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ORIGINAL ARTICLE

Heavy metals in *Scomberomorus commerson* from Sistan-Baluchestan and Hormozgan Provinces: accumulation and consumer health risk assessment

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Abstract
This study examined the levels of four heavy metals including cadmium (Cd), zinc (Zn), lead (Pb) and mercury (Hg) and their potential health risks for consumers in the commercially important fish species *Scomberomorus commerson*, collected from Sistan-Baluchestan and Hormozgan provinces, Iran. Sixty samples were collected and analyzed for heavy metals concentration in liver and muscle tissues using an ICP-OES atomic absorption spectrophotometer (PerkinElmer, Model:Optima DV 2000). The mercury content was measured using the Atomic Absorption method (novAA 400P, analytikjena) with a hydride production technique. The study also calculated the Estimated Daily Intake (EDI) and Target Hazard Quotient (THQ) of heavy metals. The study revealed variations in metal concentration across different sampling stations and tissues. Samples from Chabahar had higher levels of heavy metals compared to samples from Hormozgan, and the concentration of these metals in the liver was higher than in the muscle, except for Pb, which was slightly higher in the muscle of Hormozgan samples than in the liver. The heavy metals accumulation in the samples followed the pattern of Zn>Pb>Cd>Hg. Among the metals studied, only the Pb concentration in fish muscle from Chabahar exceeded international standards, however the average THQ calculated for all metals was less than 1. The high level of Pb concentration could be due to extensive industrial activities and, to a lesser extent, industrial effluents and human pollution. Therefore, with the industrial sector expanding in this area, especially in shipping, it is recommended to regularly monitor heavy metals.

Keywords: Pollution, Hazard Index, Fish, Aquatic environment, Gulf of Chabahar.

INTRODUCTION

Heavy metal pollution has become a significant challenge in aquatic environments due to its high toxicity, stability, and nonbiodegradable nature within the food chain. These metals transmit a wide range of toxicities, resulting in serious effects on aquatic animal communities (Ardeshir et al. 2017; Hossain et al. 2022; Nyarko et al. 2023). The development of industrial infrastructures, such as the shipping industry, extensive agricultural activities, accidental disposal of chemical waste, erosion of landfills, and wastewater from industrial and domestic sewage, contributes to an increase in heavy metal levels in water. As a result, heavy metals enter the human body through food chains (Rahman et al. 2019). Among heavy metals, the nonessential metals, such as aluminum (Al), cadmium (Cd), mercury (Hg), and lead (Pb), lack proven biological function and are considered the most dangerous group of pollutants. On the other hand, essential metals like zinc (Zn), copper (Cu), molybdenum (Mo), and iron (Fe) play known biological roles, and their toxicity occurs either due to metabolic deficiencies or at high concentrations (Sfakianakis et al. 2015).

Heavy metals readily dissolve in water and are subsequently absorbed by fish and other aquatic organisms. These pollutants can bio-concentrate even at very low concentrations, particularly in the liver. As a result, their concentrations in organisms exceed those in the environment (Korkmaz et al. 2019). Fish assimilate metals through various mechanisms, including ingestion of particulate material suspended in water, consumption of food, ion exchange across lipophilic membranes (such as the gills), and absorption on tissue and membrane surfaces (Zaynab et al. 2022). The bioaccumulation of heavy metals in

Fig.1. Map of the study areas of Sistan-Baluchestan and Hormozgan provinces, Iran.

fish bodies depends on several environmental factors, including the dose, route of exposure, pollutant type, sampling site, pH, temperature, and the ecological and physiological characteristics of the species (such as nutritional status, size, gender, life span, habitat, and position in the aquatic food chain) (Miri et al. 2017). The accumulation of heavy metals in fish tissues can lead to various metabolic, physiological, and histological changes. These changes may result in deformed shapes, vertebral column deformities, growth inhibition, increased mortality rates, and potential harm to fish population reproduction (Ezemonye et al. 2019; Taslima et al. 2022). Fish are rich in Omega-3 and Omega-6 fatty acids, high-quality proteins, vitamins, and essential minerals like phosphorus and sodium (Inengite et al. 2010; Isangedighi & David 2019). As part of a healthy diet, the American Heart Association recommends consuming two servings of fish per week (Neff et al. 2014). However, consumption of aquatic animals contaminated with heavy metals poses a serious risk to human health (Zhong et al. 2018). For instance, elevated levels of zinc can lead to symptoms such as vomiting, diarrhea, nausea, and damage to the kidneys and stomach (Mahmuda et al. 2020; Nyarko et al. 2023). In mammals, mercury accumulation results in a range of adverse effects, including impaired locomotion, reduced vision, teratogenic effects, neurological changes, and ultimately, death (Costa et al. 2020).

Prolonged exposure to cadmium may cause impaired renal and liver function, reduced reproductive capacity, bone fractures, prostatic growth, hypertension, and an increased risk of cancers (Djedjibegovic et al. 2020; Hossain et al. 2022). Additionally, lead exposure can decrease hemoglobin synthesis and elevate the risk of hypertension and kidney damage (Mahmuda et al. 2020). Consequently, monitoring levels of toxic heavy metals in aquatic biota is crucial due to the potential risks posed to humans who consume them (Ezemonye et al. 2019). Fish, being near the end of the aquatic food chain, serve as valuable indicators for monitoring metal pollution in aquatic environments (Sadeghi et al. 2020).

