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Heavy metals content of tilapia fish (*Oreochromis niloticus*) and associated human health risks in selected Tehran's fish market suppliers

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Abstract

This study investigated the contamination of heavy metals and their associated health risks in tilapia fish (*Oreochromis niloticus*) supplied in some selected Tehran fish markets. To this end, fish samples were collected from Tehran's selected fish markets, including Sharin, Mah Protein, Novin Persian Gulf, Tohfeh, and Zarafshan Jonub in May 2021. The concentration of heavy metals (Cu, Cr, Hg, Pb, Cd, Zn, Co, and As) in the edible tissue of *Oreochromis niloticus* was measured using Microwave Digestion method and flame atomic absorption device. The mean concentration of heavy metals in sampled fish, expressed as µg/g d.w. and the highest concentration of Cu, Cr, Hg, Pb, Cd, Zn, Co, and As was evaluated at 4.12 ± 0.04, 5.23 ± 0.6, 0.14 ± 0.14, 0.25 ± 0.04, 0.14 ± 0.02, 0.76 ± 0.01, 0.07 ± 0.09 in Tohfeh, Novin Persian Gulf Fisheries, Zarafshan Jonub, and Sharin, respectively. The average concentration of Cr and Cu in the studied fish markets showed a significant difference and no significant difference was observed in other heavy metals ($P>0.05$). The results showed that Cr, Co, and Cd concentrations were higher than standard values suggested by World Health Organization, Regional Organization for the Protection of the Marine Environment and Food and Agriculture Organization standards. Children and youngsters were the most vulnerable groups to the

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contaminated fish muscles in different fish stores. Hg and as showed more target hazard quotient (THQ) than the other metals, and as was the most dangerous carcinogenic metals to children. Total target hazard quotient (TTHQ) and cumulative carcinogenic risk (CCR) demonstrated that studied heavy metals in tilapia have more non-carcinogenic effects than carcinogenic problems in humans. Together, the heavy metals content of tilapia fish in Tehran's fish markets is at a cautious level for consumers, especially those who are susceptible to such toxic materials, and target consumers should be informed and warned to avoid health-related problems.

Keywords: Heavy metals; Edible tissue; Tilapia fish; Fish consumption; Risk assessment.

1. Introduction

Seafood has constituted the most important part of the human food basket in last decade worldwide (Chien *et al*., 2002). This valuable source of healthy proteins contains a wide range of nutritive ingredients for consumers which are essential for the growth, immune system and prevention of diseases (Katiyar and Arora, 2020). Fish, in particular, plays a pivotal role in supplying essential fatty acids, omega-3, minerals, vitamins, and antioxidants, which help the better function of the organs in the human body (Garai *et al*., 2021). Literature have reported that the consumption of seafood can significantly result in reducing the risk of cardiovascular diseases (Tengku Nur Alia *et al*., 2020). There are various fish species that are commercially caught in marine waters or produced in inland waters (Soares *et al*., 2008). The greatest production and consumption of fish species have been in Asian and Pacific countries, where people can purchase various fish species from commercial and local fish markets (Alipour and Banagar, 2018).

Tilapia is one of the most favorite fish species which has received a great deal of attention by researchers and fishermen due to its favorable growth rate, high tolerance to environmental changes, filet quality, relatively low cultivation period, and economical features (Veisi *et al*., 2021; Mansano *et al*., 2020). This fish is commercially produced in freshwater, marine environments, cold and warm waters and polluted aquatic systems (Ismail *et al*., 2021). Tilapia prefers mainly warm waters and is distributed in tropical regions of the world. Tilapia is on the top of the aquatic food chain and can accumulate toxic materials and heavy metals, and in turn, transport such deleterious compounds to the human diet as the last consumer (Ali *et al*., 2019). Oreochromis niloticus has been known as one of the most highly-cultivated and used tilapia species which has an omnivorous food habit, providing an opportunity to eat various materials in the environment and receives more toxic metals via ingestion process (Veisi *et al*., 2021). This fish is supplied daily in many fish markets for human consumption and is very popular among consumers due to its high-quality fillet.

Heavy metals are classified as the most ubiquitous toxic materials in the aquatic biota (Kazemi *et al*., 2022). These compounds are mainly produced by anthropogenic activities and originate from municipal wastewater, agricultural drainage, and industrial wastes (Ali *et al*., 2019). Trace elements, including Hg, Pb, As, Cd, Co, Fe, Cr, Al and Ni can cause variable toxic effects when daily intake exceeds permissible limits, which suggested by international organizations such as World Health Organization (WHO) and Food and Agriculture Organization (FAO) (Seyedi *et al*., 2021). Heavy metals in highly contaminated environments are in higher levels and can be accumulated in fish species through feeding and absorption via skin and gills (Ullrich *et al*., 2001). Such deleterious compounds can later cause many health-related problems in the human body such as cancer and tissue disorders in vital organs (Mirzabeygi *et al*., 2017). Contaminated fish species are one of the main pathways to enter toxic metals to the human body; for instance, mercury only can pollute the body via fish consumption (Boening, 2000). Many studies have been conducted to evaluate the concentration and associated health risks of heavy metals in contaminated commercial fish (Diaconescu *et al*., 2013; Ali *et al*., 2019; Tengku Nur Alia *et al*., 2020; Hamed *et al*., 2020) However, the health status of supplied tilapia fish in the fish markets of metropolis cities, like Tehran with many target fish consumers, has not been yet fully addressed and more attention should be paid to study and warn the possible hazardous effects of heavy metals to human (Shokri *et al*., 2021). In this regard, health risk assessment analysis can evaluate and assess the possible hazards of toxic metals to target human groups. Many studies have shown that non-carcinogenic and carcinogenic effects of toxic materials to human subjects can be examined using risk assessment models suggested by Environmental Protection Agency of the USA (USEPA). Such models can deepen our knowledge in understanding the adverse effects of pollutants to fish consumers, especially those who are more vulnerable like children, pregnant women and elderly people (Ali *et al*., 2019).

Fish markets are the main place to sell fish species and residents may prefer using these markets to buy their favorite fish (Shokri *et al*., 2021). In Tehran, the capital city of Iran, there are many fish stores ranging from local shops to hypermarkets which supply fish species from both marine and freshwater environments (Alipour and Banagar, 2018). Having marine resources in the Persian Gulf and Caspian Sea as well as inland waters for freshwater fish species, Iran has become one of the most countries in the world to produce seafood (Dabbagh, 2012). In addition, Iran ranked first in the world in terms of the production of inland freshwater fish species such as rainbow trout (Oncorhynchus mykiss).

