic effects of ω -6 fatty acids on human health can be lessened by supplying ω -3 fatty acids through diet comprising fish. Furthermore, understanding the atherogenic index and thrombotic index of fatty acids the of four freshwater fish species would help improve dietary guidelines. Atherogenic index and thrombotic index can be used to develop recommendations aimed at improving cardiac health (Duarte et al., 2021).

These recommendations may help in selecting fish with favorable fatty acid profiles for modifying human diet as per specific needs (Weaver et al., 2008). In addition to the health beneficial effects of PUFA, fish can also be a good source of minerals such as calcium, sodium, potassium, magnesium, zinc, iron, etc. managing mineral deficiency supplied through diet (Zhang et al., 2020). Besides providing nutraceutical effects,

these minerals have an added effects of enhancing flavor and texture the food. Over the past two decades, the aquaculture industry in India has been revolutionized through promotion of aquaculture technology. Tilapia farming and its production in the country has changed consumption pattern of fish as boneless fillets, relatively easy to cook and affordable to all. Despite high oil content in the muscle, pangassius is enjoyed as a ready-to-eat or ready-to-fry in household and restaurants. Next to the Indian major carps, *Labeo calbasu* and silver carp are proteinous and palatable. These and others freshwater fishes usually consumed as a whole, can become a potential source of important raw materials for development of variety of restructured and functional foods for the purpose of nutrition due to their intrinsic characteristics.

Nagpur city of Vidarbha region in the state of Maharashtra receiving huge influx of freshwater fish including carps, tilapia, pangassius, murrel and freshwater prawn, etc. The region constituted about 49.6 % to the inland fish production of Maharashtra (Relekar et al., 2024). The region is well known for their diversified population relishing freshwater fish in the diet. As far as the quality of available fish is concerned, limited information is available on the nutritional composition of fish to the consumer, particularly on fatty acids and mineral contents. Therefore, the present study mainly focus on the fatty acids and mineral composition of selected freshwater fish, calbasu (*Labeo calbasu*), silver carp (*Hypophthalmichthys molitrix*), tilapia (*Oreochromis niloticus*) and pangassius (*Pangasianodon pangassius*) of Nagpur region, Maharashtra, India to creat awareness about the nutritional composition of the selected fishes.

Materials and Methods

Materials: Calbasu (*Labeo calbasu*), Silver carp (*Hypophthalmichthys molitrix*), Tilapia (*Oreochromis niloticus*) and Pangassius (*Pangasianodon pangassius*) fish of an average length (35.71 ± 0.71 , 40.43 ± 0.46 , 22.49 ± 0.36 , and 40.51 ± 0.42 cm) and average weight (0.89 ± 0.28 , 1.18 ± 0.59 , 0.57 ± 0.17 and 1.16 ± 0.19 Kg per fish) were procured from Mayo Fish Market, Nagpur, Maharashtra, India and brought to Fish Processing Technology laboratory College of Fishery Science, Nagpur in iced condition. After arrival, fishes were processed for dressing (de-headed, descaled, gutted) and washed with potable water and filleted. Filleted fresh fishes were minced, dried, and grounded into a fine powder with a mortar and pestle. The prepared dry fish powder was kept in appropriately labeled sterilized metallic pouches and stored at -4°C for fatty acid profiling and analysis of mineral content. The study was carried out during the period from October 2023 to March, 2024 in the College of Fishery Science, Nagpur, India.

Fatty acid profiling: The extraction of total lipids in the sample (5g) was performed using chloroform: methanol mixture (2:1) (Folch et al., 1957). The fatty acids were obtained by the saponification of total lipids with NaOH and were converted into fatty acid methyl esters (FAMES) by methylation. The fatty acid methyl ester (FAME) was investigated by gas chromatography

with FID (Model HP 6890, Hewlett-Packard) equipped with a dB-wax column (25 9 25 mm; film thickness 0.25 mm) along with helium as a carrier gas. The sample was injected at a split mode injection port with a 1:15 split ratio at 250 °C, and the oven temperature was programmed to increase from 50 to 230 °C in steps of 10 °C min⁻¹ and then remain stable for 35 min. A suitable standard was applied for identification and quantification of individual fatty acids and the values of fatty acids were expressed as mg 100 g⁻¹ of fat (AOAC, 2005).

