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RESEARCH ARTICLE

Heavy metals in tissues of scorpionfish (*Scorpaena porcus*) caught from Black Sea (Turkey) and potential risks to human health

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Abstract Scorpionfish (*Scorpaena porcus*) is a demersal fish species commercially important for its of which meat is tough and delicious. The aim of this study was to determine heavy metal (Al, Cu, Ni, As, Cd, Hg, Pb, U) concentrations in this fish species which is traditionally consumed in the Black Sea Area and, to compare the concentrations of various toxic elements in different organs of the fish specimens (muscle, liver, gill, and skin). Within this scope, the mineralization was performed using microwave digestion system. Thirty-two scorpionfish caught from Sinop Inland Port during 2010 were analyzed. The heavy metal concentrations were determined with the method of inductively coupled plasma mass spectroscopy (ICP-MS). Verification of the method was demonstrated by analysis of standard reference material (NRCC-TORT-2 lobster hepatopancreas). After evaluation of the results, it was determined that the highest heavy metal accumulation was generally found in the liver. The maximum aluminum level and the minimum uranium level were found in the analyzed tissues. In terms of heavy metals, Al, Cu, Cd, and Hg showed a statistically significant difference between tissues ($p < 0.05$). It was determined that heavy metal concentrations obtained from the muscle tissues did not exceed the national and international recommended limits; and also it was found that daily intake amounts did not exceed tolerable daily intake amounts. Furthermore, in THQ based risk evaluation, the value 1 which is crucial for children and adults was not sur passed. In terms of public health, it was found out that there was not any risk in consumption of scorpionfish in the study area.

Keywords Heavy metal · Uranium · *Scorpaena porcus* · THQ · Black Sea · Public health

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Introduction

One of the most worrying class of chemical contaminants in terms of toxicological risk for human and wildlife is represented by heavy metals (Lionetto et al. 2012). In recent years, the concentrations of toxic metals in many ecosystems have reached unprecedented levels. Specifically aquatic ecosystems are more sensitive to heavy metal pollutants and the gradual increase in the levels of such metals in aquatic environment, mainly due to anthropogenic sources, became a problem of primary concern (Meybeck et al. 1996).

As a demersal species, scorpionfish *Scorpaena porcus* L. 1758 is a member of Scorpaenidae family which acts slowly, spends most of its life in flowing areas and has a long life span (Bostancı et al. 2012). The meat of this species is rough, white and delicious. Its economical value is very high and it is sold freshly (Akşiray 1987).

The Black Sea is a very isolated sea, and due to its geomorphologic structure and specific hydrochemical conditions, it is very vulnerable to pressure from land-based sources of pollution (Paleari et al. 2005). Contaminants such as metals are introduced into the Black Sea through rivers or direct discharge of industrial wastes, agricultural and municipal usages (Turan et al. 2009).

In the sea, pollutants are potentially accumulated in marine organisms and sediments, and subsequently transferred to humans through the food chain (Tuzen 2003). Fish occupies the highest trophic level in aquatic system (APHA 1981). Fish is a good bio-indicator because it is easy to be obtained in large quantity, has a potential to accumulate metals, a long lifespan, an optimum size for analysis and it can be easily sampled (Batvari et al. 2007).

Levels of contaminants in fish are of considerable interest because of potential effects on the fish themselves or the organisms that consume them, including top-level receptors, and people (Burger et al. 2005). Health advisories such as Food and Drug Administration (FDA) have recently raised concern on the safety of fish obtained from commercial sources (Burger et al. 2004). The main purpose of this study is to reveal whether there is a risk in the consumption of scorpionfish for human health in terms of some heavy metals (Al, Cu, Ni, As, Cd, Hg, Pb, U). It is also aimed that accumulation of heavy metals in different tissues of scorpionfish are specified so that the gap in the literature about concentrations of aluminum, nickel and uranium could be fulfilled.