Due to that, fish species are available in fish markets across the country and people can purchase fresh, canned, frozen and smoked products. However, the presence of heavy metals and their associated health risks in different fish products supplied in markets have received no considerable attention and many aspects remained in the dark for the health of consumers.

Therefore, the main objectives of this study were to (i) determine the concentration of heavy metals (Cu, Zn, Cd, Co, Cr, Pb, Hg and As) in the muscle of tilapia (Oreochromis niloticus) supplied in Tehran fish markets, (ii) compare detected heavy metals concentration with the standard limits suggested by international organizations (WHO, FAO and ROPME), (iii) assess the health risk of heavy metals to target consumers, including children, youngsters, obese people and adults, and (iv) evaluate the permissible values of this fish for daily and monthly consumptions.

2. Material and methods

2.1. Sampling

Sampling was conducted in Sharin, Mah Protein, Novin Persian Gulf Fisheries, Tohfeh and Zarafshan Jonub, where Tilapia fish was daily supplied. At each sampling fish store, three Tilapia fish with an average weight of 457 ± 5 g and length of 25 ± 2 cm were purchased from local markets in Tehran. Frozen fish, fish with damaged body, and corrupted fish samples were not included in the sampling process. Collected samples were separately labeled and codded for each supplier and kept on ice boxes to prevent unwanted pollution and changes.

2.2. Sample preparation and digestion

The samples were prepared in the lab for the digestion step using washed and clean tools such as a knife, scissors, and wooden board to collect the edible tissue of sampled fish. To digest the samples, microwave digestion method was used and fish muscle samples were first dried at 80 ^{O}C for 24 h. An amount of 0.3 g of the sample was mixed with 65% HNO3 and 35% H2O2 (with a ratio of 8 to 2) and then the digestion was performed through the microwave machine (545 ± 10 watt). Digested samples were then filtered using Millipore Whatman papers (0.45 µm). After digestion, the volume of prepared samples was reached to 50 cc by adding distilled water and stored in a refrigerator at a temperature of 4 °C until starting the further analysis (MOOPAM, 1999).

2.3. Heavy metals concentration

An atomic absorption (Themo electron corporation, M5) was used to measure the concentration of heavy metals in the digested fish muscles. The fuel used is acetylene-air type and the system are based on a flame, and the Hollow cathode lamp which has a separate computer system that stores all the information about the metal specification in it. Measurements of the metals were performed using the flame and furnace atomic absorption system. The concentration of the standards is selected according to the device sensitivity and also the limits of the elements. After adjusting the device and preparing standard solutions, first the device was calibrated with the control solution (including distilled water and concentrated nitric acid), and then for each element, first, standard solutions were provided to the device from diluted to concentrated and ten absorbents rates were recorded by the device. The absorbance of each solution was repeated three times and the average adsorption was printed on the paper. The standard curve was prepared by the machine and ready to measure the samples. After spraying each sample into the flame according to selected conditions for measurement, the sample concentration was read and the results were obtained in ppm (MOOPAM, 1999).

Final calculation of the sample concentration is obtained by using the following formula:

$$\text{Metal concentration} = \frac{(A \times V)}{B}\ (\mu g/g\ d.w.)$$

A = detected concentration = (ppm)

V = final volume = (ml)

B = initial sample weight used for digestion (g)

Considering the measurement of heavy metals and their comparison with global standards the values of the metals that exceed the allowable limits, the maximum permitted levels of usage for the four groups of fish in the community are as follows:

$$A = \frac{(B \times C)}{W}$$

A = Permissible consumption per week according to WHO, FAO, ROPME (µg/kg)

B = heavy metal concentration in tissue (µg/kg d.w.)

C = maximum allowable consumption per week (g)

W = body weight (kg)

Target human groups were considered as children (average weight 15 kg), youngsters (average weight 30 kg), adults (average weight 60 kg) and obese people (average weight 75 kg) for risk assessment analysis (Sahebi and Cohen, 2011).

2.4. Human health risk assessments

Health risk assessment indices, including estimated daily intake (EDI), estimated weekly intake (EWI), daily consumption rate (CRlim), monthly consumption rate (CRmm), target hazard quotient (THQ), carcinogenic risk (CR), total target hazard quotient (TTHQ), and cumulative carcinogenic risk (CCR) were applied using Equations (1 to7), respectively.

2.4.1 Estimated daily intake (EDI) and estimated weekly intake (EWI)

To assess the non-carcinogenic risks of studied heavy metals, Equation (1) was used based on the method reported by Kazemi *et al*. (2022) with some modifications.

$$\mathrm{EDI} = \frac{(\mathrm{EF} \times \mathrm{ED} \times \mathrm{IR} \times \mathrm{MC})}{(\mathrm{BW} \times \mathrm{AT})} \quad (1)$$

where, EDI is the estimated daily intake (mg/kg.d), EF is the exposure frequency (365 days/year), ED is the exposure duration for an adult (54 years), IR is daily ingestion rate of fish by adult person that equal 52.60 g/day (19.2 kg/year) (global average fish consumption) according to FAO (2019), MC is the heavy metal concentration (mg/kg d.w.), BW is the average body weight of fish consumers (assumed as 70 kg for Iranian fish consumers) and AT is the average time for non-carcinogenic effects (assumed as 60 × 365). EWI is calculated similarly as EDI except IR value which is equal to 368.20 g/week.

2.4.2 Daily consumption rate (CRlim) and monthly consumption rate (CRmm)

Daily consumption rate (CR_{lim}) was calculated based on the Equation (2). In this equation the permissible amount of fish muscle received daily from contaminated fish is evaluated. In addition, monthly consumption rate (CR_{mm}) was measured using Equation (3), which is related to the allowable amount of fish muscle consumed over a month.

$$\mathrm{CR_{lim}} = \frac{\mathrm{RFD} \times \mathrm{BW}}{\mathrm{C_m}} \quad (2)$$

$$\mathrm{CR_{mm}} = \frac{\mathrm{CR_{lim}} \times \mathrm{AT}}{\mathrm{MS}} \quad (3)$$

where, CR_{lim} is the daily consumption rate (g/day), RFD is the reference dose for heavy metals (assumed as 3×10^{-4}, 3×10^{-3}, 7×10^{-1}, 2×10^{-3}, and 4×10^{-3}, for AS, Cr, Hg, Ni, Pb, respectively, BW is the average body weight of fish consumers (assumed as 70 kg for Iranian fish consumers), Cm is the heavy metal concentration (mg / kg d.w.). Moreover, CR_{mm} is the monthly consumption rate (g/day), AT is the average time in a month and MS refers to the meal size (kg/meal), which in this study are assumed as 30.44 days and 0.227 kg, respectively.