Lipid health indices: Lipid health indices were calculated based on the atherogenicity (IA) and thrombogenicity (IT) index described by Ulbricht and Southgate (1991). Atherogenicity index mainly refers to the ratio between the main saturated fatty acids (C12, C14 and C16) and the sum of MUFA and PUFA. The thrombogenicity index is denoted as the ratio between pro-thrombogenic and anti-thrombogenic fatty acids. IA and IT were calculated by using the formula of Ulbricht and Southgate (1991).

Mineral analysis: The digestion method was followed for mineral (Ca, Mg, Na, K and Zn) analysis (AOAC, 2005; Paul *et al.*, 2014). The fish meat sample (3 g) was incinerated in the muffle furnace for determination of ash content and finally the resultant ash was digested with 2.5 ml HNO and 60% perchloric acid for minerals estimation. The minerals were analyzed by Atomic Absorption Spectrophotometer (AAS) (Model No. novAA 350). Values of minerals were expressed in mg 100 g⁻¹.

Statistical analysis: The experimental data were obtained in triplicate and expressed as mean ± S.D. The data were subjected to one-way ANOVA and the means were compared using Tukey's Multiple-Range Test. The statistical analysis of the data was performed by Statistical Packages for Social Science software (SPSS 8.0 for Windows developed by SPSS Inc., Chicago, IL). The statistical significance level was identified at *P* value ≤ 0.05.

Results and Discussion

The fishes in aquatic environment generally feed on a diverse range of food items available in the trophic level. The fish used in the study were sourced from capture as well as culture environment. Table 1 shows the varied and diverse composition of fatty acids among the fishes under study. Among all the species studied, the total saturated fatty acids (SFA) content ranged from 1039.09 mg 100 g⁻¹ to 4669.58 mg 100 g⁻¹. Palmitic acid was the most abundant SFA found in all species, with the highest content reported (3973.36 mg 100 g⁻¹) in pangassius. Stearic acid was the second most dominant SFA found in silver carp, while lignoceric acid in tilapia and myristic acid in pangassius. Monounsaturated fatty acids (MUFA) content in the present study varied from 1343.4 mg 100 g⁻¹ to 2419.51 mg 100 g⁻¹ with the highest oleic acid content found between 46.09 mg 100 g⁻¹ to 1855.09 mg 100 g⁻¹ in all fish species. The lowest MUFA concentration was observed in silver carp, while the highest was observed in pangassius. Other important MUFA palmitoleic acid and nervonic acid were also recorded in appreciable amounts in calbasu, silver carp, tilapia

and pangassius. Erucic acid was not detected in pangassius, which is a characteristic of oily fish muscle (Sissener *et al.*, 2018).

The content of erucic acid is responsible for lipidosis of heart muscle and tissue injury in human body (Bremer and Norum, 1982). Therefore, current study showed that pangassius is although good for consumption as compared to other fishes from an erucic acid point of view. Fish is a good source of long-chain polyunsaturated fatty acids (PUFA) and has several health benefits in the prevention and healing of diseases in humans such as diminishing liver steatosis, appropriate to avert cardiovascular diseases, rheumatoid arthritis and brain-related disorders (Zula and Desta, 2021). Moreover, long-chain PUFA reduces the risk of developing pain in older adults and provide protection against Alzheimer's disease (Wood *et al.*, 2022). The PUFA's content in all fish species varied from 446.72 mg 100 g⁻¹ to 1221.14 mg 100 g⁻¹. The highest content of linolenic acid was reported in pangassius (740.40 mg 100 g⁻¹) and calbasu (378.07 mg 100 g⁻¹), Cis-11,14,17-Eicsatrienoic in silver carp (318.08 mg 100 g⁻¹) and tilapia (348.12 mg 100 g⁻¹) among the PUFA. In fish, linolenic acid is generally responsible for the production of Docosahexaenoic acid (Kacar and Bashan, 2016).