Materials and methods

Description of the study area

Situated in the northern part of Anatolia (Turkey), Sinop Bay is an area of inland port (Fig. 1). In the bay, there are a breakwater and a fishing port, besides small fishing boats and big ships. There is not a system via which wastes of ships could be emptied. During fishing season, this area which is polluted with wastes of ships entering to the port and by anchovy oil's mixing with the water is affected directly from domestic waste. Also, being a natural harbor, many foreign and national ships anchor there under unfavorable weather conditions.

Sample collection

Fresh fish samples of scorpionfish were obtained from local fishermen in Sinop during fishing season in 2010. The samples were weighted prior to analysis and put into polyethylene bags, then brought to laboratory inside an ice box. After biometry measurements of the samples, they were stored in −20 °C until analysis.

Sample digestion

The fish samples were treated by deionized water (resistivity: 18.0 MΩ cm) before dissection. Muscle (M), gills (G), liver (L) and skin (S) of fish were dissected. Tissues were homogenized thoroughly in a laboratory blender (Waring trade marker) with stainless steel cutters. Digestion of the homogenized samples were carried out using this procedure; around 0.5 g homogenate (wet weight) was weighed and placed in polytetrafluorethylene (PTFE) vessel with 5 mL of 65 % nitric acid (65 % suprapur, Merck). Berhof speedwave MWS-3 microwave digestion system was used to digest fish samples prior to metal analysis. The microwave digestion system parameters were given at Table 1. Digestion was finally made up with 2 % nitric acid (65 % suprapur, Merck), 0.5 % hydrochloric acid (30 % suprapur, Merck) solution to 50 mL in acid washed standard flasks and then placed in 50 mL polypropylene centrifuge tubes (Matek and Blanuša 1998).

Sample analyses

Inductively coupled plasma-mass spectroscopy (Agilent 7700×) with auto sampler (Agilent ASX-500) was used to analyze digested samples for total concentrations of studied elements. As there is not any opportunity to analyze arsenic and mercury fractions with ICP-MS, in this study only total concentrations of heavy metals were determined. Obtained results were compared to international maximum residue limits. ICP-MS operation conditions were given at Table 2. Multi-element calibration solutions of all investigated elements were prepared daily by dilution of 10 mg L^{-1} mix element standard stock solution (AccuTrace MES-21-1) and 10 mg L^{-1} mercury standard stock solution (AccuTrace MES-21-HG-1). Analytical quality was confirmed through analyses of certified reference material NRCC-TORT-2 lobster hepatopancreas, and spiked samples. TORT-2 lobster hepatopancreas was used for testing reliability of ICP-MS procedure. TORT-2 lobster hepatopancreas presents total arsenic and mercury reference values. Recovered values of the studied heavy metals were between 91 and 107 %. This shows that the digestion method used and the ICP-MS analysis were reliable. Heavy metal concentrations were determined on a wet weight basis. The recovery levels of studied elements were given at Table 3.

Estimation of daily intake rate (EDI)

It was made by the formula below for the estimation of the average amount of daily intake (Singh et al. 2010);

$$EDI\ \left(\mu\text{g analysed element } kg^{-1}\text{−body weight day}^{-1}\right) = \frac{(\mathrm{C}_{\text{element}} \times \mathrm{D}_{\text{food intake}})}{B_{average\ weight}}$$

C_{element}: The average element concentration in fish

$D_{\text{food intake}}$: Daily fish consumption rate (kg person^{-1})

In this risk evaluation, 70 kg of body weight refers to adult people, 10 kg to 1-year-olds, 15 kg to 2-year-olds, 20 kg to 6-year-olds, 44 kg to 12-year-olds (Brodberg and Klasing 2003,