The Gulf of Chabahar and the Sea of Oman hold significant importance as fishing areas in Iran and fish plays a crucial role in the nutrition of both native and non-native populations. Within these waters, a diverse range of aquatic animals thrives, and *S. commerson* stands out as one of the most abundant and essential edible fish. Therefore, the main goals of this study are to (i) quantify the content of toxic metals (Cd, Zn, Hg and Pb) in the muscle and liver tissues of *S. commerson* caught from Sistan-Baluchestan and Hormozgan (industrial zone) and (ii) evaluate the risk of consumption to human health.

MATERIALS AND METHODS

Study area: Konarak (25.37° N, 60.40° E) and Chabahar (25.28° N, 60.63° E) in Sistan and Baluchestan are situated in the southeast of Iran, while Khamir (26.95° N, 55.60° E), Bandar Abbas (27.17° N, 56.27° E), and Minab (27.05° N, 56.85° E) in Hormozgan are located in the southern part of Iran (Fig. 1).

Sampling collection: Between June and September 2021, 60 samples were randomly purchased from fish markets in Sistan-Baluchestan (30 samples) and Hormozgan provinces (30 samples). Fishermen reported catching specimens from the coastal waters of Khamir, Bandar Abbas, and Minab in Hormozgan province, as well as Konarak and Chabahar in Sistan and Baluchestan provinces (Fig. 1). The characteristics of the collected samples were determined after identifying the species. The length and weight of each captured fish were measured to investigate the relationship between these parameters and the level of heavy metals contamination. The fish length ranged from 22 to 29cm, and the wet weight varied from 314 to 348 g. Each sample was subsequently placed in a plastic bag, coded, and stored at -20°C until the start of the test.

Heavy metal analysis and Quality Control: For analysis, the samples were removed from the freezer and after reaching room temperature; a portion of the fish muscle and liver were separated and placed in an oven with a temperature of 100°C to dry. The dried samples were transferred to a porcelain mortar and grind thoroughly, then 0.5 g of liver and 0.5g of muscle were weighed from each sample using an analytical balance. Finally, 7ml of 65% HNO_3 and 1 ml of H_2O_2 were added and the samples were placed in the microwave (Mileston, Model: ETHOS 1000 W) until they were fully digested. After acid digestion, the samples were poured into a balloon and made up to 50 ml with distilled water. The concentrations of Cd, Zn and Pb in liver and muscle tissues were analyzed using inductively coupled plasma-optical emission spectroscopy (ICP-OES: Perkin Elmer, Model; Optima DV 2000). Mercury content was measured using Atomic Absorption method (novAA 400P, analytikjena) with a hydride production technique (Korkmaz et al. 2019; Mashoufi et al. 2023). The measurements were performed in the central laboratory of Sistan and Baluchestan University. Method validation was conducted using sample replicates, reagent blanks, and repeated analyses of the certified reference material (DORM-2) provided by the National Research Council of Canada. The recovery rates for metals ranged from 98.4% and 101.2%, indicating the suitability of the method.

Statistical analyses: The data were statistically analyzed using SPSS software (Version 24.0 for Windows). The mean and standard deviation of metal concentrations in fish were calculated. Potential outliers were eliminated and the normality of data was checked using the Kolmogorov-Smirnov test. Statistical differences between groups were determined using an independent sample t-test if the data were normally distributed, while a Mann-Whitney U test was used if the data were not normally distributed. To compare more than two groups, one-way ANOVA was used if the data were normally distributed, while the Kruskal-Wallis test was used if the data were not normally distributed followed by post-hoc multiple comparisons using the Tukey test (Mo et al. 2019). *P*-values lower than 0.05 were considered indicative of significant differences (at a confidence level of 95%). Additionally, the Mann-Whitney U test was employed to examine the statistical significance of differences in the concentrations of elements between muscle and liver samples from the fish.

Health risk assessment:

Estimated Daily and Weekly metal Intake (EDI and EWI): Dietary metal intake has been used to assess human health concerns (Tahity et al. 2022). To do this, the EDI must be determined, which is based on the metal concentration in foods as well as the daily consumption of certain food items (Keshavarzi et al. 2018). EDI and EWI were calculated using Equation (1) and (2):

$$\text{EDI } (\mu g/day/60\text{ kg body weight}) = \text{C} \times \text{FIR} \quad (1)$$

$$\text{EWI } (\mu g/week/60\text{ kg body weight}) = \text{EDI} \times 7\text{ day} \quad (2)$$

In above equations, *C* is the heavy metal concentration in fish muscles (mg/kg), FIR (Fish ingestion rate); is daily fish consumption (g/day) per capita for Iranian population (7 g/person/day), which is used by the ISIRI (Institute of Standards and Industrial Research of Iran 2010). Then permissible tolerable amount of weekly intake (PTWI) was calculated using Equation (3) as bellow:

$$\text{PTWI } (\mu g/week/60\text{ kg body weight}) = \text{RfD} \times \text{BW} \times 7\text{ (days)} \quad (3)$$

Which *RfD* (Oral reference dose) is the reference dose of the metal (3.0×10^{-4} mg/kg/day for Hg, 1.0×10^{-3} mg/kg/day for Cd, 4.0×10^{-3} mg/kg/day for Pb, 3.0×10^{-1} mg/kg/day for Zn) (USEPA 2011) and BW is the average Iranian adult body weight (60 kg) (Miri et al. 2017; Mo et al. 2019).