2.4.3 Target hazard quotient (THQ) and total target hazard quotient (TTHQ)

Target hazard quotient (THQ) is a model recommended by USEPA (2000) to assess the non-carcinogenic risks of heavy metals. THQ is calculated based on the method presented in Equation (4).

$$\mathrm{THQ} = \frac{(\mathrm{EF_r} \times \mathrm{ED_{tot}} \times \mathrm{FIR} \times \mathrm{C})}{\mathrm{RfD_o} \times \mathrm{BW_a} \times \mathrm{ATN}} \times 10^{-3} \quad (4)$$

where, EFr is the number of days during the year (365 days), EDtot is the average age assumed as 70 years, FIR is equal to 36.66, C is the concentration of heavy metals (µg/kg), RfDo is the reference dose of studied heavy metals (assumed as 3×10^{-4},3×10^{-3}, 7×10^{-1}, 2×10^{-3}, and 4×10^{-3}, for AS, Cr, Hg, Ni, Pb, respectively), BWa is the average weight of adults (70 kg), and ATN is equal to 26280. In addition, total target hazard quotient is calculated based on the Equation(5) and represents the sum of THQs for all studied heavy metals.

$$TTHQ = THQ_{Hg} + THQ_{As} + THQ_{Ni} + THQ_{Cr} + THQ_{Pb} \quad (5)$$

If THQ or TTHQ is counted to be below 1.00, there is no significant non-carcinogenic health risks to target humans, whereas values above 1.00 indicate that there is a chance for occurrence of non-carcinogenic public health risks from eating the contaminated fish muscle (Kazemi *et al*., 2022).

2.4.4 Carcinogenic risk (CR) and cumulative carcinogenic risk (CCR)

Carcinogenic risk (CR) was assessed using a model suggested by USEPA (2000). This index is represented the potential risk of carcinogenic heavy metals and calculated based on the Equations (6) and (7).

$$CR = CDI \times SFO \quad (6)$$

$$CDI = (C_m \times Ing_R \times EF \times ED \times CF) \times (BW \times AT) \quad (7)$$

where, the CR is carcinogenic risk, the SFO is oral cancer slop factor (assumed as 15×10^{-1}, 8.5×10^{-3}, 5×10^{-1} and 3×10^{-1} for As, Pb, Cr and Hg, respectively (Ni has no SFO), EF exposure frequency (350 days), ED is 70, CF is 6×10^{-6}, BW is the body weight (70 in average), and AT is the average time (2550). Further, cumulative carcinogenic risk (CCR) was calculated using Equation (8).

$$CCR = CR_{Hg} + CR_{As} + CR_{Ni} + CR_{Cr} + CR_{Pb} \quad (8)$$

Those values with $CR>1\times10^{-4}$, $1\times10^{-6}<CR<1\times10^{-4}$, and $CR<1\times10^{-6}$ were respectively considered as no acceptable, acceptable, and negligible carcinogenic risk (Kazemi *et al*., 2022).

2.5. Statistical analysis

The analysis of heavy metals in fish muscle samples was performed considering triplicates. Metal concentrations were reported as mean ± SD. Microsoft Excel was used to analyze the data and calculate the statistics. One-way analysis of variance (ANOVA) was conducted using SPSS (v. 21, Chicago, USA) to show the differences between heavy metals in fish muscle samples.

3. Results

3.1. Heavy metals concentration in studied fish markets

3.1.1 Sharin company

Concentration of studied heavy metals based on CRM ± SE and calculated values are presented in Table 1. The concentration of heavy metals Cu, Hg, Pb, Zn, Cr, Cd, Co was at 3.37, 0.04, 0.25, 0.76, 0.93, 0.14 and 0.07 (µg/g d.w.), respectively. In comparison to WHO standard limit, the concentration of Cu, Hg, Pb, Zn was less than standard values. Cd concentration was at permissible limit, and Cr and Co were higher than the suggested values. Results showed that, compared to FAO standards, Cu, Hg, Pb, Zn, Cd and Co concentrations were lower than allowable limits, but Cr was higher than the standard value (Tables 2 and 3). The maximum permissible consumption of *tilapia* fish per week based on for heavy metals concentration which were higher than WHO and FAO standard levels for each different target groups calculated. Cr and Co metals showed 3.22and 10.71 g/week for children, 6.45 and 21.42 g/week for youngsters, 12.90 and 42.58 g/week for adults and 16.12 g and 53.57 g/week for obese people. Compared to ROPME permissible limit, Cu, Hg, Pb, Zn and Co concentrations were below the recommended standards, and Cr and Cd concentration level were higher than values stated by ROPME. In addition, the maximum allowable weekly consumption of *tilapia* fish contained Cr and Cd, which were higher than ROPME standard levels, measured at 8.06 and 5.35 g/week for children, 16.12 and 10.71 g/week for youngsters, 32.25 and 21.42 g/week for adults, 40.32 and 26.78 g/week for obese people (Tables 4-6).

Table 1. Concentration of studied heavy metals based on CRM ± SE and calculated values in this study (µg/g d.w.)

Metal	Concentration in CRM ± SE	Calculated concentration
Cu	2.98 ± 0.092	2. 98 ± 0.1
Zn	0.518 ± 0.1	0.5 ± 0.12
Cd	0.098 ± 0.128	0.1
Co	0.064 ±0.106	0.065 ± 0.10
Cr	2.83 ±0.352	2.90 ± 0.35
Pb	0.166 ± 0.126	0.166 ± 0.126
Hg	0.06 ± 0.268	0.06 ± 0.27
As	ND	ND

ND: non-detected

3.1.2 Mah Protein company

The concentration of Cu, Hg, Pb, Zn, Cr, Cd and Co was measured at 1.43, 0.02, 0.08, 0.43, 0.3, 0.04, and 0.05 μg/g d.w., respectively, in the edible tissue of tilapia fish supplied by Mah Protein company. Compared with WHO standard levels, Cu, Hg, Pb, Zn and Cd concentrations were less than standard levels, Co was in standard level and Cr was higher than standard level. In Terms of FAO regulations, Cu, Hg, Pb, Zn, Cd and Co concentrations were less than standard level, but Cr showed higher values (Tables 2 and 3). Consequently, the maximum consumption of fish per week based on Cr concentration was at 10 g/week, 20 g/week, 40 g/week 50 g/week for children, youngsters, adults and obese people, respectively. Based on the ROPME standard levels, Cu, Hg, Pb, Zn, Cd, Cr and Co heavy metals were less than legislated values (Tables 4-6).

