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RESEARCH ARTICLE

Trace metal exposure and human health consequences through consumption of market-available *Oreochromis niloticus* (L.) in Bangladesh

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Abstract

Using *Oreochromis niloticus* (L.), commonly known as tilapia, as a model, this study evaluated the exposure of trace metal and their risk assessment on human health. In addition, the status of amino acids, fatty acids, vital elements, and their benefits is also studied. Estimating the nutrient composition of fish muscle is necessary to ensure that it meets the requirements for human health, food regulations, and commercial specifications. The species examined contained appreciable concentrations of amino acids, fatty acid content, and minerals, suggesting that the fish species could be a good source of protein, fat, and minerals. Hazardous heavy metals were found to be lower compared to their corresponding maximum tolerable limits. The order of trace metals is Zn (22,709 μg/kg) > Fe (19,878 μg/kg) > Cu (1261 μg /kg) > Mn (1228 μg/kg) > Cr (474 μg/kg) > Ni (152 μg/kg) As (318 μg /kg) > Pb (281 μg/kg) > Co (24 μg /kg) > Cd (13 μg/kg) > Hg (5 μg/kg); a number of health-related indices, including estimated daily intake (EDI), target hazard quotient (THQ), and hazard index (HI), as well as carcinogenic risk (CR) indices for adult and children, were calculated to evaluate the human health hazard of the heavy metals. The THQ and HI of heavy metals for tilapia are lower than 1, posing a non-carcinogenic threat to human health due to the biomagnifications of these deadly poisonous metals. Principal component, cluster, and correlation analyses delineated the common probabilistic sources of metal contamination origin and significant inter-parameter associations. Although no human health risks for the consumption of tilapia was found, more attention must be paid for the monitoring of *Oreochromis niloticus* before entering the market.

Keywords *Oreochromis niloticus* (L.) · Trace metals · Amino acid · Fatty acid · Mineral · Human health consequences

Introduction

On one side, consumption of fish is for high proteins, amino acids (Fuentes et al. 2009), and low content of fat and calories (Cozzolino 2001; Fakhri et al. 2018; Miri et al. 2017; Longo et al. 2013), polyunsaturated fatty acid, minerals, nutrients, vitamins, and energy of human beings. On the other, partaking of fish can cause a potentially lethal disease to vulnerable people because they accumulate toxic elements from the aquatic environment (Chakraborty et al. 2010) through feed, suspended solids, and gills (Ahmed et al. 2016). Potentially toxic elements like As, Cd, Hg, and Pb have a detrimental influence on aquatic organisms and humans and are carcinogenic even at low concentrations (Hossain et al. 2019, Anandkumar et al. 2018). Prolonged uptake of heavy metal–contaminated fish causes acute

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diseases in humans such as brain damages by Pb; kidney and liver dysfunction by As, Cd, Cr, Co, Cu, and Ni; bronchial failure by Ni; ulcer, cough, and asthma caused by Cr (Sobhanardakani 2017b); cardiovascular disorder by Cd and Co; nervous system disorders by Cu (Hossain et al. 2021a,b; Ahmed et al. 2020; Sobhanardakani et al. 2018; Anandkumar et al. 2018); and dermatitis caused by Co and also cancer (Davodpour et al. 2019).

Despite being a freshwater fish, tilapia has the component of polyunsaturated fatty acids, for instance, 20:5 n-3 (EPA) and 22:6 n-3 (DHA). The lipids of freshwater fish provide a balanced n-3/ n-6 PUFA supply which is inevitable for both rearing healthy fish and producing valuable food for the mass population. The prevention of cardiovascular disease, improvement of visual acuity, and fortification of mental health are the benefits of healthy fats and omega-3 (n-3) fatty acids. According to the report of Kris-Etherton et al. (2002), two 4-oz (113 g) servings of fatty fish that are rich in omega-3 fats per week are recommended by the American Heart Association (AHA). Most importantly, the building blocks of proteins are the amino acids; both essential and non-essential amino acids synthesize protein, which is essential for the growth and development of infants to adults. Elements including Co, Cu, Fe, and Zn are essential for optimum fish growth, and a lack of essential elements can harm human health. Surprisingly, essential metals can be toxic when their concentrations exceed the maximum permissible limit (Xu et al. 2021). Different metals are accumulated in the fish body in various concentrations depending on factors such as age, feeding habit, geography, sex, size, swimming pattern, and reproductive cycle (Bawuro et al. 2018; Tasnim et al. 2010). Metal accumulation in tilapia fish may offset the fish consumption for health benefit and also high demand for health risk assessment.

Commonly, the miracle of aquaculture and poor man fish, tilapia, seems to be accepted by all walks of life in Bangladesh. So consumption of tilapia at the household level has been increasing among women, children, young, and old because of the year-round availability of affordable tilapia fish as well as price hikes standalone and paucity of hilsa fish. In general, the cream of society paid only for large tilapia from the organized supermarket. At the same time, more middle-income plain folk purchased marketable size tilapia from either supermarket or kitchen markets. The large segments of the unprivileged poverty-stricken chattering cohort tended to put forth an effort to obtain small (5–6 fish/kg) tilapia from the unstructured kitchen market for meeting the soaring demand for food. Historically, tilapia marketing is a traditional chain enclosed by primary, wholesale, and retail markets (Ahmed et al. 2012) that play a pivotal role in the consumers buying tilapia.

Having graduated as a lower-middle-income country, Bangladesh is facing severe water pollution problems due to the excessive discharge of toxic trace elements from natural and anthropogenic activities (Ahmed et al. 2015). The presence of poisonous metal in tilapia muscle is an alarming finding in more recent studies (Islam et al. 2021; Parvin et al. 2019) of Bangladesh, and so the quality of long historical tilapia fish is of prime importance in the context of massive human health. Until today there are no systematic research works on the health benefit and risk assessment of market-available tilapia in Bangladesh. Importantly, tilapia is the second highest market demand and prime protein source of the major population in Bangladesh; there must be an urgent need for systematic holistic analysis of nutrient contents, fatty acids, and amino acid analysis, and the detrimental effect of heavy metals on human health. Notwithstanding, to the best of my knowledge, our group for the first time was doing systematic baseline studies of minerals, fatty acids, amino acids, and the detrimental impact of trace and toxic metals on human health, and results were interpreted based on statistical analysis; subsequently, findings were compared with reference values of various sources of market-available tilapia.

Materials and methods

Study area and sample collection

A total of 150 samples of fish were collected from three main retail outlets—wholesale market, super shop, and kitchen market in Bangladesh. They are the major contributors to the country's tilapia fish. The fish were placed on ice and kept in the refrigerator. Fish samples are divided into three clusters based on the market.

Sample preparation

The fish samples collected from markets were thoroughly washed with tap water and distilled water to remove any adhering contaminants. The body weight and total, standard, tail, head, and a fork length of tilapia were measured. After dissecting the fish samples with a knife, non-edible parts (intestines, guts, and bones) were removed. The muscle samples were then homogenized into a fine mesh with an electric food blender and later stored in a deep freezer (− 18 °C) before analysis. Representative samples were subjected to nutritional analysis as described by the different methods.

Reagent

A 68% concentrated nitric acid (guaranteed reagent), and 30% hydrogen peroxide solution (Guaranteed reagent) was purchased from Sigma-Aldrich. Multi-element standard solution XIII came from Supelco. Certified reference materials (SRM2976, National Institute of Standards) were used to validate the accuracy of analytical methods. Other reagents were of analytical grade, and the blank levels of metal contents were confirmed to guarantee free of target metals.

Instrumentation

Amino acid analyzer

An amino acid analyzer (Shimadzu, Japan) determined the amino acid profile. The instructions for the amino acid analysis system were used to conduct the analysis (Anonymous 1993). The system of a column (Amino-Na) packed with a strongly acidic cation exchange resin was used by the amino acid analyzer for separation. The injected amino acids were separated using a binary gradient eluting process, and each amino acid was therefore identified using a fluorescence detector at high sensitivity and 120 kgf/cm^2 pressure.

Gas chromatograph

A gas chromatograph (Shimadzu GC-14B, Japan) fitted with a flame ionization detector, and a fused silica capillary column (FAMEWAX, Crossbond® polyethylene glycol, 15 m × 0.25 mm × 0.25 m film thickness, Restek, Pennsylvania, USA) was used to examine the fatty acid composition. Nitrogen was employed as the carrier gas in a splitless injection approach with a constant flow rate of 20 ml/min. The initial oven temperature was 150 °C, held for 5 min, while the injector temperature was 250 °C. The temperature was raised to 190 °C at an 8 °C/min rate, then held at 200 °C for 10 min at a 2 °C/min rate. The fatty acids were identified using the corresponding fatty acid methyl ester standards (FAME mix), and the automated GC software then displayed the results as relative percentages (Class GC-10, version-2.00).

ICPMS and AAS spectrophotometer

Concentration of trace metals including As, Cr, Cd, Co, Pb, Ni, Cu, and Hg were detected and quantified by using inductively coupled plasma-mass s(ICP-MS, NexION 2000, Perkin Elmer, USA). Other metals such as Ca, Mg, Fe, Mn, and Zn were analyzed by a flame atomic absorption spectrophotometer (Shimadzu AAS-7000, Japan).

Sample analysis

Amino acid analysis

The tilapia epidermis and muscles were used for the amino acid analyses. A fine powder was created using a pestle and mortar, after which dried materials were crushed with 6N HCl. It was then filtered in a flask with a 250-ml round container. The 250-ml round flask containing the filtrate was heated at 110 °C for 22 h. The resulting solution was kept in an evaporating dish to evaporate the HCl in the water bath. Then, it was filtered through Whatman No. 41 filter paper into a 25-ml volumetric flask and diluted with 0.1N HCl. An amino acid analyzer was used to test the fluid. The analyzer displayed two curves: one for the known solution and another for the standard solution. Amino acids were computed by comparing the areas of the two curves: [% of Amino Acid = Area of Sample Solution* Conc. of Amino Acid/Area of Standard Solution].