Non-Carcinogenic Risk Assessment: The non-carcinogenic risk assessment was estimated using the Target Hazard Quotient (THQ) and hazard index (HI). The THQ is defined as the ratio of exposure to the toxic metal to the reference dose (RfD), which represents the highest level at which no adverse health effects are expected. The reference dose is specific to each metal under assessed (Keshavarzi et al. 2018). The THQ describes non-carcinogenic health hazards posed by exposure to the respective toxic elements. If the THQ<1 means that potential non-carcinogenic health effects are not expected. However, if the THQ≥1 there is a potential risk related to the studied metal in the exposed population (Lei et al., 2015). The equation used for estimating THQ is as follows:

$$THQ = \frac{EF \times ED \times EDI}{BW \times AT \times RfD} \times 10^{-3} \quad (4)$$

Where *THQ* is the target hazard quotient, *EF* is the exposure frequency (365 days/year). *ED* is the exposure duration (70 years for non-cancer risk as used by the USEPA (United States Environmental Protection Agency). EDI; Estimated Daily Intake, BW; average body weight (60 kg), AT is the average exposure time for non-carcinogens (EF×ED) as used in characterizing non-cancer risk, and RfD (Oral reference dose) for each metal (Keshavarzi et al. 2018; Korkmaz et al. 2019).

Hazard Index (HI): To determine the potential risk of adverse health effects from a mixture of toxic metals, the hazard index (HI) was calculated as the sum of the hazard quotients using Eq (5) (Djedjibegovic et al. 2020; Nyarko et al. 2023):

$$HI = THQ(Cd) + THQ(Zn) + THQ(Hg) + THQ\ (Pb) \quad (5)$$

When *HI*<1, it is unlikely that there are obvious adverse effects. An *HI*>1, indicates the possibility of an adverse non-carcinogenic health effect and *HI*>10 has severe chronic effects on health (Djedjibegovic et al. 2020; Alsafran et al. 2021).

RESULTS

Heavy metals in fish samples: The concentrations of Cd, Zn, Hg and Pb in the muscle and liver of *S. commerson* were measured and are presented in Table 1. The concentrations of heavy metals are presented in mg/kg of dry weight of fish. The mean Cd concentration in the liver of S. commerson from Hormozgan and Sistan-Baluchestan was 0.117 and 3.910mg/kg, respectively and 0.008 and 0.266mg/kg in muscle of fish from Hormozgan and Sistan-Baluchestan respectively. Therefore, the highest concentration of Cd was observed in liver of *S. commerson* from Sistan-Baluchestan. Cadmium levels in the *S. commerson* samples followed this

Table 1. Mean±SD of heavy metals in muscle and liver tissue of *S. commerson* collected from Chabahar and Hormozgan (mg/kg).

Station	Tissues		Hg	Cd	Pb	Zn
Chabahar	Muscle	Mean±S.D	0.019±0.000512	0.266±0.05215	2.383±0.8206	34.92±2.544
		Maximum	0.02711	1.2	16.9	56.8
		Minimum	0.01707	0	0	0
	Liver	Mean±S.D	0.0534±0.0015	3.91±1.0535	3.696±0.9120	104.73±6.39
		Maximum	0.06313	32	18.9	152.9
		Minimum	0.03993	0	0	0
Hormozgan	Muscle	Mean±S.D	0.005±0.00270	0.008±0.00	0.011±0.0005	-----
		Maximum	0.081	0.008	0.024	-----
		Minimum	0.0025	0.008	0.011	-----
	Liver	Mean±S.D	0.0328±0.0090	0.117±0.0289	0.011±0.0003	-----
		Maximum	0.162	0.430	0.018	-----
		Minimum	0.0025	0.008	0.011	-----
FAO* (Staniskiene et al. 2006; Tuzen et al. 2009)			0.5	0.5	0.5	40
WHO* * (Pourang et al. 2005; Türkmen et al. 2009)			0.5	1	0.5	50
NHMRC* (Pourang et al. 2005; Türkmen et al. 2009)			1	-----	1.5	150
MAFF* (Tuzen et al. 2009)			1	0.2	2	50

*These international standard concentrations are defined only for muscle tissue.