DHA is the most vital nutrient during early stage of human brain development and critical role in lactation and pregnancy (Echeverria, 2017). In the present study, the higher concentration of EPA (6.58 mg 100 g⁻¹) and DHA (5.67 mg 100 g⁻¹) was observed in tilapia, and the lowest EPA (3.94 mg 100 g⁻¹) and DHA (3.28 mg 100 g⁻¹) in silver carp. However, similar values for EPA and DHA were observed in calbasu and silver carp. The lower EPA and DHA content in these fishes is mainly due to the lower contents of linolenic acid in fish. The higher content of EPA and DHA clearly indicated that tilapia fed on artificial food since fish feeding on artificial food contains more n-3 fatty acids (Krzebietke, 2017). In contrast to the present results of EPA and DHA for tilapia, a higher content of EPA and DHA was reported by Zula and Desta (2021). Thus, it can be stated that freshwater fish would be an appropriate source of essential fatty acids including EPA and DHA for human consumption to maintain a healthy life.

Several health organizations of the world have defined their recommended daily intake of EPA and DHA requirements through fish consumption. European Food Safety Authority recommends nearly 200 mg DHA and EPA per day or 1-2 size of fatty fish per week to prevent cardiovascular diseases (EFSA, 2010). The American Dietetic Association (ADA) recommends an average of 500 mg of total EPA and DHA per day or two 4-ounce (after cooking) servings of fatty fish per week. The American Heart Association (AHA) recommends two servings of fatty fish per week. The World Health Organization (WHO) recommends one to two servings of fish per week, with each serving providing 200 to 500 mg of total EPA and DHA, respectively (Kris-Etherton *et al.*, 2002). The Child Health Foundation recommends that pregnant and lactating women should receive an average of at least 200 mg per day of DHA (Koletzko *et al.*, 2008). In this study, the order of highest fatty acids (SFA, MUFA, PUFA) in fish were as follows:

Table 1: Fatty Acid (FA) composition (mg 100 g⁻¹) of selected freshwater fishes of Maharashtra, India