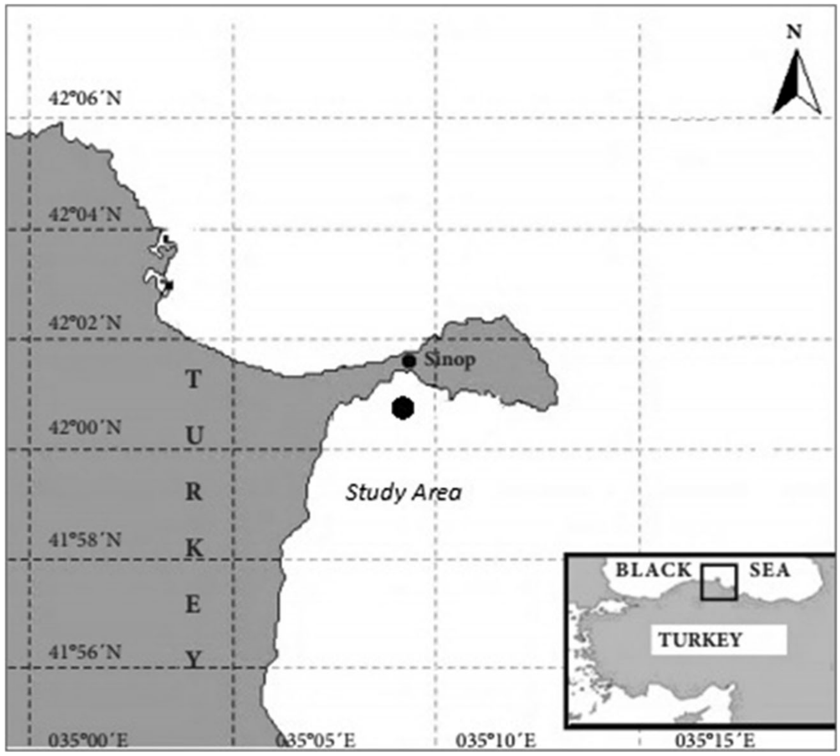

Fig. 1 Localization of the area of study: Sinop Bay (Turkey)

Yaman et al. 2014). The fish consumption rate in Turkey in 2010 was 6.918 kg person^{-1} year^{-1} (TURKSTAT 2011).

Target hazard quotients

For revealing cancerogenic risks related to fish consumption of humans, the method of predicting target hazard quotient (THQ) and total target hazard quotient (TTHQ) was applied. If the THQ value obtained is under "1," an adverse effect is out of question in terms of human health considering the studied elements.

THQ is calculated with the formula below (Chien et al. 2002);

$$\mathrm{THQ} = \frac{\mathrm{E_{fr}} \times \mathrm{ED_{tot}} \times \mathrm{FIR} \times \mathrm{C}}{\mathrm{RfD_o} \times \mathrm{BW_a} \times \mathrm{AT_n}} \times 10^{-3}$$

E_{fr}: Frequency of exposure (365 days year^{-1})

ED_{tot}: Period of exposure (average life expectancy: 70 years)

Table 1 Microwave digestion procedure

Step	1	2	3	4
Temperature (°C)	160	175	190	100
Ramp (min)	5	1	1	1
Hold (min)	5	5	10	10

FIR: Food intake rate (0.019 g day^{-1})

C: Mean heavy metal concentration in fish muscular tissue (mg kg^{-1})

*RfD_o: Oral reference dose (mg kg^{-1} day^{-1})

BW_a: Average body weight (70 kg of body weight refers to adult people, 10 kg to 1-year-olds, 15 kg to 2-year-olds, 20 kg to 6-year-olds, 44 kg to 12-year-olds)

AT_n: Period of average exposure for non-carginogens (365 days year^{-1} × number of exposure years)

*Oral reference doses (RfD_o) for each metal were given by the US EPA (2000) (Al: 1.0, Cu: 0.04, Ni: 0.02, As: 3×10^{-4}, Cd: 1×10^{-3}, Hg: 3×10^{-4}, Pb: 4×10^{-3}, U: 3×10^{-3} in mg kg^{-1} day^{-1}).