order: liver Chabahar>muscle Chabahar>liver Hormozgan>muscle Hormozgan. Zinc concentration was only determined in the Chabahar samples. The concentrations of Zn in the liver and muscles of *S. commerson* from Chabahar were 104.733 and 34.923mg/kg respectively. The mean mercury levels in the liver and muscle of *S. commerson* from Hormozgan and Chabahar were measured as 0.032, 0.005, 0.053 and 0.019 mg/kg respectively. The data show that the concentration of Hg in the liver of fish is higher than in the muscle, and the highest concentration of Hg was measured in the liver of fish from Chabahar. Mercury levels in the *S. commerson* samples followed this order: liver Chabahar >liver Hormozgan >muscle Chabahar >muscle Hormozgan. The amount of lead analyzed in the liver and muscle of *S. commerson* from Chabahar was 3.696 and 2.383mg/kg and in the liver and muscles of *S. commerson* from Hormozgan were 0.0116 and 0.119mg/kg respectively. The order of lead concentration in the *S. commerson* samples were in the following: liver Chabahar>muscle Chabahar >muscle Hormozgan >liver Hormozgan.

In general, the results of this study showed that the accumulation of metals in the liver of *S. commerson* was higher than in muscle, except for Pb, which was slightly higher in the muscle of Hormozgan samples than in liver. The amount of heavy metals in Chabahar samples was higher than Hormozgan samples. The content of Zn in the liver of *S. commerson* from Chabahar was the highest (104.733mg/kg) while the content of Hg in the muscle of *S. commerson* from Hormozgan was the lowest (0.0059mg/kg). The accumulation of heavy metals in samples follows the pattern of Zn>Pb>Cd>Hg.

Health risk assessment: Comparing the metal concentrations obtained in this study with those determined by the FAO (Food and Agriculture Organization), WHO (World Health Organization), NHMRC (National Health and Medical Research Council), and MAFF (Ministry of Agriculture, Fisheries and Food) reveals that among the studied metals, only the concentration of Pb in the muscle of *S. commerson* from Chabahar exceeded international standards (Table 1 and Fig. 2). The estimated daily intake (EDI) of heavy metals is reported in Table 2. Compared to the provisional tolerable daily intake, the heavy metals found in fish muscle investigated at two

Table 2. Estimated Daily Intake (EDI) and Estimated Weekly Intake (EWI) from fish consumption by local residents.

Heavy metal	EDI^c	EDI^h	EWI^c	EWI^h	PTWI
Lead	16.682	0.083	116.788	0.586	1.68
Cadmium	1.866	0.056	13.066	0.392	0.42
Mercury	0.138	0.041	0.972	0.289	0.126
Zinc	244.461	-----	1711.227	-----	126

^{c} Chabahar species
^{h} Hormozgan species
PTWI: Provisional Tolerable Weekly Intake

Table 3. Target hazard quotient (THQ) and Hazard Index (HI) for different heavy metals.

Station	Tissue	Cadmium	Mercury	Lead	Zinc	Hazard Index (HI)
Chabahar	Muscle	0.0311	0.0077	0.069	0.0135	0.38
	Liver	0.456	0.0207	0.1078	0.0407	
Hormozgan	Muscle	0.0009	0.0017	0.0034	-----	0.01
	Liver	0.0014	0.0095	0.0033	-----	

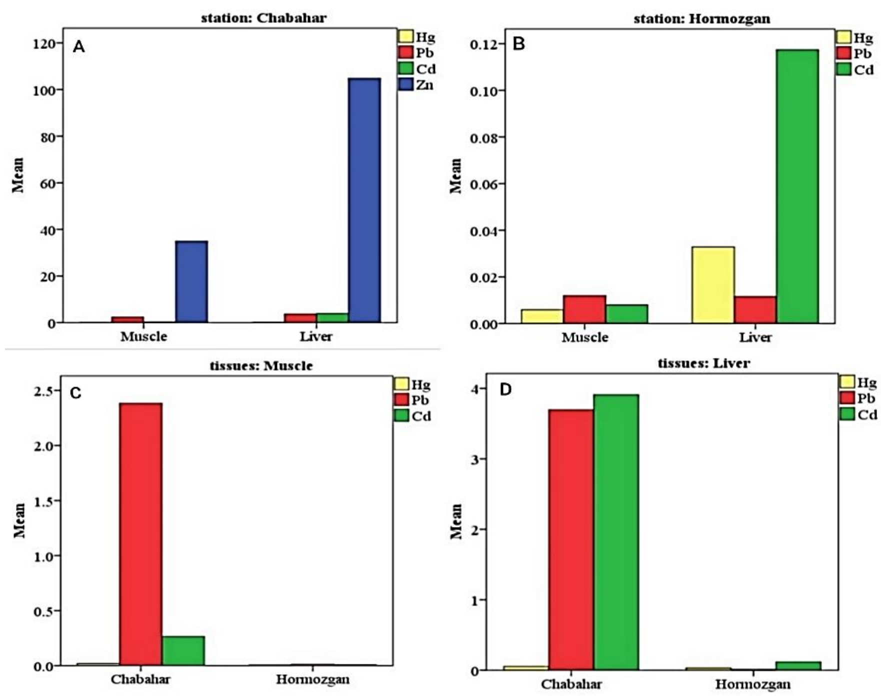

Fig.2. Heavy metals content in the muscle and liver tissue of *S. commerson* from Chabahar and Hormozgan. **A;** Comparison of the heavy metals (Hg, Pb, Cd, Zn) content in the muscle and liver tissue of *S. commerson* from Chabahar. **B;** Comparison of the heavy metals (Hg, Pb, Cd) content in the muscle and liver tissue of *S. commerson* from Hormozgan. **C;** Comparison of the heavy metals (Hg, Pb, Cd) content in the muscle of *S. commerson* from Chabahar and Hormozgan. **D;** Comparison of the heavy metals (Hg, Pb, Cd) content in the liver of *S. commerson* from Chabahar and Hormozgan.