Fish species				
Fatty acids (mg 100 g ⁻¹)	<i>L. calbasu</i>	<i>H. molitrix</i>	<i>O. niloticus</i>	<i>P. pangassius</i>
Saturated Fatty Acids (SFA)				
Lauric Acid (C12:0)	8.32±0.02 ^c	-	6.26±0.01 ^b	13.2±0.02 ^d
Tridecanoic Acid (C13:0)	-	-	1.46±0.01 ^b	-
Myristic Acid (C14:0)	28.45±0.01 ^b	-	131.45±0.01 ^c	295.48±0.02 ^d
Pentadecanoic Acid (C15:0)	17.50±0.01 ^b	-	37.50±0.04 ^d	18.61±0.01 ^c
Palmitic Acid (C16:0)	1023.46±0.02 ^b	575.17±0.02 ^a	1065.37±0.02 ^c	3973.36±0.04 ^d
Heptadecanoic Acid (C17:0)	22.57±0.03 ^b	27.46±0.02 ^c	72.77±0.03 ^d	15.90±0.01 ^a
Stearic Acid (C18:0)	280.83±0.02 ^c	308.70±0.01 ^d	203.44±0.04 ^b	69.36±0.06 ^a
Arachidic Acid (C20:0)	68.8±0.05 ^c	62.05±0.04 ^b	59.25±0.01 ^a	83.47±0.01 ^d
Heneicodenoic Acid (C21:0)	30.59±0.01 ^c	10.31±0.01 ^a	13.68±0.05 ^b	84.47±0.03 ^d
Bhenic Acid (C22:0)	124.77±0.02 ^d	11.38±0.02 ^b	11.95±0.01 ^c	8.73±0.03 ^a
Tricosanoic Acid (C23:0)	7.24±0.02 ^b	6.99±0.01 ^a	12.06±0.01 ^c	15.02±0.02 ^d
Lingnoceric Acid (C24:0)	63.49±0.01 ^b	37.03±0.03 ^a	163.41±0.01 ^d	91.98±0.02 ^c
ΣSFA	1776.02	1039.09	1778.6	4669.58
Monounsaturated Fatty Acids (MUFA)				
Myristoleic Acid (C14:1)	7.16±0.04 ^b	-	36.17±0.01 ^d	7.82±0.02 ^c
Cis-10-Pentadecanoic Acid (C15:1)	4.70±0.02 ^b	-	16.91±0.01 ^c	-
Palmetoleic Acid (C16:1)	322.23±0.01 ^d	227.54±0.04 ^b	322.06±0.04 ^c	196.29±0.04 ^a
Cis-10-Heptadecanoic Acid (C17:1)	12.43±0.03 ^b	-	20.84±0.02 ^c	-
Elaidic Acid (C18:1)	87.25±0.01 ^a	295.99±0.01 ^d	174.30±0.02 ^c	113.52±0.02 ^b
Oleic Acid (C18:1)	1051.00±1.00 ^c	46.09±0.01 ^a	865.84±0.02 ^b	1855.09±0.01 ^d
Cis-11-Eicosenic Acid (C20:1)	57.68±0.02 ^d	11.86±0.02 ^b	5.51±0.02 ^a	15.54±0.04 ^c
Erucic (C22:1)	40.50±0.01 ^b	232.82±0.01 ^d	173.29±0.01 ^c	-
Nervonic Acid (C24:1)	187.79±0.01 ^a	529.10±0.02 ^d	379.72±0.02 ^c	231.25±0.03 ^b
ΣMUFA	1770.94	1343.4	1994.64	2419.51
Polyunsaturated fatty acids (PUFA)				
Linolelaidic Acid (C18:2)	2.47±0.03 ^b	-	4.07±0.03 ^c	29.52±0.02 ^d
Linoleic Acid	8.95±0.02 ^c	8.29±0.03 ^b	95.55±0.01 ^d	-
Linolenic Acid	378.07±0.06 ^c	93.41±0.04 ^a	135.88±0.04 ^b	740.40±0.09 ^d
Cis-11,14 Eicosadienoic Acid (C20:2)	9.34±0.02 ^a	10.33±0.03 ^b	30.22±0.02 ^c	149.65±0.05 ^d
8,11,14-Eicosadienoic Acid (C20:3)	5.88±0.01 ^b	-	11.08±0.01 ^c	12.68±0.03 ^d
Arachidonic Acid	31.04±0.03 ^b	9.94±0.02 ^a	34.43±0.02 ^c	90.75±0.05 ^d
Cis-11,14,17-Eicatrienoic Acid (C20:3)	12.72±0.02 ^a	318.08±0.02 ^c	348.12±0.02 ^d	187.89±0.01 ^b
EPA (C20:5)	5.56±0.01 ^b	3.94±0.04 ^a	6.58±0.01 ^c	5.69±0.01 ^b
Cis-13,16-Docosadienoic Acid (C22:2)	7.09±0.01 ^b	-	8.22±0.05 ^c	-
DHA (C22:6)	4.98±0.02 ^b	3.28±0.02 ^a	5.67±0.01 ^b	4.96±0.03 ^b
ΣPUFA	465.8	446.72	679.85	1221.14
Σ ω-6	64.77	28.56	183.57	282.60
Σ ω-3	399.95	418.88	495.84	938.54
PUFA/SFA	0.242	0.74	0.31	0.25
ω-6/ ω-3	0.16	0.07	0.37	0.30
IA	0.69	0.32	0.59	1.41
IT	0.67	0.45	0.54	1.04

Data (n=3) are expressed as mean ± S.D. According to Tukey's test, different superscripts in the same row signify statistical difference (P<0.05).

