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RESEARCH ARTICLE

Human health risk assessment of heavy metals via consumption of commercial marine fish (*Thunnus albacares*, *Euthynnus affinis*, and *Katsuwonus pelamis*) in Oman Sea

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Abstract

This study was performed to determine the concentrations of copper (Cu), zinc (Zn), and lead (Pb) in the gill, liver, muscle, and tail fin tissues of *Euthynnus affinis*, *Katsuwonus pelamis*, and *Thunnus albacares* from Oman Sea. All samples were analyzed using a flame atomic absorption spectrophotometer and the results were expressed as $\mu g\ g^{-1}$ dry weight. Metal concentrations were significantly higher in the liver than other tissues in three species (with some exceptions) ($p < 0.05$). The concentrations of metal accumulation in tissues of tuna species followed the Zn > Cu > Pb. Correlation matrix and principal component analysis (PCA) revealed that Zn and Pb have anthropogenic sources. Estimated daily intake (EDI) in three tuna species for heavy metals were below the tolerable daily intake (TDI). Also, the mean target hazard quotient (THQ) based on studied metals in three tuna species was below 1, which suggests that consumption of these fish can be safe for human health in the Oman Sea.

Keywords Bioaccumulation · Heavy metals · Human health · Oman Sea · Tuna fish

Introduction

Fish contain high protein, Omega-3 and Omega-6 fatty acids, vitamins, and other essential minerals; therefore, fish consumption is necessary for human health (Kris-Etherton et al. 2002; Mziray and Kimirei 2016) and should be consumed in a weekly diet. Fish consumption, at least two meals per week, could prevent cardiovascular diseases (Miniadis-Meimaroglou et al. 2007; Mori 2017). It is well known that heavy metals are deliberately or accidentally discharged into aquatic environments. In the aquatic environment, the main sources of heavy metal contaminants are anthropogenic activities, such as industries and agriculture (Fallah et al. 2011). Human use of heavy metals in industries and other activities has caused marine environmental pollution and adverse effects on the health of marine organisms (Castro-Gonzalez and Mendez-Armenta 2008). Marine organisms, especially fish, are a good indicator of metal pollution monitoring in the aquatic environment (Rashed 2001; Kojadinovic et al. 2007). Since the fish are situated at the top of the food chain, contaminants could accumulate in fish tissues and transferred to humans (Yilmaz et al. 2010). Different organs in fish are used for pollution biomonitoring. The gill has a large surface area with water in fish, therefore it absorbed right amount of metal ions (Dhaneesh et al. 2012). The amount of concentrations of heavy metals in gills indicates the heavy metal concentrations in the waters (Romeo et al. 1999). The liver is an essential organ in heavy metal accumulation due to its role in fish metabolism (Squadrone et al. 2013). Muscle is significant in the human diet and used as an excellent tool for the health risk assessment in heavy metal pollution (Yi et al. 2017; Sadeghi et al. 2019). Tail fin can be used to heavy metal biomonitoring without killing fish (Mziray and Kimirei 2016) that needs more studies. Fish is one of the most critical marine products in the south Iran. Tuna fish is one of the leading fish used in Iranian canning plants. Tuna fish is widespread use in human food; therefore, determination amount of pollutant accumulation in tuna tissues is necessary and is also essential to assess the potential of exposures to humans (Kojadinovic et al. 2007; Hart et al. 2008; Percin et al. 2011). There are several major fishing centers for tuna fish in the Iranian coasts of the Oman Sea (Hamzeh et al. 2013).

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Previous studies on contamination in harbors have shown high levels of heavy metal concentration in the sediments of this area (Hamzeh et al. 2013; Pakzad et al. 2014; Sadeghi et al. 2015). Therefore, the heavy metal contamination in harbors can affect on the fish quality. According to reports by IOTC (2017), the tuna and tuna-like fishes catch is 234,000 Mt in the Indian Ocean areas. Since the Oman Sea leads to the Indian Ocean, the amount of tuna catches in this sea is very high.