Table 2. Heavy metals concentration in different fish markets in Tehran supplying tilapia fish (μg/g d.w)

Metal	Statistics	Fisheries companies				
		Sharin	Mah Protein	New Gulf Fisheries	Tohfeh	Zarafshan Jonub
Cu	Min	1.21	0.87	1.55	2.24	0.87
	Max	4.55	2.69	5.12	5.89	3.58
	Mean	3.37± 0.05	1.43 ± 0.09	3.85 ± 0.25	4.12 ± 0.04	2.14 ± 0.03
Cr	Min	0.11	0.01	1.28	1.25	1.85
	Max	1.45	0.9	7.67	5.57	5.69
	Mean	0.93 ± 0.5	0.3 ± 0.1	5.23 ± 0.6	3.89 ± 0.5	3.80 ± 0.06
Hg	Min	0.001	0.01	0.005	0.02	0.1
	Max	0.10	0.04	0.08	0.16	0.23
	Mean	0.04 ± 0.9	0.02 ± 0.11	0.02 ± 0.14	0.08 ± 0.05	0.14 ± 0.14
Pb	Min	0.5	0.01	0.02	0.05	0.04
	Max	0.42	0.18	0.28	0.34	0.18
	Mean	0.25 ± 0.04	0.08 ± 0.27	0.15 ± 0.16	0.24 ± 0.04	0.11 ± 0.12
As	Min	-	-	-	-	-
	Max	-	-	-	-	-
	Mean	ND	ND	ND	ND	ND
Cd	Min	0.01	0.001	0.04	0.005	0.01
	Max	0.23	0.09	0.32	0.20	0.12
	Mean	0.14 ± 0.02	0.04 ± 0.04	0.12 ± 0.23	0.13 ± 0.18	0.06 ± 0.16
Zn	Min	0.11	0.05	0.12	0.02	0.16
	Max	1.24	0.65	0.96	0.68	1.13
	Mean	0.76 ± 0.01	0.43 ± 0.16	0.53 ± 0.07	0.38 ± 0.05	0.49 ± 0.21
Co	Min	0.002	0.001	0.006	0.001	0.008
	Max	0.12	0.09	0.16	0.18	0.14
	Mean	0.07 ± 0.09	0.05 ± 0.18	0.06 ± 0.07	0.07 ± 0.06	0.07 ± 0.13

*ND indicated non-detected concentrations

Table 3. Standard limits of studied heavy metals, suggested by WHO, FAO and ROPME (μg/g d.w.)

Standard	Cu	Cr	Hg	Pb	Cd	Zn	Co
WHO	30.00	0.20	0.50	0.50	0. 1-0.2	30.00	0.05
FAO	30.00	0.20	0.50	2.00	0.50	30.00	0.50
ROPME	30.00	0.50	0.1-0.5	0.50	0.05	30.00	0.50

Table 4. Maximum allowable consumption rate of tilapia fish for target human groups considered for Cr at studied fisheries companies (μg/g d.w.)

Fisheries company	Human group	WHO	FAO	ROPME
Sharin	Children	3.22	3.22	8.06
	Youngsters	6.45	6.45	16.12
	Adults	12.90	12.90	32.25
	Obese people	16.12	16.12	40.32
Mah Protein	Children	10.00	10.00	-
	Youngsters	20.00	20.00	-
	Adults	40.00	40.00	-
	Obese people	50.00	50.00	-
Novin Persian Gulf Fisheries	Children	0.57	0.57	1.43
	Youngsters	1.14	1.14	2.86
	Adults	2.29	2.29	5.73
	Obese people	2.86	2.86	7.17
Tohfeh	Children	0.77	0.77	1.92
	Youngsters	1.54	1.54	3.85
	Adults	3.08	3.08	7.71
	Obese people	3.85	3.85	9.64
Zarafshan Jonub	Children	0.78	0.78	1.97
	Youngsters	1.57	1.57	3.94
	Adults	3.15	3.15	7.89
	Obese people	3.94	3.94	9.21

Table 5. Maximum allowable consumption rate of tilapia fish for target human groups considered for Cd at studied fisheries companies (µg/g d.w.)

Fisheries company	Human group	WHO	FAO	ROPME
Sharin	Children	-	-	5.35
	Youngsters	-	-	10.71
	Adults	-	-	21.42
	Obese people	-	-	26.78
Mah Protein	Children	-	-	-
	Youngsters	-	-	-
	Adults	-	-	-
	Obese people	-	-	-
Novin Persian Gulf Fisheries	Children	18.75	-	6.25
	Youngsters	37.50	-	12.5
	Adults	75.00	-	25.00
	Obese people	93.75	-	31.25
Tohfeh	Children	-	-	5.76
	Youngsters	-	-	11.53
	Adults	-	-	23.07
	Obese people	-	-	28.84
Zarafshan Jonub	Children	-	-	12.50
	Youngsters	-	-	25.00
	Adults	-	-	50.00
	Obese people	-	-	62.50

3.1.3 Novin Persian Gulf company

The concentration of Cu, Hg, Pb, Zn, Cr, Cd and Co was at 3.85, 0.02, 0.15, 0.53, 5.23, 0.12, 0.06 µg/g d.w., respectively, in the muscle of tilapia fish supplied by Novin Persian Gulf company. Based on the WHO standard levels, Cu, Hg, Pb and Zn concentrations were less than acceptable values, but Cr, Co and Cd were higher than WHO standards. FAO standard levels demonstrated that Cu, Hg, Pb, Zn, Cd and Co contents were less than the standards; however, Cr showed values higher than permissible limits (Tables 2 and 3). Recommended weekly consumption rate for fish supplied by Novin Persian Gulf company, based on the Cd, Co, Cr concentrations, was at 18.75 g/week, 12.5 g/week and 0.57 g/week for children, 37.5 g/week, 25 g/week and 1.14 g/week for youngsters, 75 g/week, 50 g/week and 2.29 g/week for adults and 93.75 g/week, 62.5 g/week and 2.86 g/week for obese people, respectively. According to the ROPME recommended values, Cu, Hg, Pb, Zn and Co contents were less than standard levels, but Cr and Cd concentrations were higher than the respective levels. Therefore, the allowable intake rate of fish muscle contained Cr and Cd were 6.25 g/week and 1.43 g/week for children, 12.5 g/week and 2.86 g/week for youngsters, 25 g/week and 5.73 g/week and 31.25 g/week and 7.17 g/week for obese people, respectively (Tables 4-6).

Table 6. Comparing the results of the present study with the results of some other studies (µg/g d.w.).