pangassius> tilapia> calbasu > silver carp. Pangassius and tilapia are the most widely cultured fish species in India and are mostly fed on artificial diets, which may be the reason for higher fatty acid content in these fishes. The fatty acid composition may also differ

due to the physiology and morphology of fish species (Rahman et al., 2019). The lower PUFA content observed in silver carp may be due to different geographical locations and wild-captured fish. Similar finding was reported by Kacar and Bashan (2016), who

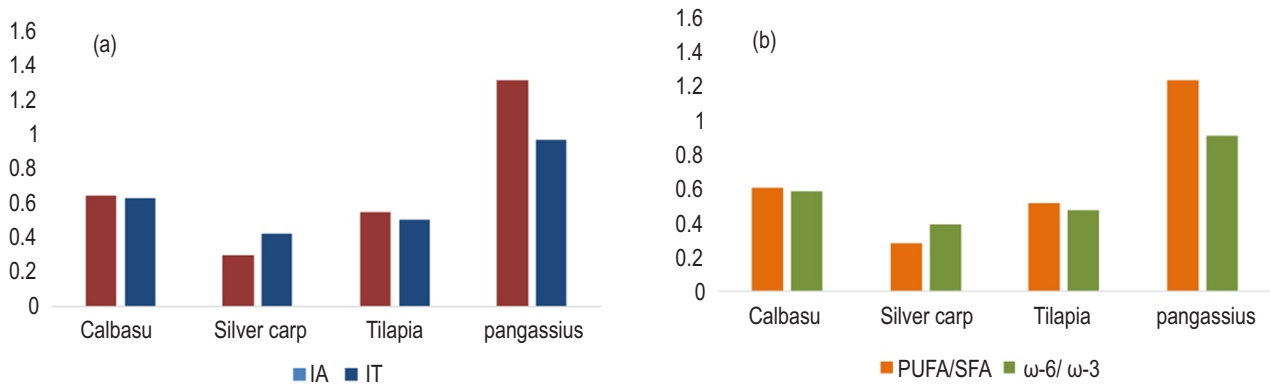


Fig. 1: (a) Atherogenicity (IA) and thrombogenicity (IT) index value of freshwater fish; (b) Ratio of PUFA and SFA and ω -6/ ω -3 of freshwater fish. Values are mean of three replicates \pm S.D

worked on fatty acid composition of wild fishes caught from the lake of Turkey. Palmitic acid and oleic acid were the most predominant SFA and MUFA in all fish species. Similar to the finding of the present study, Paul *et al.* (2018) and Azarita *et al.* (2024) reported palmitic acid as predominant SFA followed by stearic acid and myristic acid, and the oleic acid was detected as a major source of MUFA in freshwater fish viz., *Mystus vittatus*, *Ompok bimaculatus*, *Channa striata*, *Wallago attu* and *Pangasianodon hypophthalmus*.

Islam *et al.* (2021) in their study reported stearic acid and palmitic acid as the most prominent SFA, whilst elaidic acid was confirmed as the most significant MUFA and linolenic acid was found to be the dominant PUFA in wild, pond, gher and cage cultured tilapia. The results of the present study are also in agreement with results reported by Richard *et al.* (2017), who confirmed that freshwater fish is a good source of fatty acids (SFA, MUFA and PUFA) along with ω 3/ ω 6 fatty acids as (1:27). Palmitic acid and stearic acid were significant SFA, oleic acid and linoleic acids were prominent MUFA and PUFA in calbasu and silver carp (Paul *et al.*, 2018; Ahmed *et al.*, 2020). On the other hand, a similar finding was reported by Sokamte *et al.* (2020) who clearly stated that palmitic acid and stearic acid were noteworthy SFA, oleic acid was major MUFA, and linoleic and arachidonic acid were prominent PUFA along with n-6/n-3 (6.94:7.05) in fresh and smoked pangasius fillet, respectively.