stations do not pose health problems for fish consumers. The Target Hazard Quotient (THQ) for each heavy metal and the Hazard Index (HI) for heavy metals in fish caught in Chabahar and Hormozgan are separately presented in Table 3. The THQ and HI values obtained for heavy metals are below one, indicating that a non-carcinogenic health risk from consuming heavy metals in this fish is not expected for consumers. However, it's worth noting that the average concentration of Pb in the muscle of *S. commerson* caught from Chabahar exceeds the permissible limit, which may raise concerns about consumer health.

Investigation of correlation of heavy metals concentration with the length and weight of *S. commerson*: *To evaluate the correlation of the data,* the normality of the data was first checked using the Kolmogorov-Smirnov test. If the data were normal,

Table 4. Correlation of heavy metals concentration with *S. commerson* weight of Chabahar station.

Heavy metal	Muscle		Liver	
	Correlation Coefficient	*P* value	Correlation Coefficient	*P* value
Zn	-0.023	0.904	0.061	0.748
Pb	0.022	0.910	0.363	0.049
Hg	0.089	0.640	-0.108	0.577
Cd	-0.170	0.368	0.345	0.062

Table 5. Correlation of heavy metals concentration with *S. commerson* weight of Hormozgan station.

Heavy metal	Muscle		Liver	
	Correlation Coefficient	*P* value	Correlation Coefficient	*P* value
Pb	0.029	0.879	0.424	0.019
Hg	0.005	0.978	0.541	0.002
Cd	---	---	0.629	0.000

Table 6. Correlation of heavy metals concentration with *S. commerson* length of Chabahar station.

Heavy metal	Muscle		Liver	
	Correlation Coefficient	P value	Correlation Coefficient	*P* value
Zn	0.078	0.681	0.093	0.626
Pb	-0.209	0.209	0.273	0.145
Hg	0.061	0.749	-0.032	0.867
Cd	-0.088	0.645	0.392	0.032

Table 7. Correlation of heavy metals concentration with *S. commerson* length of Hormozgan station

Heavy metal	Muscle		Liver	
	Correlation Coefficient	*P* value	Correlation Coefficient	*P* value
Pb	0.068	0.720	0.454	0.012
Hg	0.071	0.709	0.560	0.001
Cd	---	---	0.601	0.000

Pearson test was used and if the data were not normal, Spearman test was used. The examination of the Kolmogorov-Smirnov test showed that the length of *S. commerson* caught from Chabahar and the zinc measured in the liver have a normal distribution, while the rest of the sample data from Chabahar and Hormozgan stations did not exhibit a normal distribution.

Correlation of heavy metal concentration with *S. commerson* weight: The results indicate a positive and significant correlation between Pb levels in the liver and the weight of *S. commerson* in Chabahar (P=0.049). However, no significant correlation was observed for other metals concerning fish weight (Table 4). Additionally, there exists a positive and significant correlation between Pb, Hg and Cd concentrations in the liver and the weight of *S. commerson* caught from the Hormozgan station (P<0.05). However, no significant correlation was found between these metals in the muscle concerning fish weight (Table 5).

Correlation of heavy metal *concentration* with *S. commerson* length: The results of the correlation between the studied heavy metals and fish length indicate a positive and significant association between cadmium levels in the liver and the length of *S. commerson* from Chabahar (P=0.032). However, no significant correlation was found for other metals concerning fish length (Table 6). Additionally, there exists a positive and significant correlation between Pb, Hg, and Cd concentrations in the liver and the length of *S. commerson* caught from the Hormozgan station (P<0.05). However, no significant correlation was observed for these metals in the muscle concerning fish length (Table 7)

DISCUSSION

Cadmium (Cd)

Cadmium, which is usually presented as an inorganic compound in the 2^+ oxidation state, can cross various biological membranes and has a long half-life (10-15 years), which leads to its gradual accumulation in the human body (Naghipour et al. 2016). The accumulation of cadmium in living organisms is a major ecological concern, primarily due to its rapid ability to accumulate. In contrast, the excretion of cadmium from living organisms is a slow process. In fish, cadmium can cause structural and morphological changes in various organs, with the highest cadmium levels detected in the kidneys and liver (Patil 2020). Even at low levels of exposure, cadmium can cause DNA damage and stress (Mahmuda et al. 2020). Higher concentrations of cadmium are carcinogenic and lead to neurological disorders and bone weakness (Han et al. 2021). In this study, the mean concentration of Cd in the muscle of Hormozgan and Chabahar fish was 0.008mg/kg and 0.266mg/kg respectively. The maximum Cd concentration in fish samples, as allowed by FAO, WHO and MAFF, is 0.5, 1 and 0.2mg/kg, respectively (Pourang et al. 2005; Staniskiene et al. 2006; Türkmen et al. 2009; Tuzen et al. 2009). Therefore, the amount of Cd in the muscle of Chabahar fish is lower than the permissible limit recommended by the FAO and WHO and slightly higher than the permissible limit recommended by the MAFF. However, the amount of Cd in the muscle of Hormozgan fish is lower than the permissible limit recommended by the FAO, WHO and MAFF standards.