Fatty acid evaluation

Preparation of fatty acid methyl ester (FAME)

The method was given to assess the relative content of fatty acids (FA) from oil samples as their corresponding methyl esters. In a 15-ml test tube, 5–7 droplets of oil were added, followed by 3 ml of 0.5 M sodium methoxide (made by combining metallic sodium with methanol), which was then stirred in a boiling water bath for around 15 min to digest the oil. As soon as it reached room temperature, 1 ml of petroleum ether (b.p. 40–60 °C) and 10 ml of deionized water were added, gently mixed, and left to sit for 5–6 min. Petroleum ether's distinct upper layer of methyl ester was carefully sorted out and placed in a vial with a cap for analysis. In a series of screw-capped test tubes, 10 ml of petroleum ether (b.p. 40–60 °C) was used to dissolve 200 mg of each of the different fatty acid standards in their corresponding methyl ester form. The data processor unit of the GC recorded the peaks of fatty acids for their retention times and regions after injecting aliquots of 1 µl fatty acid methyl ester (FAME).

Metal analysis

For the analysis, randomly selected amounts of 05–10 g of muscle tissue from the three cluster of fish samples were taken. The tissues were dried in an oven set at 70 to 73 °C until their weight remained constant. After being reduced to a fine powder, the samples were dried off in desiccators to prevent moisture buildup before digestion. The digesting process was performed by the following instructions (Mostafiz et al. 2020). About 0.50 g of tissue (dry mass) was added to a 100-ml Erlenmeyer flask along with 10 ml of concentrated nitric acid (68%) and 5 ml of concentrated perchloric acid (70%). The digestion was carried out until the solutions were clear on a hotplate (200 to 250 °C). The solutions were diluted to a maximum of 50 ml with distilled water and passed through an acid-resistant 0.45-mm filter paper. In a UV–Vis spectrophotometer, phosphorus was measured. In a flame photometer, sodium and potassium concentrations were measured. The samples were first stored in clean glass vials and diluted with extremely pure 2% HNO_3 acid before being determined by an ICPMS spectrometer (Hossain et al. 2021a, b). Among the minerals examined were manganese, iron, chromium, copper, arsenic, cadmium, lead, cobalt, mercury, and nickel. The mineral composition was calculated in g/g-ww. A flame photometer was used to detect potassium, and a UV–Vis spectrophotometer was used to measure other minerals like phosphorus.

Assurance/quality control (QA/QC)

For every digestion batch, duplicate prepared samples, reagent blanks, and verified reference material were utilized randomly throughout the measurement to maintain quality assurance and quality control. The observed high sample recovery between 95 and 101% met the quality criteria of sample recovery between 95 and 104% (Shorna et al. 2021).

Human health risk assessment

The process of estimating the type and potential of adverse health consequences in humans who may be exposed to toxins and chemicals now or in the future is known as human health risk assessment (Sobhanardakani 2017a).

Estimated daily intake of trace metals

The estimated daily intake (EDI) of trace metals through the consumption of fish was calculated by using the following equation (Ahmed et al. 2015; Shaheen et al. 2016; Storelli et al. 2020):

$$\mathrm{EDI} = \frac{CXF \times IR}{BW}$$

where C is the concentration of trace metals in fish samples (mg/kg-ww), F is conversion factor (0.085) used to convert fresh weight into dry weight, IR is fish consumption rate (5.0×10^{-3} kg per person per day), and BW is average body weight (70.0 kg for adults and 15.0 kg for children), respectively (Tayebi and Sobhanardakani 2020). The maximum tolerable daily intake (MTDI) was derived from various food safety limits for trace metals and recommended by numerous authorities, including the World Health Organization, the Joint FAO/WHO Expert Committee on Food Additives, and the European Food Safety Authority (EFSA), and was compared with the EDIs (European Food Safety Authority).

Non-carcinogenic risk estimation

The target hazard quotient (THQ) approach was followed to assess the non-carcinogenic health risk for individual metals through a single route of exposure (fish consumption for the present case). In contrast, the hazard index (HI) was calculated for THQs to collectively determine the potential risk from exposure to all metals. The THQ and HI values were estimated using equations by Shorna et al. (2021) and Yu et al. (2012) and Ahmed et al. (2015), respectively.

$$\mathrm{THQ}\frac{EFr \times ED \times FIR \times C}{BRfD \times BW \times AT} \times 10^{-3}$$

$$HI = THQ_{As} + THQ_{Pb} + THQ_{Cd} + THQ_{c} + THQ_{Ni+}THQ_{Cu} - - - - - THQ_{Zn}$$

where EFr (365 days per year) is the exposure frequency, ED (70 years) is the exposure duration, AT (365 days per year ED) is the averaging time for non-carcinogens, and RfD (mg/kg/day) is the oral reference. It is uncommon for a single metal to suffer non-carcinogenic health effects in humans below the THQ of that metal (i.e., RfD) from a single exposure pathway.

Conversely, HI denotes the overall health risk posed by metals. A detrimental impact is not detrimental to public health if the HI value is less than 1, and a negative effect would be a concern for human health if the HI value is greater than 1.

Carcinogenic risk (CR) analysis

The following equation is used to compute the target cancer risk (CR), which is used to evaluate the carcinogenic risk.

$$CR = EDI \times CSF$$

where CSF cancer slope factor

The USEPA (2010) states that the safe range for CR is 10^{-4} to 10^{-6}. A carcinogenic risk impact may emerge if the CR rises to more than 10^{-4}.

Statistical analysis

The data was statistically analyzed using the IBM SPSS Version 22 software. Descriptive statistics of some heavy metals such as Mn, Fe, Cr, Cu, As, Cd, Pb, Co, Hg, and Ni present in Tilapia fish collected from three different sources in Dhaka City were computed first. The relationship between the elements in fish species was examined through bivariate

Table 1 External feature of various market-available tilapia. Here SD indicates the standard deviation, W indicates wholesale market tilapia, K indicates kitchen market tilapia, and S indicates the super shop tilapia

Physical Properties	Tilapia		
	Wholesale market	Kitchen market	Super shop
Total length ± SD	26.5 ± 3.21 cm	28.5 ± 3.84 cm	34.5 ± 4.02 cm
Standard length ± SD	22.5 ± 2.8 cm	23.0 ± 2.51 cm	27.0 ± 3.01 cm
Tail length ± SD	4.2 ± 1.08 cm	5.4 ± 1.21 cm	7.0 ± 1.32 cm
Head length ± SD	7.0 ± 0.54 cm	6.0 ± 0.98 cm	8.0 ± 1.01 cm
Fork length ± SD	28 ± 3.21 cm	29.8 ± 2.14 cm	36.5 ± 1.58 cm
Weight ± SD	400 ± 68 gm	460 ± 35 gm	510 ± 15 gm

Pearson's correlation using the different p values (0.05, 0.01). One-sample t-tests have been done to compute the heavy metals like Mn, Fe, Cr, Cu, As, Cd, Pb, Co, Hg, and Ni contents in tilapia fish with the maximum permissible limits (MPLs). Factory analysis by principal component analysis (PCA) was done to find the principal components (PCs) and the heavy metals contributing to computing these PCs. To test the equality of these heavy metals present in tilapia fish of three different markets of Dhaka City, an analysis of variance (ANOVA) was performed. For the heavy metals, which vary significantly ($p < 0.05$), the Duncan multiple rank test (DMRT) of the post hoc test was performed.

Results and discussion

Tilapia is a benthopelagic and omnivorous fish. Average physical properties of tilapia from three representative markets are presented in Table 1.

Humans mainly intake muscle for larger fish species worldwide (Ahmed et al. 2016). Besides, fish offers polyunsaturated fatty acids (PUFAs), minerals, and a recognized balanced supply of animal protein. Thus, fish is a source of equivocal nutrients for a well-balanced diet (Pieniak et al. 2010; Galimberti et al. 2016; Storelli 2008; Taweel et al. 2013). Bangladeshi people only consume the muscle of tilapia, so the muscle is selected from the collected fish for nutritional analysis.

Assessment of amino acid in fish

The muscle consists of mainly myofibrillar proteins, sarcoplasmic proteins, connective tissue, stroma proteins, polypeptides, nucleotides, and nonprotein nitrogen compounds. Fish protein is characterized by a desirable composition of amino acids (Aubourg and Medina 1999). Amino acids are building blocks of protein, and both essential and nonessential amino acids synthesize protein, which is vital for the growth and development of infants, children, and adults. Since the makeup of amino acids in fish and humans is similar, eating fish can help people get the essential amino acids they need in sufficient amounts and the right proportions.

Table 2 Average (mean value) concentration of protein and 14 most important amino acid of tilapia. Here SD indicates the standard deviation, W indicates wholesale market tilapia, K indicates kitchen market tilapia, and S indicates super shop tilapia

Protein and amino acid	Amino acid content (%) in tilapia		
	W	K	S
	Mean ± SD	Mean ± SD	Mean ± SD
Protein	84.34 ± 0.81	82.57 ± 0.65	80.42 ± 0.744
Aspartic acid	6.67 ± 0.04	6.62 ± 0.11	6.39 ± 0.09
Threonine	2.65 ± 0.04	2.57 ± 0.07	2.53 ± 0.06
Serine	2.44 ± 0.08	2.34 ± 0.06	2.28 ± 0.02
Glutamic acid	11.07 ± 0.05	10.80 ± 0.14	10.47 ± 0.04
Glycine	3.26 ± 0.07	3.17 ± 0.03	3.06 ± 0.08
Alanine	4.81 ± 0.07	4.69 ± 0.02	4.71 ± 0.18
Valine	3.13 ± 0.11	2.96 ± 0.07	2.84 ± 0.14
Methionine	1.68 ± 0.05	1.65 ± 0.08	1.61 ± 0.06
Isoleucine	3.35 ± 0.04	3.33 ± 0.11	3.22 ± 0.07
Leucine	5.65 ± 0.07	5.51 ± 0.07	5.34 ± 0.02
Tyrosine	1.10 ± 0.06	1.06 ± 0.04	1.03 ± 0.06
Histidine	1.87 ± 0.11	1.83 ± 0.04	1.80 ± 0.04
Lysine	6.46 ± 0.17	6.31 ± 0.04	6.12 ± 0.08
Arginine	4.99 ± 0.02	4.86 ± 0.05	4.75 ± 0.06

Although human bodies cannot produce them, the essential amino acids can be obtained from food. Moreover, amino acids play an important role in the total daily energy requirement of the body through the oxidation of its carbon skeletons. In addition, amino acid is precursors of different hormones such as adrenaline, nor-adrenaline, and enzymes. Kwashiorkor and marasmus are chronic protein and calorie deficiency syndromes. In this perspective, tilapia, one of the cheapest sources of quality animal proteins, significantly prevents protein-calorie malnutrition (PCM).