Euthynnus affinis (kawakawa or mackerel tuna), *Katsuwonus pelamis* (skipjack tuna), and *Thunnus albacares* (yellowfin tuna) are three species of Scombridae family. These species are distributed in the Indo-West Pacific region, Indian and Atlantic Oceans, and also tropical and subtropical waters (Collette 2001; Hart et al. 2008; Langley et al. 2009). Since these species are located at the top of the marine food chain and most commonly used in canned tuna, the accumulation of heavy metals throughout the food web would tend to a severe risk for human health (Kojadinovic et al. 2007). The USEPA (2000) has proposed target hazard quotient (THQ) and total THQ (TTHQ) to evaluate the non-carcinogenic human health risk for heavy metal with fish consumption (Varol et al. 2017). To the best of our knowledge, very few studies have been done to determine the bioaccumulation of heavy metals in species of Scombridae family (tuna fish) in Oman Sea (Al-Busaidi et al. 2011; Ahmed and Bat 2015). Also there is no previous study of metal accumulation and risk assessment for human consumption in the tuna fish on the Iranian regions of Oman Sea. Keeping the above facts in mind, the aim of this study were (1) to determine the concentrations of copper (Cu), zinc (Zn), and lead (Pb) in the gill, liver, muscle, and tail fin tissues of *Euthynnus affinis*, *Katsuwonus pelamis*, and *Thunnus albacares* from Oman Sea, (2) to assess principal component analysis (PCA) for distribution of heavy metals in the different tissues, (iii) to evaluated EDI (estimated daily intake) of heavy metals and compare it with TDI (tolerable daily intake), and (4) to assess potential human health risks by consumption of tuna fish based on THQ (target hazard quotient) and TTHQ (total target hazard quotient).

Material and methods

Sample collection

Three fish species, namely *Euthynnus affinis*, *Katsuwonus pelamis*, and *Thunnus albacares*, which belong to the family Scombridae, were selected for this study ($n = 30$ for each species). These species are selected because they are commercially valued and used in high quantities along Iran and other parts of the world. Fish samples were collected from the Oman Sea (Geographic coordinates: 60° 74′ 56″ E and 25° 26′ 79″ N) in May 2017. The samples were kept in a cool box with ice and immediately transported to the laboratory.

Sample preparation

In the laboratory, samples were washed with distilled water. Total fish length (Cm) and weight (g) were measured before sample dissection. Gills, liver, muscle (from the dorsal region), and tail fin tissues of each three species were collected, stored in clean plastic polyethylene bags and frozen at − 20 °C before chemical analysis (Staniskiene et al. 2006).

Chemical analysis and quality assurance/control

Before the analysis, all the laboratory equipment were cleaned with nitric acid for 48 h and then rinsed with distilled water and dried in the oven at 150 °C. For metal concentration, fish tissues were dried in an oven at 105 °C to constant weight. A total of 1 g of each dried tissues was digested with 10 mL of 4:1 (v/v) HNO_3-$HCLO_4$ at 150 °C on a hot plate. After cooling solutions at room temperature, samples were filtered through a filter paper (Whatman No. 42) and diluted to 25 mL with double distilled water (AOAC 2005). All samples were analyzed three times for heavy metal concentration. Concentrations of copper (Cu), zinc (Zn), and lead (Pb) were analyzed using an atomic absorption spectrophotometer (GBC-932 Australia). All results of heavy metal concentration were expressed as $\mu g\ g^{-1}$ dry weight. Standard solutions of each metal were prepared from stock solutions (high quality and analytical grade chemicals: Merck, Darmstadt, Germany). Certified reference material, DORM-2 from the National Research Council Canada, was prepared for quality assurance and control. The recovery rates for Cu, Zn, and Pb were 101.3, 97.4, and 98.5%, respectively. Limits of detection (LOD) were 0.05 $\mu g\ g^{-1}$ for Cu and Pb and 0.01 $\mu g\ g^{-1}$ for Zn.

Health risk assessment for fish consumption

Estimated daily intake of heavy metals

The estimated daily intake (EDI) of heavy metals (Cu, Zn, and Pb) was determined according to the following equation reported by Bortey-Sam et al. (2015):

$$\mathrm{EDI} = \frac{\mathrm{MC} \times \mathrm{FDC}}{\mathrm{BW}} \tag{1}$$

where MC is the mean concentration of heavy metal in muscle tissue of fish (μg/g); FDC is the average food daily consumption of fish muscle (g/person/day), which is 25.2 g/person/day in Iran (IFO 2015), and BW is the body weight (average 70 kg for adults). EDI was expressed as μg/kg bw/day.