Reference	Study area	Cu	Cr	Hg	Pb	As	Cd	Zn	Co
AL-kahtani, 2009	Saudi Arabia	2/46	-	-	1.49	-	0.28	21.66	-
Edem Christopher *et al*., 2009	Nigeria Group A:29 cm	-	-	Nd	0.053	Nd	0.015	0.079	-
Edem Christopher *et al*., 2009	Nigeria group B:20 Cm	-	-	Nd	0.062	Nd	0.017	0.095	-
Sani, 2011	Nigeria	0.11±0.04	-	-	2±0.79	-	-	-	14.8±2.23
Taweel *et al*., 2011	Malaysia Pond A	2.65±0.76	6.21±0.60	-	0.11±0.01	-	0.01±0.0	31±2.80	-
Taweel *et al*., 2011	Malaysia Pond B	2.23±0.16	6.10±0.29	-	0.10±0.01	-	0.01±0.0	29±1.60	-
Ismaniza, and Idaliza, 2012	Malaysia Puchong	0.17 to 20.78	-	-	Nd	Nd	Nd	45.52 to 86.08	-
Sharine company	Iran Tehran	3.37±0.05	0.93±0.5	0.04±0.9	0.25±0.04	Nd	0.14±0.02	0.76±0.01	0.07 ±0.09
Mah protein company	Iran Tehran	1.43±0.09	0.3±0.1	0.02 ±0.11	0.08±0.27	Nd	0.04±0.04	0.43±016	0.05±0.18
Novin persian gulf fisheries	Iran Tehran	3.85±0.25	5.23±0.6	0.02± 0.14	0.15±0.16	Nd	0.12 ±0.23	0.53±0.07	0.06±0.07
Tohfeh company	Iran Tehran	4.12 ±0.04	3.89±0.5	0.08 ±0.05	0.24±0.04	Nd	0.13±0.18	0.38±0.05	0.07±0.06
Zarafshan Jonub company	Iran Tehran	2.14±0.03	3.80±0.06	0.14±0.14	0.11±0.12	Nd	0.06±0.16	0.49±0.21	0.07±0.13

3.1.4 Tohfeh company

The concentration of Cu, Hg, Pb, Zn, Cr, Cd and Co was at 4.12, 0.08, 0.24, 0.38, 3.89, 0.13, 0.07 µg/g d.w., respectively, in the edible tissue of tilapia fish supplied by Tohfeh company. Based on the standards reported by WHO, Cu, Hg, Pb, Zn and Cd contents showed lower values, while Cr and Co were higher than the standards. FAO standard levels for Cu, Hg, Pb, Zn, Cd and Co demonstrated that heavy metals concentration was less than the standards, but Cr was greater than the suggested concentrations (Tables 2 and 3). Cr and Co concentrations showed that compared with WHO and FAO standards, 0.77 g/week and 10.71 g/week children, 1.54 g/week and 21.42 g/week youngsters, 3.08 g/week and 42.85 g/week adults and 3.85 g/week and 53.57 g/week for obese people, respectively. To compare with ROPME standards, Cu, Hg, Pb, Zn and Co contents were less than permitted values, whereas Cr and Cd concentrations were higher. Hence, the permissible values for children, youngsters, adults and obese people were at 5.76 g/week, 11.53 g/week, 23.07 g/week and 28.84 g/week (Tables 4-6).

3.1.5 Zarafshan Jonub company

The concentration of Cu, Hg, Pb, Zn, Cr, Cd, Co was at 2.14, 0.14, 0.11, 0.49, 3.8, 0.06, 0.07 µg/g d.w., respectively, in the muscle of tilapia fish supplied by *Zarafshan Jonub company*. According to the WHO standards, Cu, Hg, Pb, Zn and Cd concentrations were less than acceptable regulations, however Cr and Co were higher than standards. FAO suggested values for Cu, Hg, Pb, Zn, Cd and Co showed concentrations less than standard levels, and Cr was higher than the permitted values (Tables 2 and 3). Permissible intake values per week showed 0.78 and 10.71g for children, 1.57g and 21.42g for youngsters, 3.15g and 50 g for adults and 3.94g and 53.57g for obese people. In comparison to ROPME standards, Cu, Pb, Zn and Co concentration was less than the standards, Hg was in standard level and Cr and Cd concentration level were higher than the recommended values. Allowable tilapia fish consumption values for this company was weekly at 1.97g and 12.5g for children, 3.94g and 25g for youngsters, 7.89g and 50g for adults, 9.21g and 62.5g for obese people (Tables 4-6).

3.2 Heath risk assessment analysis

3.2.1 Estimated daily intake (EDI)

Estimated daily and weekly intake (EDI and EWI) for adults and children are presented in Tables 7 and 8, respectively. Hg showed the greatest EDI and EWI at 3.97 (mg/kg.day) and 27.82 (mg/kg.week), respectively. In addition, Cr did show highest values for EDI and EWI at 1.17 and 8.19, respectively. Ni and Pb reveled the greatest EDI (7.13 and 49.94) and EWI at (13.45 and 94.18), respectively (Tables 7 and 8).

Table 7. Estimated daily intake (EDI) (mg/kg.day) and estimated weekly intake (EWI) (mg/kg.week) of studied heavy metals in different Tilapia fish suppliers in Tehran's markets for adults (Average body weight: 70 kg, Daily ingestion rate: 52.60 g/day and Weekly ingestion rate: 368.20 g/week).

Fish supplier	Hg		As		Cr		Ni		Pb	
	EDI	EWI	EDI	EWI	EDI	EWI	EDI	EWI	EDI	EWI
Sharin	0.84	5.92	6.71	46.96	0.25	1.75	0.07	0.48	0.18	1.26
Mah Protein	0.85	5.96	6.34	44.40	0.13	0.96	0.10	0.72	0.28	1.10
Novin Persian Gulf	0.56	3.97	6.06	42.41	0.18	1.29	0.04	0.29	0.15	1.01
Tohfeh	0.43	3.05	5.75	40.25	0.16	1.15	0.06	0.45	0.53	3.73
Zarafshan Jonub	0.51	3.61	5.77	40.43	0.24	1.69	1.53	10.70	2.88	20.18

Table 8. Estimated daily intake (EDI) and estimated weekly intake (EWI) of studied heavy metals for children in different Tilapia fish suppliers of Tehran's markets

Fish supplier	Hg		As		Cr		Ni		Pb	
	EDI	EWI	EDI	EWI	EDI	EWI	EDI	EWI	EDI	EWI
Sharin	3.95	27.63	31.31	219.15	1.17	8.19	0.32	2.24	0.84	5.90
Mah Protein	3.97	27.82	29.60	207.22	0.64	4.50	0.48	3.35	1.32	9.25
Novin Persian Gulf	2.46	18.52	28.27	197.92	0.86	6.02	0.19	1.36	0.73	5.12
Tohfeh	2.03	14.23	26.83	187.83	0.77	5.39	0.30	2.13	2.49	17.43
Zarafshan Jonub	2.41	16.87	26.95	188.67	1.12	7.89	7.13	49.94	13.45	94.18