Data of amino acid profiles of protein fractions in fish muscles are illustrated in Table 2 and Fig. 1. The variation of valine content of the wholesale market tilapia, kitchen market tilapia, and super shop tilapia was 3.13%, 2.96%, and 2.84%, respectively. As for the arginine content, 4.99%, 4.86%, and 4.75% were found in the wholesale tilapia, kitchen market tilapia, and super shop tilapia, respectively.

Histidine content in the wholesale tilapia, kitchen market tilapia, and super shop tilapia was 1.87%, 1.83%, and 1.80%, respectively. The wholesale tilapia, kitchen market tilapia, and super shop tilapia contain 3.35%, 3.33%, and 3.22% of isoleucine, respectively. Values of valine, arginine, histidine, and isoleucine coincided with the findings of Santiago and Lovell (1988). Lysine content among different essential amino acids was the highest (6%). Concentrations of lysine in the wholesale tilapia, kitchen market tilapia, and super shop tilapia were 6.46%, 6.31%, and 6.12%, respectively. The higher content of amino acid is leucine. The wholesale market tilapia, kitchen market tilapia, and super shop tilapia contain 5.65%, 5.51%, and 5.34% leucine, respectively. Data on lysine and leucine in this study is above the findings of Santiago and Lovell (1988). The value of threonine in the wholesale market tilapia, kitchen market tilapia, and super shop tilapia was 2.65%, 2.57%, and 2.53%, respectively, which is not similar to the studies of Santiago and Lovell (1988).

The non-essential amino acids are aspartic acid (6.67% wholesale market tilapia, 6.62% kitchen market tilapia, 6.39% super shop tilapia), serine (2.44% wholesale tilapia, 2.34% kitchen market tilapia, 2.28% super shop tilapia), glutamic acid (11.07% wholesale market tilapia, 10.80% kitchen market tilapia, 10.47% super shop tilapia), glycine (3.26% wholesale market tilapia, 3.17% kitchen market tilapia, 3.06% super shop tilapia), alanine (4.81% wholesale market tilapia, 4.69% kitchen market tilapia, 4.71% super shop tilapia), tyrosine (1.10% wholesale market tilapia, 1.06% kitchen market tilapia, 1.03% super shop tilapia), and methionine (1.68% wholesale market tilapia, 1.65% kitchen market tilapia, 1.61% super shop tilapia). Certain amino acids like aspartic acid, glycine, and glutamic acid also play a key role in wound healing (Chyun and Griminger 1984).

Since the makeup of amino acids in fish and humans is similar, eating fish can help people get the essential amino acids they need in sufficient amounts and the right proportions. Although human bodies cannot produce them, the essential amino acids can be obtained from food. The current investigation results showed that both species have all nine necessary amino acids. A lack of necessary amino acids may impede the process of healing and recovery (Mat Jais et al. 1994). Leucine promotes the healing of bones, skin, and muscle tissue. Isoleucine is necessary for hemoglobin formation, stabilizing, and regulating blood sugar and energy. Glycine, one of the major components of human skin collagen, and other essential amino acids such as alanine form a polypeptide that will promote regrowth and tissue healing (Witte et al. 2002). Other reports of similar nature provided valuable information on selecting fish and fish oils for nutritional purposes (Hearn et al. 1987).

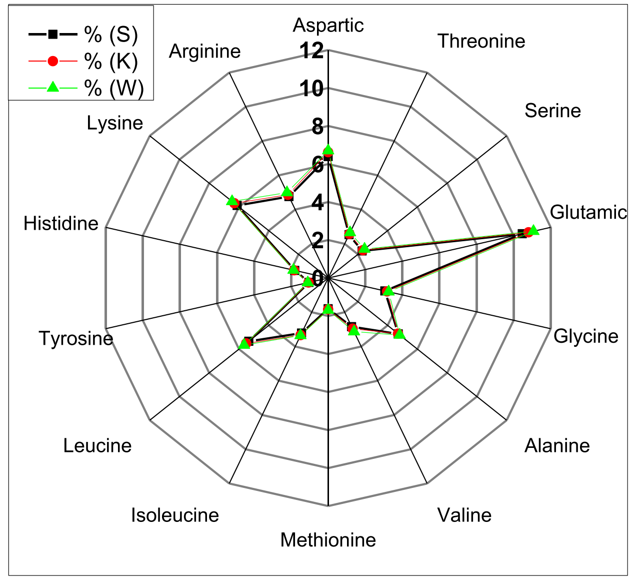

Fig. 1 The radar graph showed the percent (%) of amino acid profiling of different market-available tilapia. Here W indicates wholesale market, K indicates kitchen market, and S indicates super shop tilapia respectively

Fatty acid profiling

Fatty acids, the highly complex biomolecules of fish, indicate that fish are superior in terms of nutritional value. Basically unsaturated fatty acids like docosapentaenoic acid are highly beneficial to human health and development, including neural function and the reduction of acute diseases such as cardiovascular and inflammatory diseases (Calder 2014; Kaur et al. 2011). The fatty acid profile of tilapia depends on several internal and external factors, including diet, size, age, reproductive cycle, salinity, temperature, season, and geographic location (FAO 2009).

The saturated fatty acid (SFA) composition of Nile tilapia (O. niloticus) is shown in Table 3 and Fig. 2a, b, c, and d. Data on the fatty acid composition of fish showed that the proportion of total saturated fatty acids (31–43%) was lower than that of unsaturated fatty acids (56–68%). The monounsaturated fatty acid is superior to the polyunsaturated fatty acid. This is consistent with the study by Karapanagoitidis et al. (2006). The most abundant concentration of saturated fatty acids such as palmitic acid, stearic acid, and arachidic acid was found in Nile tilapia. Furthermore, the highest percentage of palmitic acid and myristic acid was observed in kitchen market tilapia, followed by the super shop tilapia, and the lowest percentage was observed in wholesale tilapia. Rasoarahona et al. (2005) stated that *O. macrochir*, *T. rendalli*, and *O. niloticus* contain 15–21% of palmitic acid for three seasons in Madagascar.

Table 3 Average (mean value) concentration of saturated and unsaturated fatty acid. Here SD indicates the standard deviation, W indicates wholesale market tilapia, K indicates kitchen market tilapia, and S indicates super shop tilapia

Sl. no	Test parameters	Fatty acid content (%) in tilapia		
		W	K	S
		Mean ± SD	Mean ± SD	Mean ± SD
1	Fatty acid composition of the extracted fat*	–	–-	–
	i) Saturated Fatty Acids (%)	–	–-	––
	ii) Unsaturated Fatty Acids (%)	31.27 ± 0.31	43.67 ± 0.24	35.95 ± 0.42
	iia) Mono Unsaturated Fatty Acids (%)	68.60 ± 0.53	56.40 ± 0.14	63.40 ± 0.17
	iib) Poly Unsaturated Fatty Acids (%)	49.10 ± 0.12	47.57 ± 0.56	46.54 ± 0.10
		19.62 ± 0.13	9.68 ± 0.47	16.92 ± 0.33
2	i) Saturated fatty acids %	31.27 ± 0.31	43.67 ± 0.24	35.95 ± 0.42
	a) Myristic Acid (C14:0)	2.58 ± 0.06	6.29 ± 0.06	3.66 ± 0.06
	b) Palmitic Acid (C16:0)	22.47 ± 0.36	33.46 ± 0.06	26.69 ± 0.10
	c) Stearic Acid (C18:0)	5.05 ± 0.01	3.08 ± 0.05	5.10 ± 0.05
	d) Arachidic Acid (C20:0)	0.64 ± 0.01	0.74 ± 0.05	0.53 ± 0.01
	e) Lignoceric Acid (C24:0)	0.49 ± 0.02	0.21 ± 0.01	0.17 ± 0.08
3	Ii)Unsaturated Fatty Acids %	68.60 ± 0.53	56.40 ± 0.14	63.40 ± 0.17
	Ii-1) Monounsaturated Fatty Acids %	49.10 ± 0.12	47.57 ± 0.56	46.40 ± 0.10
	a) Myristoleic Acid (C14:1)	0.94 ± 0.04	0.25 ± 0.05	1.00 ± 0.01
	b) Palmitoleic Acid (C16:1)	9.50 ± 0.01	12.83 ± 0.29	8.85 ± 0.06
	c) Oleic Acid (C18:1)	38.43 ± 0.03	33.25 ± 0.01	36.28 ± 0.06
	d) Eicosenoic Acid (C20:1)	0.29 ± 0.01	0.85 ± 009	0.40 ± 0.01
	Ii-2)Polyunsaturated Fatty Acids %	19.62 ± 0.12	9.68 ± 0.47	16.92 ± 0.33
	a) Linoleic Acid (C18:2)	15.95 ± 0.03	8.19 ± 0.02	13.77 ± 0.11
	b) Linoleic Acid (C18:3)	0.89 ± 0.01	0.21 ± 0.01	0.84 ± 0.03
	c) Arachidonic Acid (C20:4)	1.14 ± 0.01	0.53 ± 0.01	0.65 ± 0.01
	d) Eicosapentaenoic acid (EPA) (C20:5)	0.19 ± 0.01	0.12 ± 0.02	1.21 ± 0.01
	e) Docosahexaenoic acid (DHA) (C22:6)	1.39 ± 0.01	0.58 ± 0.01	0..97 ± 0.12

In the case of arachidic acid, the highest level (5%) was found in wholesale and super shop tilapia, and the lowest level (3%) was found in kitchen market tilapia. The proportion of arachidic and lignoceric acid was less than 1% in three groups of tilapia fish.

In the case of total unsaturated fatty acids, the proportion of monounsaturated fatty acids (46–49%) is higher than that of polyunsaturated fatty acids (9–19%) in the Nile tilapia (*O. niloticus*). Among them, high oleic acid and palmitoleic acid have been observed as a characteristic property of tilapia (Andrade et al. 1997).

The highest amount of oleic acid was found in wholesale market tilapia (38.43%), followed by super shop tilapia (36.28%) and the lowest was found in kitchen market tilapia (33.25%). The sequence of palmitoleic acid in three tilapias was different from oleic acid. The highest amount of palmitoleic acid was observed in kitchen market tilapia (12.83%), followed by wholesale market tilapia (9.50%) and the lowest was observed in super shop tilapia (8.85%). The value of myristoleic and eicosenoic acid was below or near 1% in three clusters of tilapia fish.