Target hazard quotients

Target hazard quotients (THQ) were used to assess the risk of heavy metal contamination for human health. According to Yi et al. (2017), THQ is less than 1 which indicates that there are no adverse effects during a lifetime for human health. Also, THQ exceeded which suggests adverse health effects for consumers. THQ was calculated according to the following equation (USEPA 2000):

$$\mathrm{THQ} = \frac{\mathrm{EF} \times \mathrm{ED} \times \mathrm{FIR} \times \mathrm{C}}{\mathrm{RFD} \times \mathrm{BW} \times \mathrm{ATn}} \times 10^{-3} \tag{2}$$

where EF is the exposure frequency (days per year); ED is the exposure duration (years); FIR is the food ingestion rate (g/person/day); C is the metal concentration in fish (μg/g); RFD is the oral reference dose (μg g^{-1}/day). BW is the body weight (kg), and ATn is the average exposure time for non-carcinogens effects (days per year × ED). All parameters and values used in THQ estimation are shown in Table 1.

Total THQ (TTHQ) was calculated as the sum of the individual THQ for each metal in each species according to the method of Li et al. (2013):

$$\mathrm{TTHQ} = THQ_{\mathrm{Cu}} + THQ_{\mathrm{Zn}} + THQ_{\mathrm{Pb}} \tag{3}$$

Statistical analysis

Statistical analysis was performed using SPSS (Statistical Package for Social Sciences) software (version 22.0, SPSS Company, Chicago, USA). The data were first checked for normality using the Shapiro-Wilk test. Comparisons significant differences of heavy metal concentrations among three fish species and tissues were determined using one-way ANOVA followed by Duncan's test. Comparisons of heavy metal concentrations on each tissue of fish species were tested using Kruskal–Wallis test. Spearman correlation rank tests were used to test relationships between concentrations of the same heavy metal in different tissues and between the concentrations of different heavy metals in the same tissues. Principal component analysis (PCA) (PAST 1.9 Windows) was used to investigate the distribution of heavy metals in the different tissues. A $p < 0.05$ was defined as statistically significant. Microsoft Office Excel (2013) was used to draw the diagrams.

Results and discussion

Heavy metal concentrations in tuna fish

The results of heavy metal determination accumulated (mean ± standard deviation) in gill, liver, muscle, and tail fin tissues of *Euthynnus affinis*, *Katsuwonus pelamis*, and *Thunnus albacares*, as well as the range of the weight and length of the fish sampled, are shown in Table 2. According to the results, Cu and Zn concentrations were significantly higher in the liver than in other tissues in three species ($p < 0.05$) (Table 2). Between the three measured heavy metal, Zn concentration detected in all tissues of *Euthynnus affinis* was significantly higher than in the other two species ($p < 0.05$). In addition, concentration levels from highest to the lowest for Zn in gill, muscle, and tail fin tissues were detected as follows: *Euthynnus affinis* > *Katsuwonus pelamis* > *Thunnus albacares.* This pattern was *Euthynnus affinis* > *Thunnus albacares* > *Katsuwonus pelamis* for Zn in liver tissue (Table 2). A comparison of heavy metals concentration in fish tissues showed that there was a significant difference between the amount of metal accumulation in liver tissue of all three fish species (with some exceptions)($p < 0.05$). Also, Table 2 showed no significant difference found for Cu concentration in muscle and tail fin tissues of all three tuna species ($p > 0.05$).

In this study, the accumulation of heavy metals in the liver tissue of three fish species was recorded more than other tissues. Most authors reported similar results for high heavy metal concentrations in the liver (e.g., Kojadinovic et al. 2007; Ahmed and Yousuf 2013; El-Moselhy et al. 2014). Therefore, the liver is suitable organ for heavy metals monitoring in fish and aquatic environments. The highest concentrations of Cu were shown in the liver, while the lowest

Table 1 Summary statistic of parameters and values in the target hazard quotients formula

Factor	Definition	Unit	Value	Reference
EF	Exposure frequency	Days per year	365	USEPA 2000
ED	Exposure duration	Years	70	USEPA 2000
FIR	Food ingestion rate	g/person/day	25.2	IFO 2015
C	Metal concentration	μg/g		This study
RFD	Oral reference dose	μg g^{-1}/day	Cu = 4×10^{-2}; Zn = 3×10^{-1}; Pb = 4×10^{-3}	USEPA 2010, 2011
BW	Body weight	kg	70	USEPA 2000
ATn	Average exposure time for non-carcinogens effects	days per year × ED	365 × 70	USEPA 2000