The freshwater fish generally contain higher levels of n-6 fatty acids than n-3 fatty acids (Kacar and Bashan, 2016). The ratio of n-6/n-3 and PUFA/SFA is of great importance for obtaining health benefits in human body. The diet should contain a higher amount of n-3 PUFA than n-6 PUFA to achieve optimal health benefits (Panpipat and Yongsawatdigul, 2008), as found in the current study. In our study, n-6/n-3 ratio ranged between 0.07 in silver carp to 0.37 in tilapia, which is considered good from a nutritional point of view. Garg *et al.* (2006), demonstrated that the ratio of n-6/n-3 should not exceed 4-1 as far as health benefits are concerned, which was lower in this study revealing that fish under

study were good for consumption. In a recent study, Azarita *et al.* (2024) also recorded ratio ω -6/ ω -3 to be 0.82, 1.11 and 1.02 in *H. nemurus*, *H. wyckii* and in *M. nigriceps*, respectively. The ratio of n3/n6 in the present study varied between 2.70 in tilapia to 14.66 in silver carp. Tilami *et al.* (2018) observed n3/n6 ratio of 1.7 in commercially important river fish species of Czech Republic. The variation in fatty acid composition in these fishes could be the effect of natural or artificial feed composition and varied with different geographical locations (Tilami *et al.*, 2018). Also, n-3 fatty acid levels were higher in herbivorous and planktivorous fish compared to carnivorous fish (Devadawson *et al.*, 2016).

The relationship between pro-thrombogenic (SFA) and anti-thrombogenic fatty acids (MUFA, n-6, and n-3 PUFA) is expressed by atherogenicity (IA) and thrombogenicity (IT) index of fatty acids in the food, which describes the risk for the development of cardiovascular diseases. Moreover, the atherosclerosis index can be used as a preliminary indicator of acceleration of atherosclerosis related to multiple inflammatory pathways (Acay *et al.*, 2014) and IT confirms a propensity of clot formation in blood vessels. In the present study, the atherogenicity index value of silver carp was lowest, (0.32) followed by tilapia (0.59), calbasu (0.69) and highest in pangassius (1.41). Similar the thrombogenicity index was in the order: silver < tilapia < calbasu < pangassius. The atherogenicity index and thrombogenicity index values found in the selected freshwater fishes, except pangassius were nearly close to the value noted for the Eskimo diet (IA 0.39 and IT 0.28) and as per FAO/WHO (1994) recommended value ranged between 0.4 to 0.5, which shows low chance of coronary heart disease (Ulbricht and Southgate, 1991). Monterio *et al.* (2017) and Tilami *et al.* (2018) also noticed similar values of atherogenicity and thrombogenicity index in their studies. Generally, lower and index were found in wild fish. In the present study, silver carp and calbasu were sourced from wild environment, while tilapia was collected either from wild or culture and pangassius exclusively from culture environment. The herbivorous, planktonic and omnivorous species exhibited higher atherogenic index and

Table 2: Mineral contents (mg 100 g⁻¹) of selected freshwater fishes of Maharashtra, India

Minerals	Fish species			
	<i>L. calbasu</i>	<i>H. molitrix</i>	<i>O. niloticus</i>	<i>P. pangassius</i>
Calcium	168.38±0.55 ^d	113.92±0.06 ^c	86.10±0.01 ^a	110.27±0.05 ^b
Sodium	38.16±0.51 ^a	38.79±0.16 ^a	55.93±0.31 ^c	48.06±0.30 ^b
Potassium	142.46±0.92 ^a	224.63±0.02 ^b	121.40±0.4 ^a	110.06±0.41 ^a
Magnesium	7.20±0.20 ^d	3.92±0.16 ^b	6.53±0.40 ^c	2.76±0.24 ^a
Zinc	0.74±0.05 ^a	1.60±0.20 ^b	1.62±0.21 ^b	1.70±0.24 ^b
Iron	0.43±0.02 ^a	0.47±0.03 ^a	0.64±0.05 ^c	0.57±0.01 ^b

Values are mean of three replicates ±S.D. According to Tukey's test, different superscripts in the same row signify statistical difference ($P < 0.05$).

thrombotic index values due to higher saturated fatty acid contents in the flesh, whereas carnivorous species showed lower atherogenic index and thrombotic index values (Devadawson et al., 2016).