TTHQ is calculated with the formula below (Chien et al. 2002);

$$\mathrm{TTHQ} = \mathrm{THQ}_{(\text{toxicant 1})} + \mathrm{THQ}_{(\text{toxicant 2})} + \cdots + \mathrm{THQ}_{(\text{toxicant } n)}$$

Table 2 ICP-MS instrument operating conditions

Radio frequency power	1550 W
RF matching	2.1 V
Sample depth	8 mm
Carrier gas	0.95 L/min
S/C temperature	2 °C
Nebulizer type	MicroMist

Table 3 The recoveries of studied elements ($n = 10$)

Element	Certified value (TORT-2)	Measured value	Recovery (%)
Cu	106.0 ± 10.0	109.02 ± 5.18	102.85
Ni	2.50 ± 0.19	2.67 ± 0.36	106.80
As	21.6 ± 1.80	22.41 ± 0.91	103.75
Cd	26.7 ± 0.60	24.30 ± 0.83	91.01
Hg	0.27 ± 0.06	0.25 ± 0.07	92.59
Pb	0.35 ± 0.13	0.33 ± 0.09	94.29
	Blank value	Spiked value	
Al[a]	0.96 ± 0.16	102.08 ± 3.97	101.12
U[a]	0.54 ± 0.11	105.61 ± 3.69	105.07

[a] Standard added method (100 mg kg^{-1} standard for Hg, 100 μg kg^{-1} for U was added blank muscle tissue)

Statistical analyses

Descriptive analysis, one-way ANOVA and Tukey post hoc were performed using IBM SPSS Statistics V20. The statistical significance was determined through 0.05 alpha level. If $p < 0.05$, it was evaluated as there was a statistically significant difference between the groups.

Results and discussion

Biometric results of fish caught from Sinop Bay are given at Table 4.

Significant positive correlation was found between total length, weight, and heavy metal concentrations ($p < 0.05$).

Heavy metal concentrations in different fish tissues are presented at Table 5.

The order of heavy metals with regard to total concentration was Al > Cu > As > Pb > Ni > Cd = Hg > U. The highest amount of heavy metal was usually found in the liver tissues. A possible reason that liver tissue had the highest amount of heavy metal might be due to its role as the main site for synthesis of various proteins and other molecules which had high affinities for metal, as well as being the main site of the detoxification of various contaminants (Fernandes et al. 2008; Vaseem and Banerjee 2013). Levels of statistical significance in the distributions of heavy metals in the tissues are given at Table 6. It was seen that there was not any statistically significant difference between tissues with regard to nickel, arsenic, lead, and uranium ($p > 0.05$). However, it was determined that there was a statistically significant difference between tissues in terms of aluminum, copper, cadmium, and mercury ($p < 0.05$).

Table 4 Biometric results of fish samples

$n = 32$	Minimum	Maximum	Mean ± sd[a]
Total length (cm)	10.50	19.00	14.40 ± 0.36
Weight (g)	24.50	168.20	62.66 ± 3.32

[a] Standard deviation

Daily heavy metal intake amounts obtained from consumption of scorpionfish were compared to provisional weekly intake amount and tolerable daily intake amounts. The obtained results were shown at Table 7.

THQs and TTHQ for children and adults were ascertained to be <1 (Table 8). In the risk evaluation with regard to Cr, Hg, Cd, Pb in the muscles of commercial fish species, European anchovy *Engraulis encrasicolus*, European pilchard *Sardina pilchardus* and red mullet *Mullus barbatus* gathered from Mediterreneaen, the coast of Sicily (Italy), there was not found any carcinogenic risk to humans THQs <1 (Copat et al. 2012) as in this study. Similarly, in a study carried out in Tianjin (China), THQ predictions with regard to Cu, Hg, Cd, and Pb in the aquacultured fish showed values lower than 1 for children and adults (Wang et al. 2005). As a result of the risk evaluation related to the consumption of edible marine species gathered from Adriatic Sea, THQ value in terms of Hg in the species of Albacore *Thunnus alalunga*, rosefish *Helicolenus dactylopterus*, thornback ray *Raja clavata* was determined as >1 (Storelli 2008). In their study carried out in Portugal, Vieira et al. (2011) performed a risk evaluation related to mercury on children between the ages of 1–3 consuming Horse mackerel *Trachurus trachurus* and found THQ value as 1.309. They estimated that there was a carcinogenic risk related to mercury to aforementioned age group.