The highest amount of polyunsaturated fatty acid was found in super shop tilapia (19.92%), followed by wholesale tilapia (16.62%) and the lowest was found in kitchen market tilapia (9.68%). The sequence of linoleic acid in three group of tilapias was similar to the total unsaturated fatty acid. The highest amount of linoleic acid was observed in wholesale tilapia (15.95%), followed by super shop tilapia (13.77%) and the lowest was observed in kitchen market tilapia (8.19%). The value of other individual unsaturated fatty acids such as linolenic, arachidonic, eicosapentaenoic, and docosahexaenoic acids was below or near 1% in three tilapia fish.

Assessment of minerals

Five minerals were identified in three tilapias, and the concentrations of these minerals varied (Fig. 3). Mean metal concentrations in fish samples decreased in the order K > Mg > Ca > P > Na, with K being the most abundant metal (mg/100 g wet weight).

Calcium is essential for bone formation and mineralization. It also plays an important role in the normal functioning of muscles, the nervous system and the blood clotting process. Deficiency of calcium causes osteomalacia (bone softening) in adults, women, and the elderly. Calcium content ranged from 122 to 343 mg/100 g (Table 4). These results are within the range of fish and seafood reported elsewhere (FAO/IN FOODS 2013). As expected, calcium levels were much higher in species which bones are commonly consumed and included in the edible parts. Calcium deficiency has not been assessed nationally. However, it has been implicated in developing rickets, which affected approximately 550,000 children in 2008 (Craviari et al. 2008; Fischer et al. 1999). A study in two rural sub-districts

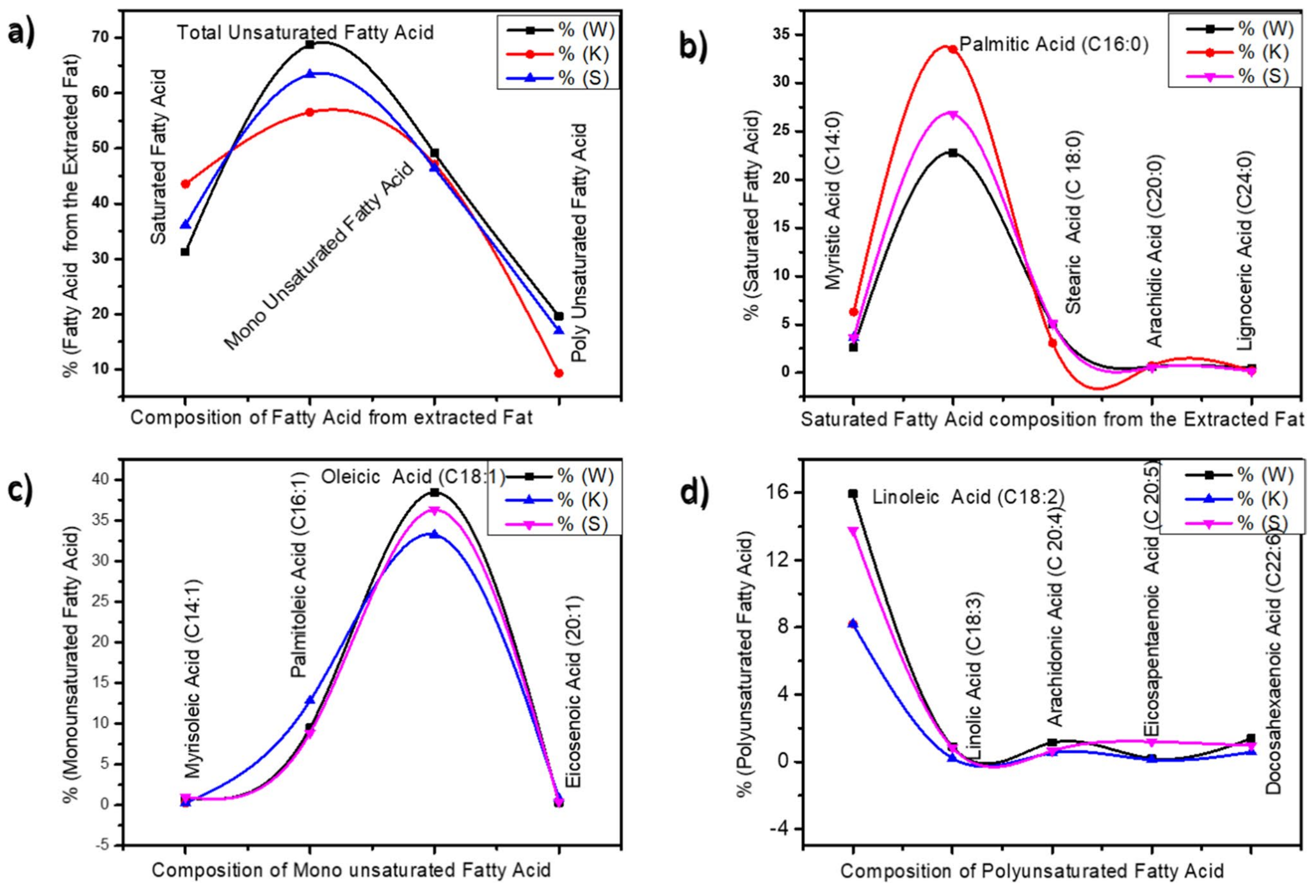

Fig. 2 Percent (%) of total fatty acid of different market-available tilapia: **a** different types of fatty acid, **b** saturated fatty acid **c**, monounsaturated fatty acid, and **d** polyunsaturated fatty acid. Here W indicates wholesale market tilapia, K indicates kitchen Market tilapia, and S indicates super shop tilapia

of Bangladesh found that no woman or young child had diets adequate in calcium, reflecting low dietary intake and low dietary diversity (Arsenault et al. 2013). In developed countries, dairy products tend to be the primary source of dietary calcium; however, this is not the case in Bangladesh, where the frequency of dairy consumption is very low. The high calcium content interferes with the phosphorus, zinc, iron, and manganese content in tilapia. The content of these minerals has been analyzed for the completeness of the data, but they are not currently associated with significant public health problems; therefore, their nutritional value is not discussed here. The phosphorus content ranged from 643 to 1041 mg/100 g (Table 4 and Fig. 3), with a higher composition in fish species with bones in edible parts, also consistent with values reported elsewhere (FAO/IN FOODS 2013). Table 4 also represents the ranges for magnesium (153–200 mg/100 g), sodium (394–457 mg/100 g), and potassium (1216–1641 mg/100 g) were substantially similar to those reported for other fish and seafood elsewhere (FAO /IN FOODS 2013).

Assessment of trace metals

The mean concentrations of heavy metals determined of tilapia fish collected from three different markets in Dhaka, Bangladesh, are shown in Table 5. Figure 4a and b represents bi-functional and toxic trace metals in different market available tilapia. Mean (mg/kg-ww) trace metal concentrations in the fish species examined were in descending order of Zn > Fe > Mn > Cr > As > Ni > Co > Pb > Cu > Cd > Hg. The table below shows two descriptive statistics, the mean and standard deviation (SD) of heavy metals.

Lead is a non-essential trace metal, and its adverse health effects are well known. Lead has been shown to cause leukemia, gastrointestinal colitis, and brain dysfunction (Garcia-Leston et al. 2010). Among the tilapia classes, the highest Pb concentration was 147 µg/kg in the wholesale market, while tilapia in the kitchen market had the lowest Pb concentration of 74.66 µg/kg (Table 5). According to the ANHMRC, the maximum allowable concentration of all Pb is 2000 µg/kg

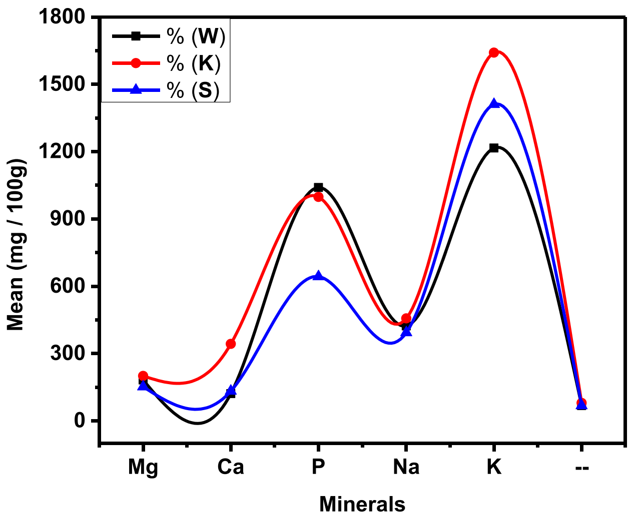

Fig. 3 Mineral content (mg/100 g) of different market-available tilapia. Here W indicates wholesale market tilapia, K indicates kitchen market tilapia, and S indicates super shop tilapia

Table 4 Average some important selective minerals contents in Tilapia. Here SD indicates the standard deviation, W indicates wholesale market tilapia, K indicates kitchen market tilapia, and S indicates super shop tilapia

SL	Mineral (major)	Mineral content (mg/100 g) in tilapia		
		W	K	S
		Mean ± SD	Mean ± SD	Mean ± SD
1	K	1217 ± 35.93	1641 ± 45.03	1411 ± 13.52
2	P	1041 ± 2.31	998 ± 19.85	643 ± 7.25
3	Ca	122 ± 2.08	343 ± 9.85	134 ± 9.86
4	Mg	182 ± 2.51	200 ± 2.51	153 ± 12.50
5	Na	423 ± 13.31	457 ± 45.32	394 ± 13.52

(wet weight) (Plaskett and Potter 1979). This observation showed that the Pb content of all fish species analyzed was well within the acceptable limit for human consumption.

Chromium is actively involved in insulin function and lipid metabolism (Ahmed et al. 2015). Western Australian Food and Drug regulations established the maximum concentration of Cr is 5.5 mg/Kg (Plaskett and Potter 1979). The range of Cr in different fish species found in this study fell within the range of variability reported for different fish species in different parts of Bangladesh (Table 5).

Cadmium can cause various diseases, including kidney, lung, liver, skeletal, reproductive, and cancer effects (Zhu et al. 2011). The lowest and highest cadmium content in fish species was found as 9.7 μg kg^{-1} in the wholesale market and 17.4 μg kg^{-1} in the kitchen market. There is no maximum Cd level for dietary intake of fish consumption in the Bangladeshi legislation. The estimated daily intake (EDI) of cadmium through fish consumption was found to be 0.001 mg d^{-1}.