Previously the average concentration of Cd in the muscle of *S. commerson* and *Auxis thazard thazard* in Cambodia was reported as 0.003 and 0.004mg/kg respectively (Agusa et al. 2007). In *Rastrelliger kanagurta* from Mumbai the reported concentration was 0.007mg/kg (Deshpande et al. 2009), which falls within the concentration range observed in Hormozgan fish in the present study. Additionally, studies in Iran found that *S. commerson* had Cd levels of 0.16mg/kg (Sadeghi et al. 2015) and 0.315mg/kg (Khoshnood et al. 2012), which closely align with the results obtained from Chabahar in the present study. However, Cd levels in *S. commerson* from the coast of the Persian Gulf were reported as 0.0005mg/kg, lower than the results of the present study (Pilehvarian et al. 2015). In contrast, Cd levels in *S. commerson* from the Gulf of Aden (Al-Shawafi, 2002) and the Persian Gulf (Bushehr) (Hosseini et al. 2018) were reported to be 1.07mg/kg and 1.55mg/kg, respectively, significantly higher than the results of the present study. This variation in heavy metal concentrations among different fish species depends on factors such as fish size, age, feeding behavior, habitat, and chemical species (Tchounwou et al. 2012) The study results indicate that the highest concentration of Cd, measuring 3.910mg/kg, is found in the liver of *S. commerson* caught from Chabahar. Previously, Ahmed et al. (2015) demonstrated that the Cd content in the liver and muscle of *S. commerson* varied between 0.54 to 2.03mg/kg and 0.19 to 0.68mg/kg, respectively, across different years. According to the findings of this study, the Cd concentration in the muscle and liver of Chabahar fish is approximately 33 times higher than that in Hormozgan fish. The likely reason for the elevated cadmium levels in fish caught from Chabahar, compared to those from Hormozgan, is that Cd can be released into wastewater from industrial and mining activities, with extensive industrial shipping contributing to the contamination in Chabahar.

Zinc (Zn)

Zinc is an important mineral element in human nutrition and is critical for growth, the function of numerous enzymes (as a cofactor), and many cellular processes. Zinc may also play an important role in cancer etiology and outcomes (Grattan & Freake 2012). Zn deficiency in the human organism leads to several disorders, but excessive Zn intake can cause acute adverse effects on the kidneys and stomach (Medeiros et al. 2012). Furthermore, zinc pollution has adversely affected the hatching success and survival of several fish species and also prevents the normal formation and pigmentation of various organs (Taslima et al. 2022).

In this study, the mean concentration of Zn in the muscle of Chabahar fish was 34.923mg/kg which is below the permissible limit recommended by FAO, WHO, NHMRC, and MAFF standards. Additionally, the concentration of zinc in the liver of *S. commerson* in Chabahar was 104.733mg/kg, which is approximately three times its concentration in muscle tissue. It was previously reported in two separate studies conducted in the Persian Gulf that the concentration of zinc in *S. commerson* was 7.8mg/kg (Sadeghi et al. 2015) and 4.25mg/kg (Hosseini et al. 2018), respectively, which is significantly lower than the results of the present study. Also, Ahmed et al. (2015) reported that the amount of Zn in the muscle of *S. commerson* ranges from 3.17 to 9.43mg/kg and in the liver from 16.46 to 53.25mg/kg, which is significantly lower than the results of the present study; however, the concentration of zinc in the liver is approximately five times higher than in muscle (Ahmed et al. 2015).

The reason for the higher Zn concentration in this study, compared to some previous studies, may be due to the high pollution of the Gulf of Chabahar resulting from human and industrial activities. However, the mean concentration of Zn in the muscle tissues of white fish and common carp has been reported as 29.97mg/kg and 30.20mg/kg, respectively, which is consistent with the results of the present study (Elsagh 2012). In another study, the mean concentration of Zn in the muscle of *Sarda sarda* and *Scomber scombrus* was 64.9mg/kg and 88.2mg/kg, respectively, which is higher than the results of this study (Tuzen 2009). Recently, in a study on *Capoeta fusca* from the Lar wetland in Iran, the average concentration of Zn in muscle tissue was determined to be 70.183mg/kg (Mashoufi et al. 2023), which is also significantly higher than the result obtained from the present study. In general, the concentration of zinc in the liver and muscle of *S. commerson* was higher than that of other evaluated metals because zinc is an essential metal involved in many metabolic processes. This issue has already been confirmed by some other studies (Askari Sary & Velayatzadeh 2014; Pastorino et al. 2020).