3.2.2 Daily and monthly permissible consumption rate (CRlim and CRmm)

CR_{lim} and CR_{mm} results are shown in Table 9. Hg showed the largest CR_{lim} and CR_{mm} values at 7.11 and 965.23 mg/kg.bw, respectively. In addition, fish muscle did reveal the greatest As CR_{lim} and CR_{mm} at 0.004631 and 0.62 mg/kg.bw, respectively. In terms of Cr, muscles had the highest CR_{lim} and CR_{mm} at 3.89 and 521.66 mg/kg.bw, respectively. For Ni, CR_{lim} and CR_{mm} did demonstrate higher values at 4.13 and 553.65 mg/kg.bw, while Pb showed 1.37 mg/kg.bw and 183.85 mg/kg.bw for CR_{lim} and CR_{mm}, respectively.

3.2.3 Target hazard quotient (THQ)

Non-carcinogenic risk assessment analysis is reported in Table 10. THQ values are shown based on the target human groups, including adults and children. Hg showed the greatest THQ for both adult and children at 40.43 and 0.08, respectively. Adults and children, for As, had the largest THQ at 2.79 and 13.02, respectively. Fish muscle, contaminated with

Cr, showed highest THQ at 48.00 × 10^{-5} for adults, while raw materials showed the largest values at 18.00 × 10^{-3} for children. Fish muscle containing Ni revealed high THQ values for adults and children at 25.62 × 10^{-4} and 12.00 × 10^{-2}, respectively. Pb did reveal the greatest THQ in adults and children at 25.00 × 10^{-4} and 21.00 × 10^{-3}, respectively. Based on the criteria described in the methodology section, Hg showed THQ more than 1 for adults, which means that there is a non-carcinogenic health risk for this group, but children had THQ below 1, meaning that there is no non-carcinogenic risk for this group. THQ demonstrated values above 1 for As in both adults and children, assuming that this heavy metal could induce non-carcinogenic effects in target human groups. Cr, Ni and Pb revealed THQ values smaller than 1 in both adults and children, meaning that these heavy metals have no non-carcinogenic risks to humans.

Table 9. Daily and monthly permissible consumption rate (CRlim and CRmm) of consumed fish muscle in different Tilapia fish suppliers of Tehran's markets (mg/kg.bw)

Fish supplier	Hg		As		Cr		Ni		Pb	
	CR_{lim}	CR_{mm}	CR_{lim}	CR_{mm}	CR_{lim}	CR_{mm}	CR_{lim}	CR_{mm}	CR_{lim}	CR_{mm}
Sharin	4.48	600.55	0.003008	0.40	1.52	204.46	0.30	41.22	0.86	116.07
Mah Protein	7.11	965.23	0.002816	0.37	3.89	521.66	4.13	553.65	0.91	133.54
Novin Persian Gulf	7.84	1052.24	0.004290	0.57	1.54	206.60	1.61	216.05	1.37	183.85
Tohfeh	0.45	60.71	0.004631	0.62	0.19	25.62	0.30	41.12	0.87	116.62
Zarafshan Jonub	2.94	394.95	0.004495	0.60	2.92	392.15	1.08	145.05	0.98	131.41

Table 10. Target hazard quotient (THQ) of studied heavy metals in different Tilapia fish suppliers of Tehran's markets for adults and children.

Fish supplier	Hg		As		Cr		Ni		Pb	
	Adult	Children	Adult	Children	Adult	Children	Adult	Children	Adult	Children
Sharin	4.09	0.00	2.61	12.18	57.00 × 10^{-6}	18.00 × 10^{-3}	25.56 × 10^{-4}	0.12	25.00 × 10^{-3}	21.00 × 10^{-3}
Mah Protein	2.54	0.00	2.79	13.02	23.00 × 10^{-6}	8.00 × 10^{-3}	19.00 × 10^{-5}	0.01	19.00 × 10^{-3}	18.00 × 10^{-3}
Novin Persian Gulf	2.33	0.00	1.83	8.54	63.00 × 10^{-6}	14.00 × 10^{-3}	48.8 × 10^{-5}	0.02	16.00 × 10^{-3}	17.00 × 10^{-3}
Tohfeh	40.43	0.08	1.69	7.91	48.00 × 10^{-5}	15.00 × 10^{-3}	25.62 × 10^{-4}	0.12	21.00 × 10^{-3}	16.00 × 10^{-3}
Zarafshan Jonub	6.22	0.01	1.74	8.15	29.00 × 10^{-6}	81.00 × 10^{-4}	72.6 × 10^{-5}	0.03	13.00 × 10^{-3}	18.00 × 10^{-3}

3.2.4 Carcinogenic risk (CR) assessments

Carcinogenic risk assessments of studied trace elements are presented in Table 11. Results showed that Hg had the highest CR in fish muscles for adult and children at 42.00×10^{-12} and 1.94×10^{-10}, respectively. For As, fish showed the greatest CR for adult and children at 5.79×10^{-5} and 2.70×10^{-4}, respectively. Adults and children who eat fish muscle containing Cr concentrations had the largest CR for at 6.39×10^{-8} and 2.84×10^{-7}, respectively. Pb revealed CR values for adults in a higher level at 1.13×10^{-8}, while children did show greatest values for spiced muscles at 81.00×10^{-8} compare to other cooking methods. Based on the criteria outlined in the methodology, CR index for As in children group showed values more than 1.00×10^{-4}, meaning that this heavy metal has a carcinogenic risk for children. As demonstrated CR values in the range of $1.00\times10^{-6} < CR < 1.00\times10^{-4}$ for adults, meaning acceptable carcinogenic risks for these groups in consuming fish muscle. However, Hg, Cr, and Pb showed CR values smaller than 1.00×10^{-6} in all human groups with the negligible carcinogenic risks for these consumers.

Table 11. Carcinogenic risk (CR) of studied heavy metals in different Tilapia fish suppliers of Tehran's markets for adults and children.