Nickel is generally found in very small amounts in the environment. It can accumulate in the human body and give rise to various pulmonary adverse health effects, such as lung inflammation, fibrosis, emphysema, and tumors (Forti et al. 2011). The highest and lowest nickel levels in fish species were found at174 μg kg^{-1} in the wholesale market and 127 μg kg^{-1} in the super shop.

Iron deficiency symptoms are physical and cognitive development, anemia, morbidity, and mortality. The lowest and highest iron levels in fish species were found at 17,712 μg kg^{-1} in the super shop and 21,362 μg kg^{-1} in the whole sale market.

Manganese is an essential element for all living organisms, and a deficiency of Mn causes severe skeletal and reproductive abnormalities in mammals (Sivaperumal et al. 2007). The minimum and maximum manganese levels observed were 818 μg/kg in super shop tilapia and1760 μg/kg in kitchen market tilapia.

Zinc is an essential trace element for metabolic processes, the proper functioning of the immune system and healthy skin. According to WHO and ANHMRC, the maximum allowable limit for Zn is 1000 mg/kg (Bebbington et al. 1977). In this study, however, the highest and lowest Zn concentrations were found as 27,491 μg/kg in the wholesale market, and 18,441 μg/kg in the super shop, respectively (Table 5). The present value below the tolerable limit of WHO and ANHMRC indicates no risk to human health, and its deficiency leads to poor growth, skin problems, and hair loss. The adverse effect of Zn is the skin irritation, deficiencies in iron and copper, headache, tiredness, nausea, vomiting, fever, and abdominal pain. High Zn content interferes with Cu uptake. Excessive levels of Zn, around 50 mg/day over weeks, can adversely affect the availability of Cu to the body (Powers et al. 2003). Very high levels of Zn decrease the function of immunity as well as the levels of high-density lipoprotein (HDL). The zinc content of tilapia may depend on the diet, protein source, and the presence of other components, including calcium, phosphorus, and phytic acid (FAO/WHO 2009). Although the presence of Cu is essential for the functioning of various enzymes and the synthesis of hemoglobin (Sivaperumal et al. 2007), an excess of Cu can lead to acute toxicity such as human death. According to ANHMRC and FAO, the recommended maximum allowable Cu content is 30,000 μg/kg on a wet weight basis (Bebbington et al. 1977). Australian Food Standard Code prescribed Cu levels should not exceed 10,000 μg/kg (wet weight basis). The safe limit for Cu is 20 mg/kg w/w based on the UK Food Standards Committee Report (Cronin et al. 1998). The highest average concentration of Cu content was 1658 μg/kg in wholesale market tilapia, followed by super

Table 5 Mean, SD, minimum, median and maximum values of different trace metals in tilapia. Here SD indicates the standard deviation, W indicates wholesale market tilapia, K indicates kitchen market tilapia, and S indicates super shop tilapia

		Toxic metal content in tilapia (µg/ Kg)										
Sample	Metals	Zn	Fe	Mn	Pb	Cd	Cr	Cu	Co	As	Hg	Ni
W(50)	Mean	27,491	21,362	1107	147	9.70	546	1121	24.94	272	7.07	174
	± SD	1029	2113	163	19.39	1.61	44.55	102	2.21	6.89	0.91	16.09
	Minimum	26,312	19,321	928	125	8.01	517	1025	23.2	266	6.2	156
	Median	27,951	21,223	1149	157	9.8	523	1110	24.2	271	6.99	179
	Maximum	28,210	23,541	1245	160	11.23	597	1228	27.44	279	8.02	187
K(50)	Mean	22,197	20,560	1760	74.6	17.4	568	1658	34.4	421	4.68	153
	± SD	869	886	136	4.71	0.59	50.84	179	3.32	10.44	0.73	12.71
	Minimum	21,451	19,818	1612	69.7	16.6	523	1459	31.2	410.1	4.16	142
	Median	21,998	20,321	1788	75	17.2	557	1710	34.25	423	4.68	151
	Maximum	23,142	21,541	1879	79.2	18.1	623	1806	37.8	431	5.2	167
S(50)	Mean	18,441	17,712	818	90.4	10.53	308	1004	11.81	260	5.45	127
	± SD	870	1952	135	16.82	1.06	78.13	118	1.53	1.79	1.08	5.39
	Minimum	17,523	15,541	663	71	9.3	223	876	10.27	210	4.2	121
	Median	18,547	18,274	879	99.2	11.1	323	1025	11.98	261	5.99	127
	Maximum	19,254	19,321	912	101	11.2	377	1110	13.25	262	6.16	132

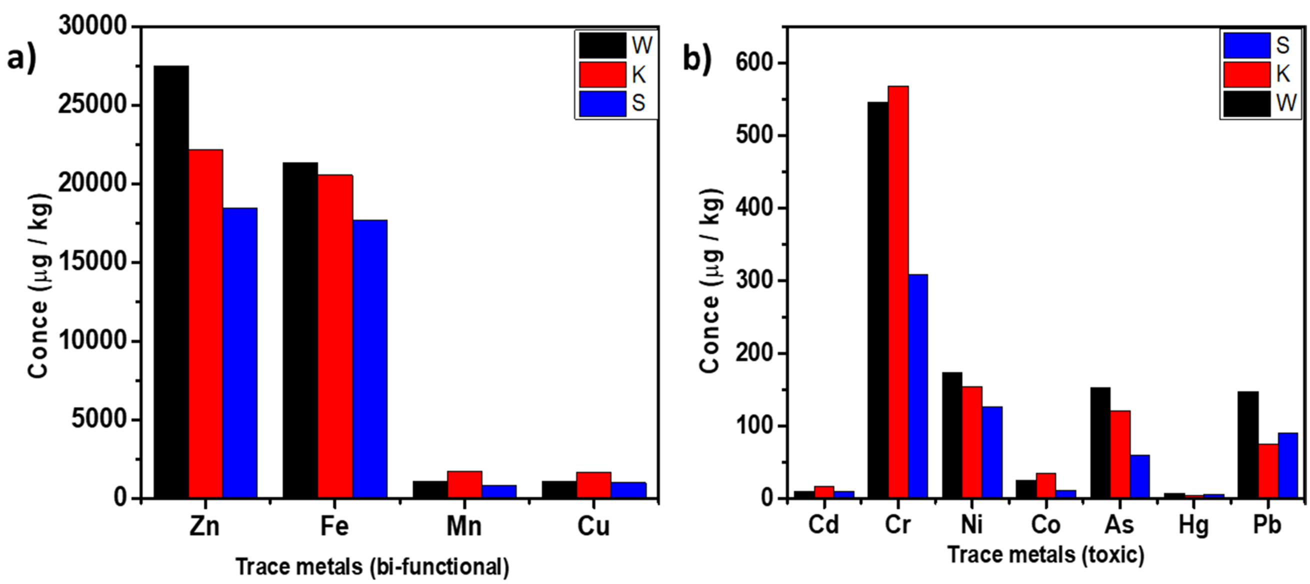

Fig. 4 Trace metal content of market available tilapia in Bangladesh: **a** bi-functional trace metals and **b** toxic trace metals. Here W indicates wholesale market tilapia, K indicates kitchen market tilapia, and S indicates super shop tilapia

shop tilapia. The lowest average concentration of Cu content was found in 1004 µg/kg in kitchen market tilapia (Table 5).

Mercury (Hg) can cause damage to the central nervous system, impairment of pulmonary and kidney function, chest pain, and dyspnea. Owing to its risk, the USEPA has considered mercury a priority pollutant. The highest average concentration of Hg content was 7.07 µg/kg found in wholesale market tilapia, followed by kitchen market tilapia. The lowest average concentration of Hg content was found in 4.68 µg/kg in the wholesale market tilapia (Table 5).

Cobalt (Co) has a dual effect on humans. A tiny amount of Co is needed for vitamin B12 formation. However, high exposure can have human health implications (Javadian 2014). The minimum and maximum manganese levels observed were 34.4 µg/kg in wholesale market tilapia and 11.81 µg/kg in super shop tilapia.

Table 6 Pearson correlation among heavy metals present in tilapia fish available in different markets of Bangladesh

	Mn	Fe	Cr	Cu	As	Cd	Pb	Co	Hg	Ni	Zn
Mn	1										
Fe	.503	1									
Cr	.694*	.634	1								
Cu	.880**	.240	.528	1							
As	.921**	.257	.565	.948**	1						
Cd	.918**	.254	.414	.857**	.939**	1					
Pb	−.182	.571	.362	−350	−454	−516	1				
Co	.913**	.547	.889**	.842**	.838**	.714*	.067	1			
Hg	−.552	.213	−.070	−.684*	−.678*	−.670*	.573	−.445	1		
Ni	.282	.506	.711*	.273	.145	-.096	.627	.592	.155	1	
Zn	.211	.769*	.731*	.029	-.035	-.164	.879**	.475	.443	.825**	1

*Correlation is significant at the 0.05 level (2-tailed), ** correlation is significant at the 0.01 level (2-tailed)

Table 7 Communality of variance in the amount of heavy metals present in tilapia fish available in different markets of Bangladesh. Extraction method: principal component analysis

	Communalities	
	Initial	Extraction
Mn	1.000	.953
Fe	1.000	.685
Cr	1.000	.876
Cu	1.000	.909
As	1.000	.976
Cd	1.000	.921
Pb	1.000	.910
Co	1.000	.981
Hg	1.000	.725
Ni	1.000	.740
Zn	1.000	.995

Arsenic can cause dermatitis, mild pigmentation keratosis of the skin, vasospasticity, gross pigmentation with hyperkeratinization of exposed areas, wart formation, reduced nerve conduction velocity, and lung cancer. The lowest and the highest levels of arsenic in tilapia from three different markets were found at 260 μg/kg in super shop, 421 μg/kg in kitchen market, and 272 μg/kg in the wholesale market.

Pearson's correlation of different minerals at 0.05 and 0.01 levels of significance in fishes is presented in Table 6.