Mercury (Hg)

Mercury contamination in aquatic organisms is largely due to environmental pollution, food webs, and biological factors that may increase the concentration of the contaminant several thousandfold from water to fish, especially in top predators (Pouilly et al. 2012). High concentrations of mercury and lead cause defects in important fish organs such as abnormal and irregular fins, tails, heads, and several problems in the spine (Taslima et al. 2022). However, mercury contamination of human populations that consume fish, specifically the consumption of muscle tissues, is well known and causes a variety of neurological and movement problems in mammals (Costa et al. 2020). There have also been reports of decreased parasympathetic modulation of autonomic cardiac function in children exposed to mercury in utero (Abd Elnabi et al. 2023).

In this study, the mean Hg concentrations in the muscle of Chabahar and Hormozgan fish were 0.0198 and 0.0059mg/kg, respectively, which are lower than the permissible limits recommended by FAO, WHO, NHMRC, and MAFF standards. In a study conducted on the Portuguese coast, the Hg content in the muscle of *Scomber scombrus*, *Scomber colias*, *Engraulis encrasicolus*, *Trachurus trachurus*, and *Sardina pilchardus* was reported to range from 0.003 to 0.20mg/kg, which was far below the FAO and WHO thresholds (Costa et al. 2020). The results of the mentioned study agree with the results of the present study. Based on the results of this study, the average Hg concentrations in the liver of Chabahar and Hormozgan fish were 0.053 and 0.0328mg/kg, respectively. Previously, the Hg content in *S. commerson* at the coast of the Persian Gulf (Pilehvarian et al. 2015) and in Cambodia (Agusa et al. 2007) was reported as 0.022 and 0.07mg/kg, respectively, which is consistent with the results of this study. However, in another study, the Hg concentrations in *Rastrelliger kanagurta* and *Scomberomorus guttatus* were reported to range from 1.0 to 1.1 and 2.0 to 2.2mg/kg, respectively, which are higher than the results of this study (Alina et al. 2012). In general, the average concentration of mercury in the liver was higher than that in muscle, which is consistent with the role of the liver as an accumulating and metabolizing organ (Ahmed et al. 2015; Hosseini et al. 2018). In this study, a significant correlation was observed between the length and weight of *S. commerson* and the Hg level in the liver, which is consistent with the results of some other studies (Malvandi et al. 2015; Costa et al. 2020). This finding suggests that mercury accumulation is a continuous process occurring at various stages of the fish's life cycle (Costa et al. 2020). However, in another study, no significant relationship was reported between the length and weight of black fish and mercury concentration (Mashoufi et al. 2023).

Lead (Pb)

Recent years have seen a surge in concern over lead contamination in numerous public water systems. Research has revealed that Pb is prone to build up in several body organs, including blood and bones, and it modifies a wide array of genes linked to the growth of the nervous system (Green & Planchart 2018). Exposure to Pb is associated with a range of neurological conditions, including Alzheimer's disease, Parkinson's disease, and so on. Lead is also recognized as a contributing factor to cardiovascular issues in those suffering from diabetes (Abd Elnabi et al. 2023). Moreover, a variety of studies have indicated that lead exposure negatively influences the physical growth of children, particularly males, due to its interference with the equilibrium of sex hormones, affecting the reproductive system's normal operations (Zhou et al. 2020).

The results indicated that the average Pb concentration in the muscle of *S. commerson* from Chabahar and Hormozgan was 2.383mg/kg and 0.0119mg/kg, respectively, and in the liver, it was 3.698mg/kg and 0.0116mg/kg, respectively. The maximum permissible concentrations of Pb in fish samples set by FAO, WHO, NHMRC, and MAFF are 0.5, 0.5, 1.5, and 2mg/kg, respectively. Consequently, the Pb levels in the muscle of *S. commerson* from Chabahar exceed all these international standards. However, the THQ of Pb was less than one, indicating no significant non-carcinogenic health risk to fish consumers. Previously, the mean concentration of Pb in the muscle of *O. ruber* and *L. fulviflammus* from Bushehr were reported to be 2.23mg/kg and 2.15mg/kg, respectively, aligning with the findings regarding Pb concentration in Chabahar fish muscle. Additionally, the average concentration of Pb in the muscle and liver of *S. commerson* and *P. niger* from Asalouieh was reported as 72.22mg/kg, 16.25mg/kg, 6.47mg/kg, and 13.55mg/kg, respectively, significantly surpassing the results of this study. In all these instances, the lead concentrations were above the international standards (Hosseini et al. 2018). In research on *Capoeta fusca*, the mean concentration of Pb in muscle tissue was found to be 28.143mg/kg, markedly higher than the findings of this study (Mashoufi et al. 2023).