Table 2 Mean concentrations (±SD: standard deviation) of Cu, Zn, and Pb (µg g^{-1} dry weight) in gill, liver, muscle, and tail fin tissues of *Euthynnus affinis*, *Katsuwonus pelamis*, and *Thunnus albacares* from Oman Sea

Species	Weight (g)	Length (cm)	Cu	Zn	Pb
Euthynnus affinis	1800 ± 147.19	41.8 ± 1.54			
Gill			37.93 ± 12.86^{a}	351.43 ± 104.91^{a}	6.16 ± 1.43^{a}
Liver			60.92 ± 5.55^{b}	515.5 ± 34.61^{b}	3.39 ± 0.49^{b}
Muscle			7.12 ± 2.06^{c}	89.18 ± 10.31^{c}	1.28 ± 0.22^{c}
Tail fin			2.91 ± 1.48^{c}	9.81 ± 8.52^{d}	5.27 ± 2.50^{a}
Katsuwonus pelamis	2140 ± 211.87	43.7 ± 1.56			
Gill			23.85 ± 8.16^{a}	125.52 ± 41.24^{a}	4.41 ± 0.61^{a}
Liver			41.02 ± 5.84^{b}	144.01 ± 10.06^{a}	3.19 ± 0.71^{a}
Muscle			4.71 ± 1.32^{c}	30.57 ± 3.70^{b}	1.10 ± 0.24^{b}
Tail fin			2.95 ± 1.32^{c}	7.12 ± 1.67^{c}	7.43 ± 3.0^{c}
Thunnus albacares	4560 ± 353.39	83.5 ± 7.98			
Gill			16.91 ± 5.67^{a}	106.29 ± 35.50^{a}	3.41 ± 0.99^{a}
Liver			31.81 ± 1.83^{b}	239.51 ± 11.93^{b}	2.13 ± 0.37^{b}
Muscle			2.31 ± 1.22^{c}	15.45 ± 6.70^{c}	0.67 ± 0.16^{c}
Tail fin			1.44 ± 0.40^{c}	4.19 ± 0.64^{d}	3.23 ± 0.66^{a}

Different letters in superscript show significant difference among tissues of each tuna fish species ($p < 0.05$).

concentrations were recorded in the tail fin of three tuna species. Among tuna species, *Euthynnus affinis* contained the highest Cu concentration in gill, liver, and muscle tissues (Fig. 2). The level of Cu in the gill of *Euthynnus affinis* (37.93 ± 12.86 µg g^{-1} dry weight) was higher than those observed in this species from Karachi Pakistan by Ahmed and Yousuf (2013) (16.57 + 3.40 µg g^{-1} dry weight). Also, mean concentration of Cu for *Euthynnus affinis* in the literature reported 17.2 µg g^{-1} dry weight (Agusa et al. 2005), 6.63 + 1.65 µg g^{-1} dry weight (Ahmed and Yousuf 2013), 1.64 ± 0.04 µg g^{-1} dry weight (Sivaperumal et al. 2006) for muscle, and 59.07 + 24.59 µg g^{-1} dry weight (Ahmed and Yousuf 2013) for liver tissues. Cu level in the liver of *Katsuwonus pelamis* in the present research was found to be lower than levels reported by Kojadinovic et al. (2007) and Ahmed and Yousuf (2013). For the *Katsuwonus pelamis,* the Cu concentration in gill and muscle were slightly higher than those described in the samples of the previous researches (7.39 + 1.91; 1.02 ± 0.89 µg g^{-1} dry weight) (Ahmed and Yousuf 2013; Kojadinovic et al. 2007) and was slightly lower than those reported in *Katsuwonus pelamis* liver tissue from the Western Indian Ocean (93.6 ± 75.3 µg g^{-1} dry weight) (Kojadinovic et al. 2007). Cu level in liver tissue of *Thunnus albacares* was very lower than those reported by Kojadinovic et al. (2007) (121 ± 74 µg g^{-1} dry weight). Mean value of Cu detected in *Thunnus albacares* was higher than those observed in muscle of this species from Red Sea (0.35 ± 0.07 µg g^{-1} dry weight) (Al-Shwafi 2002), Mozambican channel, and Reunion Island (Indian Ocean) (0.97 ± 0.23 and 1.99 ± 1.47 µg g^{-1} dry weight) (Kojadinovic et al. 2007).