The correlation table presents the mathematical association among the heavy metals in correlation coefficients (r). Two-tailed t-test results are shown by asterisk (*) with r with their significance level. Here, there is a very strong and positive correlation between Mn and As ($r = 0.921$), Cd and Mn ($r = 0.918$), Mn and Co ($r = 0.913$), Mn and Cu ($r = 0.88$), Cr and Co ($r = 0.889$), Cu and As ($r = 0.948$), Cu and Cd ($r = 0.857$), Cu and Co ($r = 0.842$), As and Cd ($r = 0.939$), As and Co ($r = 0.838$), Zn and Ni ($r = 0.825$), and they are significant at 1% level of significance. Some strong positive associations were observed between Mn and Cr ($r = 0.694$), Fe and Zn ($r = 0.769$), Cr and Ni ($\underline{r} = 0.711$), and Cr and Zn ($r = 0.731$), Cd and Co ($r = 0.714$), and they are significant at 5% level of significance. However, a moderately strong and negative correlation exists between Hg and Mn (r = −0.552), Hg and Cu ($r = -0.684$), Hg and As ($r = -0.678$), and Hg and Cd ($r = -0.670$), and they all are significant at 5% level of significance.

Table 8 Total variance explained in the amount of heavy metals present in tilapia fish available in different markets of Bangladesh

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.77	52.49	52.49	5.77	52.49	52.4	5.453	49.58	49.58
2	3.90	35.41	87.90	3.90	35.41	87.90	4.21	38.33	87.90
3	.665	6.05	93.95						
4	.324	2.94	96.89						
5	.199	1.81	98.70						
6	.083	.758	99.46						
7	.053	.483	99.94						
8	.007	.061	100						

Extraction method: principal component analysis

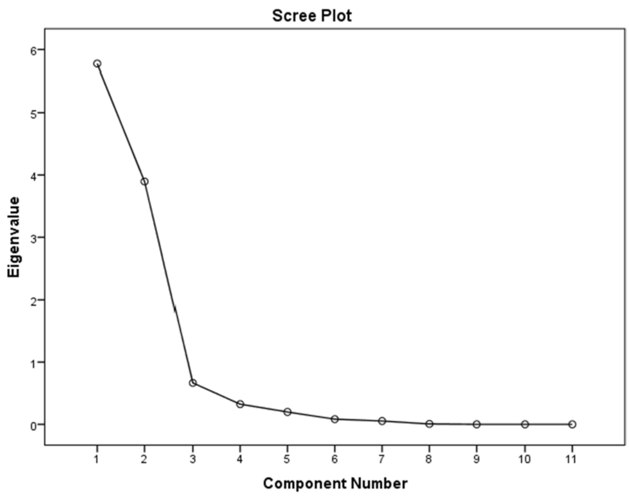

Fig. 5 Scree plot of trace element of tilapia. Component analysis of a calculated parameters by scree plot of the characteristic roots i.e., eigenvalue and component number of marketable tilapia in Bangladesh

Mean contents of the heavy metals in tilapia fish were compared with their respective maximum permissible limits (5.0 mg/kg for Mn, 100 mg/kg for Fe, 1.0 mg/kg for Cr, 30 mg/kg for Cu,1.0 mg/kg for As, 0.05 mg/kg for Cd, 0.2 mg/kg for Pb, 1.0 mg/kg for Co, 0.5 mg/kg for Hg, 40.0 mg/kg for Zn and 1.0 mg/kg for Ni) by using one-sample t-test. The test results show that the average amount of Mn, Fe, Cd, Ni, Zn, Cr, Cu, As, Co and Hg were significantly lower than the maximum permissible limits (MPLs) ($p < 0.05$) at 5% level of significance. This result is consistent with the study of Sobhanardakani et al. 2012 as well as Tayebi and Sobhanardakani 2020. However, the difference between mean contents of Pb and its MPL was insignificant ($p > 0.05$) at 5% level of significance.

Factor analysis with principal component analysis (PCA)

The commonality Table 7 shows how much of the variance, i.e., the commonality value, which must be greater than 0.5, to be considered for further analysis. Otherwise, these variables must be removed from further steps factor analysis in the variables accounted for by the extracted factors. Here, more than 90% of the variance in Mn, Cu, As, Cd, Pb, Co, and Zn are accounted for in the total variation. About 80–90% of the variance in Cr is accounted for, and 70–80% of the variance in Hg and Ni is accounted for in the total variation.

The eigenvalue represents the number of extracted factors, the sum of which should be equal to a number of the factors-analyzed items. The list of factors extracted from the analysis is shown next, along with each factor's eigenvalues.

Table 9 Component matrix of trace elements present in tilapia fish available in different markets of Bangladesh

	Component	
	1	2
Mn	.970	−.109
Fe	.523	.641
Cr	.792	.499
Cu	.910	−.286
As	.922	−.354
Cd	.839	−.465
Pb	−.092	.949
Co	.976	.166
Hg	−.537	.660
Ni	.442	.738
Zn	.325	.943

Extraction method: principal component analysis. Two components were extracted

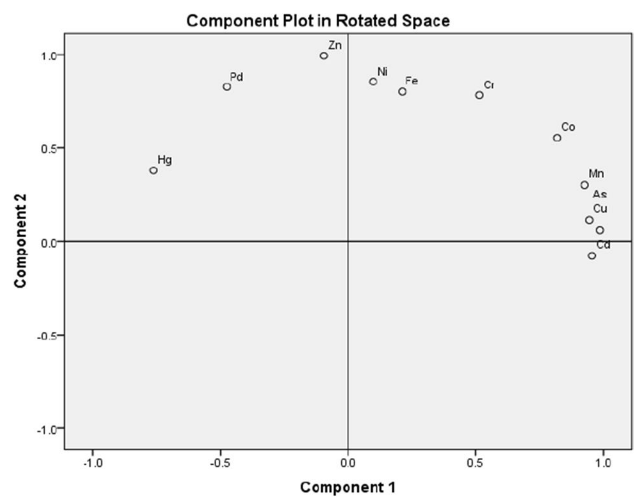

Fig. 6 Principal component plot in rotated space analyzed by scree plot of the characteristic roots (eigenvalues) and component plot in rotated space of trace metals in marketable tilapia

For the purposes of analysis and interpretation, we are solely interested in initial eigenvalues and extracted sums of squared loadings. The presence of eigenvalues greater than 1 is necessary to determine how many components or factors are expressed by a certain set of variables.

Table 8 of total variance explained below shows that for the 1st component, the value is $5.77 > 1$, for the 2nd component $3.90 > 1$, and for the 3rd component $0.665 < 1$. Thus, the specified set of 11 variables represents two components. Moreover, the extracted sum of squared holding cumulative % of variance shows that the first factor accounts for 52.49% of the variance features from the stated observations and the second factor accounts for 87.90% (Table 8). Thus, two

Table 10 Comparison of heavy metals in fish from three types of markets. Here SD indicates the standard deviation, W indicates wholesale market tilapia, K indicates kitchen market tilapia, and S indicates super shop tilapia

Heavy metals	Comparison of metals in markets			Significance (p value)
	W (Mean ± SD)	K (Mean ± SD)	S (Mean ± SD)	
Mn	1760 ± 136[a]	1107 ± 163[b]	818 ± 135[b]	0.001
Fe	20,560 ± 886[ab]	21,362 ± 2113[a]	17,712 ± 1952[b]	0.092
Cr	568 ± 50.85[a]	546 ± 44.56[a]	308 ± 78.14[b]	0.003
Cu	1658 ± 179[a]	1121 ± 102[b]	1004 ± 118[b]	0.002
As	421 ± 10.44[a]	272 ± 6.89[b]	260 ± 1.79[b]	0.000
Cd	17.42 ± 0.60[a]	9.70 ± 1.62[b]	10.53 ± 1.07[b]	0.000
Pb	74.66 ± 4.72[b]	681 ± 134[a]	90.40 ± 16.82[b]	0.000
Co	34.43 ± 3.33[a]	24.95 ± 2.22[b]	11.81 ± 1.53[c]	0.000
Hg	3.12 ± 2.75[b]	7.07 ± 0.91[a]	5.45 ± 1.09[ab]	0.090
Ni	153 ± 12.71[a]	174 ± 16.09[a]	127 ± 5.4[b]	0.009
Zn	22,197 ± 862[b]	27,491 ± 1029[a]	18,441 ± 870[c]	0.000

Means containing the same letter do not differ significantly at a 5% level of significance

Table 11 Estimated daily intake (EDI) and target hazard quotients (THQ) of adult and children for individual metals through tilapia fish consumption

Parameter	EDI(mg d^{-1})		RfD (mg/kg/day)	THQ		CSF	CR	
	Adult	Children		Adult	Children		Adult	Children
Mn	7.47E-06	3.49E-05	0.14	0.000533	0.002489	NA	-	-
Fe	0.000121	0.000563	0.7	0.000172	0.000805	NA	-	-
Cr	2.85E-06	1.33E-05	1.5	1.9E-06	8.88E-06	0.5	1.43E-06	6.66E-06
Cu	7.65E-06	3.57E-05	0.04	0.000191	0.000893	NA	-	-
As	1.94E-06	9.07E-06	0.0003	0.006476	0.030222	1.5	2.91E-06	1.36E-05
Cd	6.07E-08	2.83E-07	0.001	0.000283	0.000283	6.3	3.83E-07	1.79E-06
Pb	1.7E-06	7.93E-06	0.004	0.001983	0.001983	0.0085	1.45E-08	6.74E-08
Co	1.21E-07	5.67E-07	3.01	4.03E-08	1.88E-07	NA	-	-
Hg	3.04E-08	1.42E-07	0.0007	4.34E-05	0.000202	NA	-	-
Ni	9.11E-07	4.25E-06	0.02	4.55E-05	0.000213	1.7	1.55E-06	7.23E-06

$HI_{Adult} = 0.000533$, $HI_{Children} = 0.002489$

components effectively represent all the characteristics or components highlighted by the stated 11 heavy metals.

The eigenvalues are graphed against each of the components in the scree plot (Fig. 5). The graph can be used to decide how many components to keep. Where the curve begins to flatten is where the action is. It is evident that between factors 2 and 3, the curve starts to flatten. Also, note that just two factors were kept because the eigenvalues of factors 3 and forward are less than 1.

The loadings (extracted values of each item under three variables) of selected variables on the three extracted factors are displayed in Table 9 component matrix. The factor contributes to the variable more when the absolute value of the loading is bigger. The 8 items were separated into two variables based on the three most significant items, which had similar responses in components 1 and 2.