The most significant mineral constituents found in fish in appreciable amounts are calcium, magnesium, sodium, potassium and phosphorus (macro-elements), while iodine, iron, fluorine and selenium (micro-elements) are important from the functionality point of view (Usyudus et al., 2008). Minerals are the basic unit of different enzymes and help in different metabolic processes and fish growth (Ullah et al., 2022). These minerals take part in the osteal system and tooth tissue generation, cell regeneration, regulate blood pH and growth process, the regulation of metabolic responses (Lenntech, 2013). Ca (1300 mg), Na (2300 mg), Mg (420 mg), K (4700 mg), Zn (11 mg), and Fe (18 mg) are the current daily values, or Adequate Intake (AI), of minerals that the FDA (2023) recommended for adult.

The mineral (Ca, Na, Mg, K, Zn, Fe) composition of freshwater fish species under study is presented in Table 2. The edible dry powder of fish was used for the estimation of mineral content. The calcium content ranged between 86.10 to 168.38 mg 100 g⁻¹. The highest sodium content was noticed in the tilapia (55.93 mg 100 g⁻¹), while the lowest was recorded in calbasu (38.16 mg 100 g⁻¹). Potassium content was found higher (224.63 mg 100 g⁻¹) in silver carp and lower (110.06 mg 100 g⁻¹) in pangassius. The magnesium, Zinc and Iron were found in the range of 2.76–7.20 mg 100 g⁻¹, 0.74–1.70 mg 100 g⁻¹ and 0.43 to 0.64 mg 100 g⁻¹, respectively, in all species. Usually, the freshwater fish contains lesser amount of minerals as compared to marine water fish except for potassium content (Ullah et al., 2022). In a study by Azarita et al. (2024), Ca and P were found in the higher quantum in three bagridae fish species of Kampar Kanan River, Indonesia, which were from 1.49 mg g⁻¹ to 1.66 mg g⁻¹ and 2.74 to 7.03 mg g⁻¹ respectively. Paul et al. (2018) also observed varied results for the mineral content in the minor carps than in the present study.

Paul et al. (2018) measured minerals like K (116.41 to 145.08 mg/kg), Na (39.09 to 61.29 mg kg⁻¹), Fe (0.43 to 0.66 mg kg⁻¹) and Zn (0.57 to 0.80 mg kg⁻¹) from edible meat of minor carps.

However, the calcium content in the minor carp was found higher in *L. calbasu* (195 mg 100g⁻¹) than in the present study. The variation in mineral composition of fresh and marine water fishes was observed (Ullah et al., 2022) compared to the present study. In a study of Ullah et al. (2022), the maximum and minimum Ca content was found in *S. phasa* (3.495%) and *P. pangassius* (0.55%). Also, Mg content ranged between 0.28% to 1.88%. The higher and lower content of P was observed in *S. phasa* (2.11%) and *L. saval* (0.826%), respectively. The variation in mineral content may also be due to the diverse nature of nutrients in the wild and limited availability of nutrients particularly in feed in the cultured environment (Mustafa et al., 2022), which are also in line with the current study. Tilapia and pangassius used in the present study are generally harvested from a cultured environment, while calbasu and silver carp were captured from a wild environment. Therefore, varied mineral composition was expected in the meat of these fishes.

The study demonstrates notable variations in the composition of fatty acids and mineral content in freshwater fish species. Selected species provide significant amounts of polyunsaturated fatty acids (PUFAs), specifically EPA and DHA, with levels ranging from 3.28 mg 100 g⁻¹ to 6.58 mg 100g⁻¹. These fish exhibit higher omega-3 fatty acid content compared to omega-6 fatty acids. From saturated fatty acids point of view, freshwater fish present a heart-healthy alternative to red meat along with minerals like Ca, Na, K, Mg, Zn, and Fe. This information would be helpful for consumers as well for health organizations, promoting fish consumption as a means to achieve optimal health benefits and prevent nutritional disorders stemming from nutrient deficiencies.

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