High levels of heavy metal in three tuna species tissues could be due to high concentrations of this metal in the water. Regarding the levels of heavy metals in different tissues of three tuna species, the highest values were recorded for Zn in *Euthynnus affinis*. Mean value of Zn detected in gill tissues of *Euthynnus affinis* was higher than those reported in this species from Karachi Pakistan by Ahmed and Yousuf (2013) (16.34 + 5.13 µg g^{-1} dry weight). The level of Zn in the present study was extremely lower from that reported in the muscle of *Euthynnus affinis* (953 µg g^{-1} dry weight) from coastal areas of Malaysia (Agusa et al. 2005). Mean concentration of Zn for *Katsuwonus pelamis* in the literature reported 208 ± 61 µg g^{-1} dry weight (Kojadinovic et al. 2007) and 68.1 + 21.13 µg g^{-1} dry weight (Ahmed and Yousuf 2013) for liver tissue. Comparing present results to those reported by Ahmed and Yousuf (2013), it can be concluded that Zn contents in the muscle of *Euthynnus affinis* from Karachi Pakistan (16.33 + 2.26 µg g^{-1} dry weight) are extremely lower than our data. Mean Zn concentration in the muscle of *Katsuwonus pelamis* was 30.57 ± 3.71 µg g^{-1} dry weight. Study conducted by Kojadinovic et al. (2007) reported higher concentration of Zn in *Katsuwonus pelamis* (125 ± 94 µg g^{-1} dry weight) as compared with that reported in this study. On the other hand, Zn concentration detected in *Katsuwonus pelamis* was higher than the maximum level of Zn (6.87 + 2.41 µg g^{-1} dry weight) observed in this species from Karachi Pakistan (Ahmed and Yousuf 2013). Mean value of Zn recorded in the liver and muscle tissues of *Thunnus albacares* were lower than those observed from Mozambican channel (Indian Ocean) (439 ± 254 and 64.1 ± 47.3 µg g^{-1} dry weight, respectively) (Kojadinovic et al. 2007). Bhoyroo et al. (2015) reported mean Zn concentrations in the Scombridae family, including *Thunnus albacares* in the EEZ (exclusive economic zone) of Mauritius between 1.34 and 10.03 mg/kg dry weight that was higher than the results in the present study. According to Hamzeh et al. (2013), Zn level is higher than the concentration of other contaminants in the surface sediments of several harbors of Oman Sea. Also, according to unpublished results of the previous work of the authors, the amount of Zn and Pb in the sediments of the Ramin, Beris, and Konarak harbors were higher than other heavy metals. Since tuna fish feed on small fish and other benthic organisms such as crustacean (Collette 2001), high levels of Zn accumulation in tuna tissues can be related to this case.