Fish supplier	TTHQ		CCR	
	Adult	Children	Adult	Children
Sharin	6.72	12.34	58.00×10^{-5}	27.28×10^{-5}
Mah Protein	5.35	13.05	54.01×10^{-5}	25.53×10^{-5}
Novin Persian Gulf	4.17	8.59	52.00×10^{-5}	24.59×10^{-5}
Tohfeh	42.14	8.14	4.04×10^{-5}	23.40×10^{-5}
Zarafshan Jonub	7.97	8.21	4.02×10^{-5}	23.64×10^{-5}

3.2.5 Total target hazard quotient (TTHQ) and cumulative carcinogenic risk (CCR)

TTHQ and CCR values for trace elements detected in different fish muscle cooking methods are shown in Table 12. Results showed that fish had the highest TTHQ for children at 13.05, whereas this index did reveal the greatest values for adults at 42.14. CCR values showed the highest risk for adults and children at 58.00×10^{-5} and 27.28×10^{-5}, respectively. TTHQ for adults and children showed values ranged between 5.35 and 42.14, meaning that studied heavy metals had significant non-carcinogenic risks (TTHQ > 1) for studied human groups. In addition, CCR showed values between 4.02×10^{-5}-58.00×10^{-5} ($1.00\times10^{-6} < CR < 1.00\times10^{-4}$) meaning that studied heavy metals have acceptable carcinogenic risks for children and adults in this study.

Table 12. Total target hazard quotient (TTHQ) and cumulative carcinogenic risk (CCR) of studied heavy metals in different Tilapia fish suppliers of Tehran's markets for adults and children.

Fish supplier	Hg		As		Cr		Ni		Pb	
	Adult	Children	Adult	Children	Adult	Children	Adult	Children	Adult	Children
Sharin	41.00×10^{-12}	1.93×10^{-10}	5.79×10^{-5}	2.70×10^{-4}	6.39×10^{-8}	2.83×10^{-7}	-	-	1.24×10^{-9}	5.87×10^{-9}
Mah Protein	42.00×10^{-12}	1.94×10^{-10}	5.47×10^{-5}	2.54×10^{-4}	3.12×10^{-8}	1.35×10^{-7}	-	-	7.46×10^{-10}	3.40×10^{-9}
Novin Persian Gulf	28.00×10^{-12}	1.29×10^{-10}	5.23×10^{-5}	2.44×10^{-4}	4.86×10^{-8}	1.93×10^{-7}	-	-	7.15×10^{-10}	3.31×10^{-9}
Tohfeh	21.00×10^{-12}	1.00×10^{-10}	4.00×10^{-5}	2.32×10^{-4}	4.11×10^{-8}	2.03×10^{-7}	-	-	2.32×10^{-9}	81.00×10^{-8}
Zarafshan Jonub	25.00×10^{-12}	1.18×10^{-10}	4.00×10^{-5}	2.33×10^{-4}	5.73×10^{-8}	2.84×10^{-7}	-	-	1.13×10^{-8}	5.61×10^{-8}

4. Discussion

Understanding the health status of fish plays a pivotal role in having a healthy society, especially in developing countries, where people have increasingly desired to consume sea foods in their daily diets. Knowledge about the concentration of heavy metals in fish is important in both aspects of human health and management, for example, some heavy metals such as Cu and Zn are essential for metabolic activities, while some others such as Hg, Cd and Pb are toxic in exceeding values for the human body (Canli and Atli, 2003; Diaconescu *et al.*, 2013). Various research and studies have reported that the accumulation of toxic metals in a tissue is mainly due to the concentration of such materials in the water and the exposure time that they are being face with. Environmental factors such as salinity, pH and temperature play an important role in the accumulation of metals as abiotic factors. Ecological, gender and size requirements in aquatic animals are also known as processes affecting the accumulation of metals in their tissues (Esmaeilbeigi *et al.*, 2021). Muscle is the most edible organ of fish consumed by human societies, therefore it directly affects human health because of potential toxic materials content (Mansour and Sidky, 2002). Studies have shown that fish is the main source of some toxic heavy metals like Hg and consumers receive non-essential chemicals via eating contaminated fish. Tilapia fish has become one of the most popular fish species in Iran due to its favorable quality such as fillet, no razor and good taste. This omnivorous fish is classified as a non-native fish, and in aquatic environments can easily and quickly breed, and in turn, destroy native species and provide the situation for the destruction of domestic fish as an invasive aquatic species. For this reason, environmentalists consider all aspects of breeding and cultivation programs to prevent ecological adverse effects in the environment. According to the results obtained from statistical analysis, the Kruskal-Wallis test showed that the amount of Cr in the Novin

Persian Gulf Fisheries company and the amount of Co, in Sharin, Tohfeh and Zarafshan jonub companies, and Cd content in Sharin Company were higher than other studied companies. In addition, the results of this study showed that heavy metal content of Cr and Cu in tilapia fish supplied by Sharin, Mah Protein, Novin Persian Gulf Fisheries, Tohfeh and Zarafshan Jonub companies showed a significant difference (P<0/05). There was no significant difference in the concentration of other studied heavy metals (P> 0.05). Table 6 shows the maximum and minimum amount of Cu at 4.12 µg/g in the fish daily supplied by Tohfeh company and 1.43 µg/g for the Mah protein company, and for Cr 5.23 µg/g for the Novin Persian Gulf Fisheries and 0.3 µg/g for Mah protein company.

In the study conducted by Edem Christopher *et al*. (2009), the amounts of Pb, Zn, Cd, As and Hg were measured in two groups in terms of the amount of heavy metals in the edible tissues (Table 6). According to this study, the muscle consumption of this fish was allowed and compared with the results of the present study, the measured values of metals except Cd were corresponded. Based on the finding obtained by Mohammed *et al*. (2009), the heavy metals accumulation in tilapia fish from Al-Khadoud spring and Al-Hassa, Saudi Arabia, determined the seasonal amounts of Fe, Zn, Cu, Pb, Mn and Cd and the sum of mean values for metals were above the standard limits, which were in line with the results of the present study on Cd metal (Mohammed *et al*., 2009).

Furthermore, according to Sani (2011), the amount of metals was related to different fish species (Canli and Atli, 2003) and the Co rate in muscle was higher than the human consumption limit according to the FAO standard, which is consistent with the results of this study. A study by Alipour and Banagar (2018) was carried out and according to this study, the highest concentrations of heavy metals, including Fe, ranging from 93.9 to 743 mg / kg, followed by Al 39.15 to 320.00 mg/kg, 45.52 to 86.8, and Cu 17.00 to 20.78 mg/Kg was determined and the concentrations of As, Cd and Pb were not very low. In comparison with the Malaysian Food and Drug Administration, the values of metals were lower than the permitted levels, which was determined by the results of this study except for the metal Cd. Based on the study by Muiruri *et al*. (2013), concentrations of Pb, manganese and chrome in water and Pb, Ni and Mn in fish gill was more than the specified values according to the WHO, this represents a threat to use of this river's fish (Muiruri *et al*., 2013). According to a study by Sahebi and Cohen (2011) by the EPA and the WHO, the permitted amount for *sciaenidae* fish, as a carnivorous fish, is due to the high accumulation of Hg in the muscle tissue, there is a constraint on consumption for large longitudinal groups (Sahebi and Cohen, 2011). With respect to the sum of Hg that is given by the WHO, for adults weighting at 60 kg, the maximum permissible consumption rate of this fish for large longitudinal groups in the summer and winter is 52 and 73 g/week, and based on EPA, the acceptable limit for people with the similar situations in the previous group are between 31 and 44 g/week in the summer and winter weekly. Compared to the results of the present study, the amount of tilapia muscle consumption per week was determined at a rate of 93.75 g which is lower than the universal values for fish consumption.