The position of heavy metals is presented in the dimensions of the first three-components in the Fig. 6.

Duncan multiple rank test (DMRT) of post hoc

Duncan multiple rank test (DMRT) of post hoc was used in the study to compare the presence of average amount (ppb) of heavy metals in three types of markets in Dhaka City. The results are presented in Table 10.

Analysis of variance (ANOVA) indicates that except Fe, all other heavy metals such as Mn, Cr, Cu, As, Cd, Pb, Co, Hg, Ni, and Zn are significantly different at a 5% level of significance ($p < 0.05$).

Results of the Duncan multiple rank test (DMRT) of post hoc tests are shown in the above table by alphabetic symbols in the mean ± SD of the heavy metals present in tilapia fishes collected from three different types of markets available in Dhaka City. Post hoc tests show that the fish samples from wholesale market contain the heavy metals than those from kitchen market and super shop. The fishes from kitchen market are in the middle position in terms of containing these heavy metals in the collected fish. Finally, tilapia fishes from super shops contain the least amount of these heavy metals compared to the other two types of markets. There might be reasons for this. First, it might be their mechanism of maintaining the quality of their products. Next, some super shops have their firm where they try to keep the quality of their fish.

Human health risk assessment through tilapia fish consumption

The evaluation of human health risks encompasses the identification, collection, and exposure to hazardous substances, as well as the link between exposure, dosage, and harmful effects on humans (Sobhanardakani 2017a, b). Excessive essential and toxic elements in tilapia could lead to adverse health effects in humans (Korashyet al. 2017; Morcillo et al. 2016; Park et al. 2007). The EDI, THQ, HI, and CR are used as indexes to evaluate the potential human health risks of target metals by consuming tilapia from the different markets of Bangladesh. The EDI of metals through the consumption of fish was calculated and is shown in Table 11. All the calculated THQ values of heavy metals were within the safe limits (THQ < 1) (Table 4). Furthermore, the variations in the range of HI values 5.33×10^{-04} for adults and 2.49×10^{-03} for children in tilapia samples were also within the safe limit (HI < 1) in this study. Therefore, we can conclude that consumers might have no potential significant health risk through only consuming the analyzed tilapia. The THQ is an index that can be used to assess the potential non-carcinogenic risk to humans from individual metal exposure via tilapia consumption. A THQ value of 1 or higher indicates that metal exposure from the ingestion of fish poses a non-carcinogenic risk to the human body. A THQ of less than 1 indicates that there is no obvious risk. The estimated daily intake (EDI) of arsenic from fish consumption was 1.94×10^{-6} mg/d. According to Chinese food safety standards, fish samples contain 0.10 mg/kg of arsenic (FAO/WHO 2009). Until recently, there has been a lack of arsenic limit value that has been proven entirely safe. Despite this, most experts believe that ingesting these minute amounts of arsenic as part of a balanced diet poses minimal risk. For ingested arsenic, the Regional Office for Asia and the Pacific of the UN Food and Agriculture Organization has set a provisional maximum tolerable daily intake of 0.126 mg/d (FAO 2009). Several findings of this study indicate that high arsenic levels in tilapia are of particular concern. An estimated 35 million people are exposed to As concentrations in drinking water greater than 0.05 mg/L (drinking water standard in Bangladesh) (BGS and DPHE 2001). Moreover, half-life of arsenic in human is 10 h. Therefore, elevated level of arsenic is excreting from human body.

As shown in Table 11, the CRs of As, Cr, Cd, Pb, and Ni were 1.36×10^{-5}, 6.66×10^{-6}, 1.79×10^{-6}, 6.74×10^{-8}, and 7.23×10^{-6}, respectively. CR was in the acceptable risk range (10^{-6} to 10^{-5}) recommended by many regulatory agencies. The study suggested that consuming tilapia from the market may pose a no carcinogenic risk to consumers.

Conclusion

This study aimed to investigate the amino acid, fatty acid, mineral, essential, and toxic metal content of commercially available tilapia fish and to assess the potential health risk associated with the consumption of this fish. The results of this investigation indicated significant differences in accumulated trace elements in the three market hubs of tilapia fish. The present study reveals that the quality of tilapia in the super shop is comparatively better than in the wholesale market and kitchen market. The EDI and CR values represent that tilapia consumption will have no health risks for consumers. Despite no potential health risk for adults and children through consumption of market-available tilapia fish in Bangladesh, due to human health effects of heavy metals and also lack of proper information about habitat, routine monitoring of tilapia is essential before entering commonly consumed poor man fish into the market. Excessive consumption of fish should be avoided as a way to minimize the adverse effects associated with metal biomagnification.

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Data availability Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

Declarations

Ethics approval and consent to participate Not applicable.

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References

Ahmed N, James AY, Madan MD, James FM (2012) From production to consumption: a case study of tilapia marketing systems in Bangladesh. Aquacult Int 20:51–70. https://doi.org/10.1007/s10499-011-9441-0

Ahmed MK, Shaheen N, Islam MS, Habibullah-Al-Mamun M, Islam S, Mohiduzzaman M, Bhattacharjee L (2015) Dietary intake of trace elements from highly consumed cultured fish (Labeorohita, Pangasiuspangasius and Oreochromismossambicus) and human health risk implications in Bangladesh. Chemosphere 128:284–292

Ahmed MK, Baki MA, Kundu GK, Islam MS, Islam MM, Hossain MM (2016) Human health risks from heavy metals in fish of Burigangariver. Bangladesh Springerplus 5(1):1697. https://doi.org/10.1186/s40064-016-3357-0

Ahmed ASS, Hossain MB, Semme SA, Babu SMOF, Hossain K, Moniruzzaman M (2020) Accumulation of trace elements in selected fish and shellfish species from the largest natural carp fish breeding basin in Asia: a probabilistic human health risk implication. Environ Sci Pollut Res 27(30):37852–37865

Anandkumar A, Nagarajan R, Prabakaran K, Chua Han B, Rajaram R (2018) Human health risk assessment and bioaccumulationof trace metals in fish species collected from the Miri coast, Sarawak, Borneo. Mar Pollut Bull 133:655–663. https://doi.org/10.1016/j.marpolbul.2018.06.033

Andrade AD, Visentainer JV, Matsushita M, de Souza NE (1997) Omega-3 fatty acids in baked freshwater fish from south of Brazil. Arch Latinoam Nutr 47(1):73–76

Anonymous (1993) Amino acid analysis system instruction manual. Shimadzu HPLC amino acid analysis system. Analytical Instruments Division, Kyoto, pp 63–65

Arsenault JE, Yakes EA, Islam MM, Hossain MB, Ahmed T, Hotz C, Lewis B, Rahman AS, Jamil KM, Brown KH (2013) Very low adequacy of micronutrient intakes by young children and women in rural Bangladesh is primarily explained by low food intake and limited diversity. J Nutr 143:197–203

Aubourg SP, Medina I (1999) Influence of storage time and temperature on lipid deterioration during cod (Gadusmorhua) and haddock (Melanogrammusaeglefinus) frozen storage. J Sci Food Agric 79(13):1943–1948

Bawuro AA, Voegborlo RB, Adimado AA (2018) Bioaccumulation of heavy metals in some tissues of fish in Lake Geriyo, Adamawa State, Nigeria. J Environ Public Health 1854892. https://doi.org/10.1155/2018/1854892

Bebbington GN, Mackay NJ, Chvojka R (1977) Heavy metals, selenium and arsenic in nine species of Australian commercial fish. Mar Freshw Res 28(3):277–286

BGS and DPHE (2001) Arsenic contamination of groundwater in Bangladesh. British Geology Survey and Department of Public Health Engineering, Bangladesh, BGS Technical Report, WC/00/19

Calder PC (2014) Very long chain omega-3 (n-3) fatty acids and human health. Eur J Lipid SciTechnol 116:1280–1300

Chakraborty P, RaghunadhBabu PV, Acharyya T, Bandyopadhyay D (2010) Stress and toxicity of biologically important transitionmetals (Co, Ni, Cu and Zn) on phytoplankton in a tropical freshwater system: An investigation with pigment analysis by HPLC. Chemosphere 80(5):548–553. https://doi.org/10.1016/j.chemosphere.2010.04.039

Chyun JH, Griminger P (1984) Improvement of nitrogen retention by arginine and glycine supplementation and its relation to collagen synthesis in traumatized mature and ageing rats. J Nutr 114:1705–1715

Cozzolino SMF (2001) Evaluation of some essential and trace elements in diets from 3 nurseries from Juiz de Fora, MG, Brazil, by neutron activation analysis. J Radioanal Nucl Chem 249:15–19

Craviari T, Pettifor JM, Thacher TD, Meisner C, Arnaud J, Fischer PRR (2008) An overview and future directions, with special reference to Bangladesh. J Health Popul Nutr 26:112–121

Cronin M, Davies IM, Newton A, Pirie JM, Topping G, Swan S (1998) Trace metal concentrations in deep sea fish from the North Atlantic. Mar Environ Res 45(3):225–238

Davodpour R, Sobhanardakani S, Cheraghi M, Abdi N, Lorestani B (2019) Honeybees (*Apis mellifera* L.) as a Potential Bioindicator for Detection of Toxic and Essential Elements in the Environment (Case Study: Markazi Province, Iran). Arch Environ Contam Toxicol 77:344–358

Fakhri Y, Saha N, Miri A, Baghaei M, Roomiani L, Ghaderpoor M, Bay A (2018) Metal concentrations in fillet and gill of parrotfish (Scarusghobban) from the Persian Gulf and implications for human health. Food ChemToxicol 118:348–354

FAO/INFOODS (2013) Food Composition Database for Biodiversity Version 2.1 – Bio Food Comp 2.1 Food and Agriculture Organization of the United Nations, Rome

FAO/WHO (2009) Codex general standard for food additives. Food and Agricultural Organization of the United Nations and World Health Organization, Rome

Fischer PR, Rahman A, Cimma JP, Kyaw-Myint TO, Kabir ARML, Talukder K, Hassan N, Manaster BJ, Staab DB, Duxbury JM, Welch RM, Meisner CA, Haque S, Combs GF (1999) Nutritional rickets without vitamin D deficiency in Bangladesh. J Trop Pediatr 45:291–293

Forti E, Salovaara SC, Bulgheroni Y, Pfaller A, Prieto RW, P, (2011) In vitro evaluation of the toxicity induced by nickel soluble and particulate forms in human airway epithelial cells. Toxicol in Vitro 25:454–461