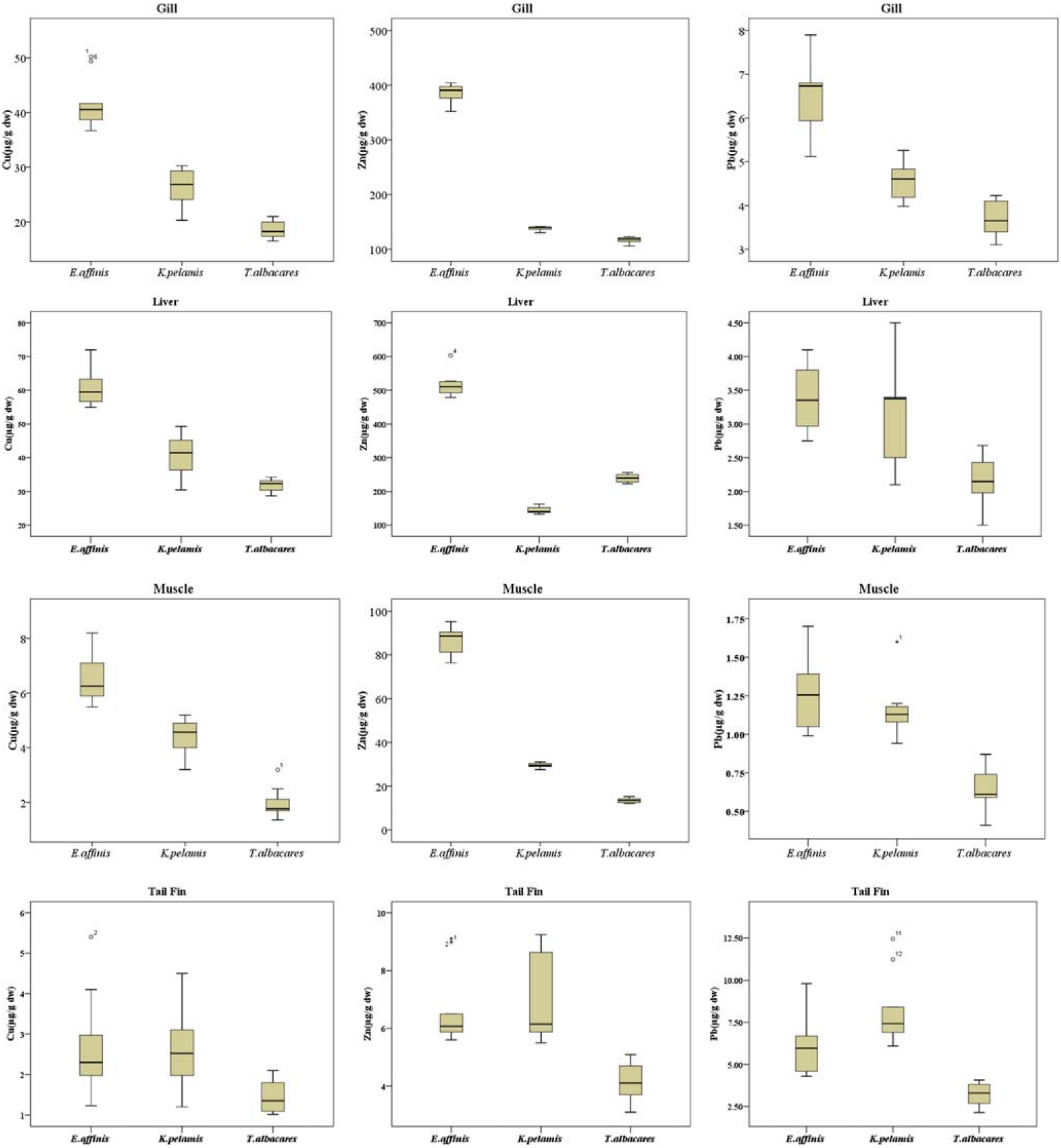

Fig. 1 Box plots (median, first and third percentiles, minimum and maximum values, and outliers) for the concentrations of Cu, Zn, and Pb in tissues of *Euthynnus affinis*, *Katsuwonus pelamis*, and *Thunnus albacares* from Oman Sea

According to Ahmed and Yousuf (2013), Pb concentration in liver and gill tissues of *Euthynnus affinis* and *Katsuwonus pelamis* were lower than Pb in both species in this research. Agusa et al. (2005) reported mean Pb concentrations in the muscle of *Euthynnus affinis* from coastal areas of Malaysia 0.041 μg g^{-1} dry weight that was lower than those observed in the present study for this species (1.27 ± 0.22 μg g^{-1} dry weight). The highest lead concentration in the muscle of *Euthynnus affinis* recorded 0.4958 + 0.13641 μg g^{-1} dry weight in Karachi Fish Harbour, Pakistan (Ahmed and Bat 2015), which was less than the results of the present study. Mean value of Pb recorded in the muscle of *Katsuwonus pelamis* was higher than those observed in this species from Sultanate of Oman (0.0492 ± 0.197 μg g^{-1} dry weight) (Al-Busaidi et al. 2011) and the Mozambican channel (Indian Ocean) (0.07 ± 0.08 μg g^{-1} dry weight) (Kojadinovic et al. 2007). Ahmed and Yousuf (2013) reported maximum lead concentrations in the muscle of *Katsuwonus pelamis* from Karachi Pakistan 0.54 + 0.17 μg g^{-1} dry weight which was lower than results in present study. Among three tuna species, *Thunnus albacares* contained the lowest Pb concentration in muscle tissue with a mean concentration of 0.67 ± 0.16 μg g^{-1} dry weight. Mean concentration of Pb in *Thunnus albacares* from Western Indian Ocean, Mozambique Channel, in muscle tissue (0.09 ± 0.14 μg g^{-1} dry weight) (Kojadinovic et al. 2007) were lower than those found in this study (0.67 ± 0.16 μg g^{-1} dry weight).