Human health risk assessments have become one of the most important numerical and statistical tools to evaluate the potential hazardous effects of toxicant to target human groups. EDI and EWI evaluate the amount of toxic materials receive during a day and week in a common human diet program. These indices can be used in calculating CR_{mm} and CR_{lim} indices as well as THQ. Results showed that Hg showed the greatest EDI and EWI at 3.97 (mg/kg.day) and 27.84 (mg/kg.week), respectively. In addition, Cr did show highest values for EDI and EWI at 1.17 and 8.19, correspondingly. Ni and Pb reveled the greatest EDI (7.13 and 49.94) and EWI at (13.45 and 94.18), in that order. Hg is classified as one of the ubiquitous and dangerous heavy metals in the aquatic systems, leading to the bioaccumulation in the edible tissue of fish (Astani *et al*., 2016). Tilapia is a carnivorous fish species and eat meat-based materials which contain more heavy metals in their body due to high amount of fat in the texture. Cr, in addition, grouped as one of the most carcinogenic and hazardous materials to the human health, and causes different types of cancers in the human body such as brain, intestine, skin, liver and kidney (Kazemi *et al*., 2022).

The results showed it is possible that tilapia fish received more heavy metals through feeding on other aquatic animals such as fish larvae, amphibians, mollusks, and macro-invertebrates. Moreover, Hg showed the largest CR_{lim} and CR_{mm} values at 7.11 and 965.23 mg/kg.bw, respectively. Studied fish muscle did reveal the greatest As CR_{lim} and CR_{mm} at 0.004631 and 0.62 mg/kg.bw, respectively. In terms of Cr, sampled muscles had the highest CR_{lim} and CR_{mm} at 3.89 and 521.66 mg/kg.bw, respectively. For Ni, CR_{lim} and CR_{mm} did demonstrate higher values at 4.13 and 553.65 mg/kg.bw, while Pb showed 1.37 and 183.85 mg kg^{-1} bw^{-1} for CR_{lim} and CR_{mm}, respectively. These indices are very important in showing the acceptable and allowable amount of contaminated fish that seafood consumers can receive daily or weekly. In the present study, As showed the lowest amount of CR_{lim} and CR_{mm} meaning that this heavy metal is more toxic to fish consumers that the other respective heavy metals. Our findings showed that Hg had THQ more than 1 for adults, which means that there is a non-carcinogenic health risk for this group, but children had THQ below 1, meaning that there is no non-carcinogenic risk for this group. THQ demonstrated values above 1 for As in both adults and children, assuming that this heavy metal could induce non-carcinogenic effects in target human groups. Cr, Ni and Pb revealed THQ values smaller than 1 in both adults and children, meaning that these heavy metals have no non-carcinogenic risks to humans. Target hazard quotient is mainly used for the non-carcinogenic effects of toxic materials causing many problems in the human body (Kazemi *et al*., 2022).

In the present study, Hg and As THQ values were more than the acceptable limits (THQ > 1), this means that such metals are more toxic to humans than the other studied metals. CR index for As in children group showed values more than 1.00×10^{-4}, meaning that this heavy metal has a carcinogenic risk for children. Children are classified as the most vulnerable groups in facing toxic substances in fish muscles and foods (Parang and Esmaeilbeigi, 2022; Mohammad *et al*., 2009). As demonstrated CR values in the range of $1.00\times10^{-6} < CR < 1.00\times10^{-4}$ for adults, meaning acceptable carcinogenic risks for these groups in consuming fish muscle. However, Hg, Cr, and Pb showed CR values smaller than 1.00×10^{-6} in all human groups with the negligible carcinogenic risks for these consumers. TTHQ for adults and children showed values ranged between 5.35-42.14, meaning that studied heavy metals had significant non-carcinogenic risks (TTHQ>1) for studied human groups. In addition, CCR values were between 4.02×10^{-5} and 58.00×10^{-5} ($1.00\times10^{-6} < CR < 1.00\times10^{-4}$) which states that the studied heavy metals have acceptable carcinogenic risks for children and adults in this study. TTHQ and CCR demonstrate the combined non-carcinogenic and carcinogenic effects of studied heavy metals in a particular food consumed by human subjects (Okati and Esmaili-sari, 2018; Asadi *et al*., 2022). In this research, investigating the heavy metals did show combined non-carcinogenic effects, while these metals revealed acceptable carcinogenic capacity to human subjects.

Conclusions

This study investigated the residual content of heavy metals and associated health risk of tilapia fish (*Oreochromis niloticus*) supplied in different fish markets in Tehran. The concentration of heavy metals, including Cu, Cr, Hg, Pb, As, Cd, Zn and Co were measured using fish muscle samples. Health risk assessment analysis was then performed for the target human groups, including children and adults. Results showed that the concentration of Cr and Cd in all studied fish markets in Tehran was higher than the respective values for Cu, Hg, Pb, As, Cd and Zn in the muscle of tilapia. Permissible values in the studied fish suppliers in Tehran showed that the health status of tilapia fish is in a dangerous condition for children as the most vulnerable human groups to toxic materials such as Hg, Cr, As, Cd and Co. In the present study, the concentration of Cr and Cd was higher than the standard levels recommended by the WHO, FAO and ROPME. Hg and as showed more THQ than the other metals, and as was the most dangerous carcinogenic metals to children. TTHQ and CCR demonstrated that studied heavy metals in tilapia have more non-carcinogenic effects than carcinogenic problems to humans.

In addition, heavy metals content of tilapia fish in Tehran's fish markets is in a cautious status in terms of highly-toxic heavy metals such as Cr and Cd and more efforts should be made to warn and inform fish consumers for the potential adverse effects of these heavy metals for the human health. It is suggested that susceptible groups of consumers such as elderly people, children and pregnant women should be informed for the potential hazardous effects of heavy metals in fisheries products. The health organization also could play a key role in monitoring the quality of fish and warn susceptible groups for the potential issues if it is necessary.

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