Moreover, the highest Pb concentrations in *S. cucullata* from the Gulf of Chabahar during winter and summer were reported to be 17.48mg/kg and 14.95mg/kg, respectively, exceeding both the international standards and the results of the current study (Bazzi 2014). In the studies mentioned, the THQ is above 1, indicating significant advancements in human and industrial activities, particularly in shipping and related sectors within the studied areas. However, the average concentration of Pb in the muscle and liver of *Euthynnus affinis* were reported as 1.28mg/kg and 3.39mg/kg, respectively. Although these values exceed international standards, the THQ was calculated to be less than 1, aligning with the findings of this study (Sadeghi et al. 2020). Conversely, other studies reported lead concentrations lower than those found in this study, which fell beneath the permissible limits set by international standards (Khoshnood et al. 2012; Askari Sary & Velayatzadeh 2014; Pilehvarian et al. 2015). In the current study, the concentration of lead in the liver of *S. commerson* from Chabahar was higher than in the muscle, whereas in fish from Hormozgan, no such difference was observed, and the Pb content in the muscle was marginally higher than in the liver. Most previous research indicates that the concentration of Pb in fish liver is typically higher than in muscle (Ahmed et al. 2015; Sadeghi et al. 2020). The findings of this study also reveal a positive and significant correlation between Pb concentration and fish weight, a pattern noted in some prior studies. However, this trend is generally not present in the case of essential heavy metals such as zinc (Hosseini et al. 2018).

It is important to acknowledge the limitations of this study. First, sampling was not conducted across different seasons to compare pollution levels throughout the year. Additionally, the concentration of heavy metals in other fish tissues, like gills and skin, was not assessed. Moreover, since only one type of fish sample was examined, the study did not adequately explore the impact of genetic variation among different species on the heavy metal absorption.

CONCLUSIONS

This study provides insights into the heavy metals levels found in edible fish samples from the Gulf of Chabahar and Hormozgan. Zinc is necessary for human health, whereas cadmium, lead, and mercury are harmful. The recorded concentrations of heavy metals in fish were benchmarked against the safe consumption thresholds set by the FAO, WHO, NHMRC, and MAFF. The findings reveal that, although the THQ values for each metal and the HI for all metals were below 1, the Pb concentration in certain *S. commerson* samples exceeded the acceptable limits. Consequently, consuming fish tainted with lead poses a health risk. The elevated lead levels in fish from the Gulf of Chabahar may result from the growth of the shipping industry, ship deterioration and leakage, and, to a lesser extent, industrial effluents and human pollution. Over time, the heavy metals accumulation poses a health risk to fish, necessitating regular and frequent monitoring to safeguard fish health and avert potential hazards to consumers. The use of microbial bioremediation, a new and cost-effective approach, is recommended to address the problem of heavy metal pollution at the Chabahar site.

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مقاله کامل

فلزات سنگین در ماهی *Scomberomorus commerson* از استان‌های سیستان و بلوچستان و هرمزگان: تجمع و ارزیابی ریسک سلامت مصرف کننده

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چکیده: این مطالعه به بررسی غلظت چهار فلز سنگین (کادمیم، روی، سرب و جیوه) و خطرات بالقوه آنها برای سلامتی مصرف‌کنندگان در گونه ماهی مهم تجاری *Scomberomorus commerson* جمع‌آوری شده از استان های سیستان و بلوچستان و هرمزگان، ایران، پرداخته است. ۶۰ نمونه جمع‌آوری شد و غلظت فلزات سنگین در بافت‌های کبد و عضله با استفاده از دستگاه جذب اتمی (ICP-OES (Perkin Elmer, Model; Optima DV 2000 آنالیز شد. مقدار جیوه با استفاده از روش جذب اتمی (novAA 400P, analytikjena) با تکنیک تولید هیدرید اندازه‌گیری شد. همچنین میزان مصرف روزانه تخمینی (EDI) و ضریب خطر هدف (THQ) برای فلزات سنگین محاسبه شد. این مطالعه نشان داد که غلظت فلزات در ایستگاه‌ها و بافت‌های مختلف نمونه‌برداری متفاوت است. نمونه‌های چابهار نسبت به نمونه‌های هرمزگانی دارای سطوح بالاتری از فلزات سنگین بودند و غلظت این فلزات در کبد بیشتر از عضله بود، به‌جز سرب که در عضله نمونه‌های هرمزگان کمی بیشتر از کبد بود. تجمع فلزات سنگین در نمونه‌ها از الگوی Zn>Pb>Cd>Hg پیروی می‌کند. در بین فلزات مورد مطالعه، تنها غلظت سرب در ماهیچه ماهی چابهار فراتر از استانداردهای جهانی بود، با این وجود میانگین THQ محاسبه شده برای همه فلزات کمتر از ۱ بود. سطح بالای غلظت سرب می‌تواند به دلیل فعالیت‌های صنعتی گسترده و تا حدودی پساب‌های صنعتی و آلودگی‌های انسانی باشد. بنابراین، با گسترش بخش صنعتی در این حوزه، به‌ویژه در حوزه کشتیرانی، توصیه می‌شود که به‌طور منظم بر سطح فلزات سنگین نظارت شود.

کلمات‌کلیدی: آلودگی، شاخص خطر، ماهی، محیط آبی، خلیج چابهار.