Box plots (median, first and third percentiles, minimum and maximum values, and outliers) for the concentrations of Cu, Zn, and Pb in gill, liver, muscle, and tail fin tissues of tuna fish species from Oman Sea are presented in Fig. 1. The mean concentration of Cu, Zn, and Pb was lower in all tissues of *Thunnus albacares* (expect Zn in the liver).

The results indicated a significant number of positive correlations of heavy metals in tissues of three tuna species (Table 3). The highest positive correlation was found between gill and muscle tissues of *Thunnus albacares* for Cu ($r = 0.754$, $p < 0.05$). Also, a few significant negative correlations were observed for *Thunnus albacares* between gill and liver for Cu ($r = -0.745$, $p < 0.05$) and Pb ($r = -0.855$, $p < 0.01$) and between liver and muscle for Cu ($r = -0.900$, $p < 0.01$). However, a significant negative correlation was shown between the liver and muscle of *Katsuwonus pelamis* ($r = -0.853$, $p < 0.01$) for Pb. Comparing with published data, Burger and Gochfeld (2005) and Al-Busaidi et al. (2011) found no significant correlation between the heavy metal in fish tissues; while the significant correlation was found for the metal in tuna fish and dolphins from the Ecuadorian coast (Araujo and Cedeno-Macias 2016). There was no clear correlation between gill, liver, and muscle with tail fin as a non-destructive organ in three tuna species for pollution monitoring. However, a few positive correlations were recorded between gill and tail fin for Zn in *Katsuwonus pelamis* ($r = 0.661$, $p < 0.05$), muscle and tail for Cu and Zn in *Euthynnus affinis* (Cu: $r = 0.697$, Zn: $r = 0.636$ $p < 0.05$). A similar result for the relationship between heavy metal concentrations in tissues with tail fin in three marine fish species have been reported by Mziray and Kimirei (2016) which recommended that tail fin was not a good organ for all species and all metals, in pollution biomonitoring.

The correlation matrix was used for principal components extracted (Fig. 2). Two PC from three extracted PC had Eigenvalues greater than 0.6 that are used for assessment. Eigenvalue of PC1 and PC2 was 1.9 and 0.9, respectively. PC1 with 65.13% variance was highly influenced by Zn. The PC2 accounted for 32.55% variance and had high influenced with Pb. PC loading of Zn and Pb in tuna fish tissues suggested the anthropogenic source of heavy metals.

Table 3 Spearman correlation matrix of heavy metal concentrations between different tissues of *Euthynnus affinis*, *Katsuwonus pelamis*, and *Thunnus albacares*

Spices	Heavy metal	Gill vs. liver	Gill vs. muscle	Gill vs. tail fin	Liver vs. muscle	Liver vs. tail fin	Muscle vs. tail fin
Euthynnus affinis	Cu	0.139	0.358	0.127	− 0.152	− 0.467	0.697*
	Zn	0.152	0.321	0.067	0.321	− 0.212	0.636*
	Pb	0.188	− 0.055	0.164	− 0.224	− 0.224	0.576
Katsuwonus pelamis	Cu	− 0.042	0.309	0.527	− 0.042	0.358	0.030
	Zn	0.273	0.042	0.661*	− 0.406	0.418	− 0.042
	Pb	− 0.276	0.333	− 0.103	− 0.853**	0.104	0.042
Thunnus albacares	Cu	− 0.745*	0.754*	0.152	− 0.900**	− 0.006	0.079
	Zn	− 0.297	0.596	0.564	− 0.565	− 0.224	0.353
	Pb	− 0.855**	0.584	0.624	− 0.310	− 0.503	0.456