Fuentes A, Fernández-Segovia I, Escriche I, Serra JA (2009) Comparison of physicochemicalparameters and composition of mussels (MytilusgalloprovincialisLmk.) from differentSpanish origins. Food Chem 112:295–302

Galimberti C, Corti I, Cressoni M, Moretti VM, Menotta S, Galli U, Cambiaghi D (2016) Evaluation of mercury, cadmium and lead levels in fish and fishery products imported by air in North Italy from extra-European Union Countries. Food Control 60:329–337

Garcia-Leston J, Mendez J, Pasaro E, Laffon B (2010) Genotoxic effects of lead: an updated review. Environ Int 36:623–636

Hearn TL, Sojoutas SA, Hearn JA, Sojoutas DS (1987) Polyunsaturated fatty acids and fat in fish flesh for selecting species for health benefits. J Food Sci 52(5):1209–1211

Hossain MB, Shanta TB, Ahmed ASS, Hossain MK, Semme SA (2019) Baseline study of heavy metal contamination in the Sangu River estuary, Chattogram. Bangladesh Mar Pollut Bull 140:255–261

Hossain MB, Runu UH, Sarker MM, Hossain MK, Parvin, (2021a) A vertical distribution and contamination assessment of heavy metals in sediment cores of ship breaking area of Bangladesh. Environ Geochem Health 43:4235–4249

Hossain MB, Shanta TB, Semme SA, Ahmed ASS, Hossain MK, Porag GS, Parvin A, Shanta TB, Senapathi V, Sekar S (2021b) Contamination levels and ecological risk of heavy metals in sediments from the tidal river Halda. Bangladesh Arab J Geosci 14:158. https://doi.org/10.1007/s12517-021-06477-w

Islam S, Bhowmik S, Hossain MK, Nordin N, Rahman M, Ahmed MK, Parvin A, Hossain MA (2021) Tilapia from Most of the Sources in Bangladesh are Safe for Human Consumption: A Hazard Index (HI) Based Study on Heavy Metals. J Aquat Food Prod Technol 30(8):1017–1027. https://doi.org/10.1080/10498850.2021.1963377

Javadian H (2014) Application of kinetic, isotherm and thermodynamic models for the adsorption of Co(II) ions on polyaniline/polypyrrole copolymer nanofibers from aqueous solution. J Ind Eng Chem 20(6):4233–4241

Karapanagoitidis IT, Bell MV, Little DC, Yakupitiyage A, Rakshit SK (2006) Ply unsaturated fatty acid content of wild and farmed

tilapias in Thailand: Effect of aquaculture practices and implications for human nutrition. J Agric Food Chem 54(12):4304–4310
Kaur G, Cameron-Smith D, Garg M, Sinclair AJ (2011) Docosapentaenoic acid (22: 5n–3): a review of its biological effects. Prog Lipid Res 50:28–34
Korashy HM, Attafi IM, Famulski KS, Bakheet SA, Hafez MM, Alsaad AMS (2017) Gene expression profiling to identify the toxicities and potentially relevant human disease outcomes associated with environmental heavy metal exposure. Environ Pollut 221:64–74
Kris-Etherton PM, Harris WS, Appel LJ (2002) Fish consumption, fish oil, omega-3 fatty acids, and cardiovascular disease. Circulation 106(21):274–757
Longo G, Trovato M, Mazzei V, Ferrante M, Conti GO (2013) Ligiaitalica (Isopoda, Oniscidea) as bioindicator of mercury pollution of marine rocky coasts. PLoS ONE 8:e58548
Mat Jais AM, McCulloh RK, Croft K (1994) Fatty acid and amino acid composition in haruan as a potential role in wound healing. Gen Pharmacol 25:947–950
Miri M, Akbari E, Amrane A, Jafari SJ, Eslami H, Hoseinzadeh E, Taghavi M (2017) Health risk assessment of heavy metal intake due to fish consumption in the Sistan region. Iran Environ Monit Assess 189:583
Morcillo P, Esteban MA, Cuesta A (2016) Heavy metals produce toxicity, oxidative stress and apoptosis in the marine teleost fish SAF-1 cell line. Chemosphere 144:225–233
Mostafiz F, Islam MM, Saha B, Hossain MK, Moniruzzaman M, Al-Mamun MH (2020) Bioaccumulation of trace metals in freshwater prawn Macrobrachiumrosenbergii from Farmed and Wild Sources and Human Health Risk Assessment in Bangladesh. Environ Sci Pollut Res (international) 27:16426–16438
Park S, Lee YK, Jung M, Kim KH, Chung N, Ahn EK (2007) Cellular toxicity ofvarious inhalable metal nanoparticles on human alveolar epithelial cells. Inhal Toxicol 19:59–65
Parvin A, Hossain MK, Islam S, Das SS, Munshi JL, Suchi PD, Moniruzzaman M, Saha B, Golam Mustafa M, MG, (2019) Bioaccumulation of heavy metals in different tissues of Nile tilapia (*Oreochromisniloticus*) in Bangladesh. Mal J Nutr 25(2):237–246
Pieniak Z, Verbeke W, Scholderer J (2010) Health-related beliefs and consumer knowledge as determinants of fish consumption. J Hum Nutr Diet 23:480–488
Plaskett D, Potter IC (1979) Heavy metal concentrations in the muscle tissue of twelve species of teleost from Cockburn Sound, Western Australia. Mar Freshw Res 30(5):607–616
Powers KM, Smith-Weller T, Franklin GM, Longstreth WT, JrPD S, Checkoway H (2003) Parkinson's disease risks associated with dietary iron, manganese, and other nutrient intakes. Neurology 60(11):1761–1766
Rasoarahona JRE, Barnathan G, Bianchini JP, Gaydou EM (2005) Influence of season on the lipid content and fatty acid profiles of three tilapia species (*Oreochromis niloticus*, *O. macrochir* and *T. rendalli*) from Madagascar. Food Chem 91:683–694
Santiago CB, Lovell RT (1988) Amino Acid Requirements for Growth of Nile Tilapia. J Nutr 118:1540–1546
Shaheen N, Ahmed MK, Islam MS, Habibullah-Al-Mamun M, Tukun AB, Islam S, Rahim ATM (2016) Health risk assessment of trace elements via dietary intake of 'non-piscine protein source' foodstuffs (meat, milk and egg) in Bangladesh. Environ Sci Pollut Res 23:7794–7806
Shorna S, Shawkat S, Hossain A, Quraishi SB, Ullah AA, Hosen MM, Hossain MK, Saha B, Paul B, Al-Mamun MH (2021) Accumulation of Trace Metals in Indigenous Fish Species from the Old Brahmaputra River in Bangladesh and Human Health Risk Implications. Biol Trace Elem Res 199(9):3478–3488. https://doi.org/10.1007/s12011-020-02450-y
Sivaperumal P, Sankar T, Nair PV (2007) Heavy metal concentrations in fish, shellfish and fish products from internal markets of India vis-a-vis international standards. Food Chem 102(3):612–620
Sobhanardakani S (2017a) Tuna fish and common kilka: Health risk assessment of metal pollution through consumption of canned fish in Iran. J Consum Prot Food Saf 12:157–163
Sobhanardakani S (2017b) Potential health risk assessment of heavy metals via consumption of caviar of Persian sturgeon. Mar Pollut Bull 123(1–2):34–38
Sobhanardakani S, Tayebi L, Farmany A, Cheraghi M (2012) Analysis of trace elements (Cu, Cd, and Zn) in the muscle, gill, and liver tissues of some fish species using anodic stripping voltammetry. Environ Monit Assess 184:6607–6611
Sobhanardakani S, Tayeb L, Hosseini SV (2018) Health risk assessment of arsenic and heavy metals (Cd, Cu Co, Pb, and Sn) through consumption of caviar of Acipenserpersicus from Southern Caspian Sea. Environ Sci Pollut Res 25:2664–2671
Storelli MM (2008) Potential human health risks from metals (Hg, Cd, and Pb) andpolychlorinated biphenyls (PCBs) via seafood consumption: estimation of target hazardquotients (THQs) and toxic equivalents (TEQs). Food Chem Toxicol 46:2782–2788
Storelli A, Barone G, Dambrosi A, Garofalo R, Busco A, Storelli MM (2020) Occurrence of trace metals in fish from South Italy: assessment risk to consumer's health. J Food Compos Anal 90:103487
Tasnim F, Hossain MA, Nusrath S, Hossain MK, Lopa D, Haque KM (2010) Quality Assessment of Industrially Processed Fruit Juices Available in Dhaka City. Bangladesh Mal J Nutr 16(3):431–438
Taweel A, Shuhaimi-Othman M, Ahmad AK (2013) Assessment of heavy metals in tilapia fish (Oreochromisniloticus) from the Langat River and Engineering Lake in Bangi, Malaysia, and evaluation of the health risk from tilapia consumption. Ecotoxicol Environ Saf 93:45–51
Tayebi L, Sobhanardakani S (2020) Analysis of heavy metal contents and non-carcinogenic health risk assessment through consumption of tilapia fish (Oreochromis niloticus). Pollution 6(1):59–67
USEPA (2010) Integrated Risk Information System (IRIS). United States Environmental Protection Agency, Washington, DC, Available online, https://www.epa.gov/ncea/iris/index.html, Accessed date: 15 September 2018
Witte MB, Thornton FJ, Tantry U, Barbul A (2002) L-Arginine supplementation enhances diabetic wound healing; involvement of the nitric oxi-de synthase and arginase pathways. Metabolism 51(10):1269–1273
Xu H, Yang H, Ge Q, Jiang Z, Wu Y, Yu Y, Han D, Cheng J (2021) Long-term study of heavy metal pollution in the northern Hangzhou Bay of China: Temporal and spatial distribution, contamination evaluation, and potential ecological risk. Environ SciPollu Res 28:10718–10733
Yu T, Zhang Y, Hu XN, Meng W (2012) Distribution and bioaccumulation of heavy metals in aquatic organisms of different trophic levels and potential health risk assessment from Taihu Lake. China Ecotoxicol Environ Saf 81:55–64
Zhu F, Fan W, Wang X, Qu L, Yao S (2011) Health risk assessment of eight heavy metals in nine varieties of edible vegetable oils consumed in China. Food Chem Toxicol 49:3081–3085