*Correlation is significant at the 0.05 level

**Correlation is significant at the 0.01 level

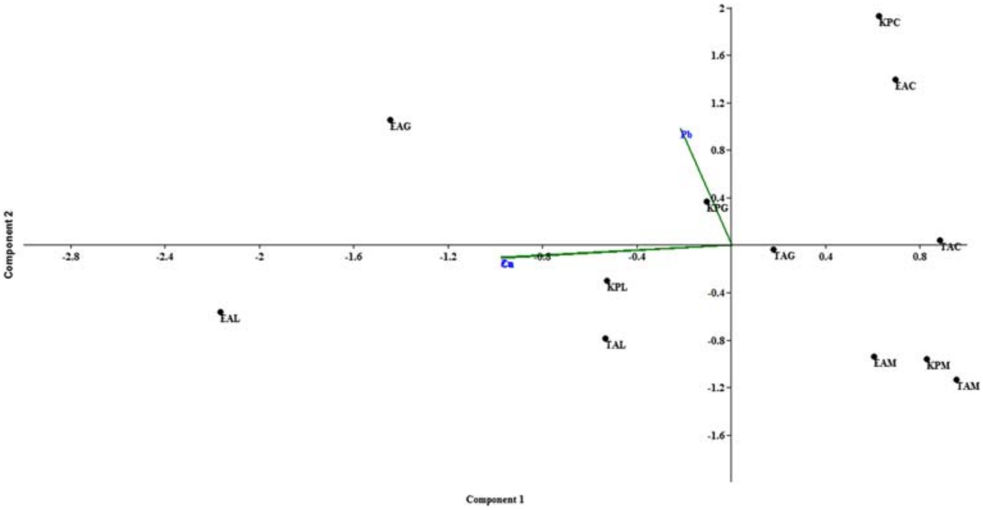

Fig. 2 PCA of heavy metals in tuna fish tissues. EA *Euthynnus affinis*, KS *Katsuwonus pelamis*, TA *Thunnus albacares*. G gill, L liver, M muscle, T tail fin

Health risk assessment

The EDI values compared with TDI values (respective tolerable daily intake) of Cu, Zn, and Pb through the tuna fish consumption were calculated and listed in Table 4. The results showed that the EDI in three tuna species for Cu, Zn, and Pb were below the tolerable daily intake, suggesting that consumption of *Euthynnus affinis*, *Katsuwonus pelamis*, and *Thunnus albacares* has no risks for people in the Oman Sea. Also, the lowest and highest daily intakes were recorded for Pb and Zn, respectively, at three tuna species. The mean THQ values of Cu, Zn, and Pb (based on the mean concentration) for average 70 kg adult humans at *Euthynnus affinis*, *Katsuwonus pelamis*, and *Thunnus albacares* were below 1 (Table 4). Higher THQ of Zn showed in *Euthynnus affinis* (0.11). Also, the higher THQ in *Katsuwonus pelamis* and *Thunnus albacares* recorded for Pb (0.11 and 0.06). Based on USEPA (2011) recommendation, THQ < 1 indicates no risk effect on human health. Therefore, the consumption of three tuna species from Oman Sea may be safe. Total THQ value of all heavy metals followed the descending order of *Katsuwonus pelamis* > *Euthynnus affinis* > *Thunnus albacares*. Similarly, consumption of tuna species from the eastern Pacific Ocean (Ordiano-Flores et al. 2011), the Indian Ocean around Sri Lanka (Jinadasa et al. 2018), and Galicia-Spain (Núñez et al. 2018) were found to be safe for human consumption without no threat to health.

Conclusions

The results of the present study showed new information on the concentration of heavy metals in the gill, liver, muscle, and tail fin tissues of the Scombridae family from the Oman Sea, Iran. Accumulation of heavy metals in the liver tissue of *Euthynnus affinis*, *Katsuwonus pelamis*, and *Thunnus albacares* were recorded more than other tissues. The mean heavy metal concentration in muscle tissue of three tuna species followed the descending order of Zn > Cu > Pb. Zn concentration was significantly higher than in all tissues of *Euthynnus affinis* other both species. According to the results, estimated daily intakes for Cu, Zn, and Pb were lower than tolerable daily intake in all species. The target hazard quotient and total target hazard quotient for all heavy metal in muscle tissues of three tuna species were less than 1. Thus, the consumption of these species from Oman Sea has no threat to human health. The results showed in this research will provide baseline information for future studies on bioaccumulation of heavy metal contamination and human risk assessment in commercial fish species of the Oman Sea.

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Table 4 Estimated daily intake (EDI) (μg/kg bw/day) compared with tolerable daily intake (TDI), target hazard quotient (THQ), and total THQ (TTHQ) of heavy metals in tuna fish species of the Oman Sea

Species	EDI			THQ			TTHQ
	Cu	Zn	Pb	Cu	Zn	Pb	
Euthynnus affinis	2.56	32.1	0.46	0.06	0.11	0.009	0.179
Katsuwonus pelamis	1.69	11	0.40	0.042	0.037	0.11	0.189
Thunnus albacares	0.83	5.56	0.24	0.02	0.018	0.06	0.098
TDI	500	300	1.5				

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