According to our results of obtained daily intake amounts, there was not any threat to public health in comsumption of scorpionfish. In a study done in France, heavy metal amounts taken daily from the consumption of fish and crustaceans were determined as 1233 μg day^{-1}Al, 109 μg day^{-1} Cu, 53 μg day^{-1} Ni, 4.1 μg day^{-1} Cd (Biego et al. 1998) and these values were higher than the values obtained in this study. In a study done in United Kingdom (UK), daily intake amounts obtained by fish consumption were found as 0.086 mg day^{-1} aluminum, 0.061 mg day^{-1} arsenic, 0.012 mg day^{-1} copper, 2.00 μg day^{-1} nickel, 0.18 μg day^{-1} cadmium, 1.00 μg day^{-1} mercury and 0.28 μg day^{-1} lead (Ysart et al. 2000) which were higher than those obtained in this study. The reason why the obtained values in this study were lower than the values of the studies done in France and UK was that the rate of fish consumption in Turkey (6.918 kg person^{-1} year^{-1}) is very lower than fish consumption in France 32 kg per son^{-1} year^{-1} and UK 24 kg person^{-1} year^{-1} (Failler et al. 2008). Estimated THQ and DIR values of heavy metals (Pb, Cd, As, Hg) in different fish species from recent studies are shown at Table 9.

There are many researches on heavy metal contamination in different fish species in various places in the world. Some of

Table 5 The mean heavy metal concentrations in the tissues of studied samples (mg kg^{-1} ± sd, for uranium μg kg^{-1} ± se) and distribution order in the tissues

	Al	Cu	Ni	As	Cd	Hg	Pb	U
Muscle (M)	0.28 ± 0.16	0.07 ± 0.009	0.01 ± 0.007	0.14 ± 0.09	nd	0.01 ± 0.00	0.04 ± 0.03	0.35 ± 0.19
Gill (L)	1.13 ± 0.38	0.06 ± 0.01	0.02 ± 0.008	0.11 ± 0.04	nd	nd	0.04 ± 0.02	0.60 ± 0.17
Liver (L)	1.63 ± 0.64	0.45 ± 0.17	0.005 ± 0.001	0.19 ± 0.08	0.02 ± 0.007	nd	0.03 ± 0.006	0.58 ± 0.15
Skin (S)	1.02 ± 0.17	0.14 ± 0.03	0.005 ± 0.002	0.08 ± 0.02	nd	0.01 ± 0.007	0.05 ± 0.01	0.51 ± 0.23
Distribution order	L > G > S > M	L > S > M > G	G > M > L = S	L > M > G > S	L > M = G = S	M = S > G = L	S > G = M > L	G > L > S > M

sd standard deviation, *nd* not detected

Table 6 Results of Tukey post hoc tests performed for measured concentrations in different tissues

	Al	Cu	Ni	As	Cd	Hg	Pb	U
M-L	*	*	ns	ns	*	*	ns	ns
M-G	ns	ns	ns	ns	ns	*	ns	ns
M-S	*	ns	ns	ns	ns	*	ns	ns
L-G	ns	*	ns	ns	*	ns	ns	ns
L-S	ns	*	ns	ns	*	*	ns	ns
G-S	ns	ns	ns	ns	ns	*	ns	ns

ns not-significant ($p > 0.05$)

*$p < 0.05$

these studies are mentioned below. Nonetheless, there is only a few studies which feature not only heavy metal concentrations in different tissues of scorpionfish but also its risk evaluation to human health.

Aluminum is not considered to be an essential element in humans. Exposure to aluminum has been implicated in a number of human pathologies including encephalopathy/dialysis dementia, Parkinson disease and Alzheimer's disease (Narin et al. 2004). Permitted levels for the concentration of aluminum in tissues of fish have not been revealed. The European Food Safety Authority EFSA set the weekly aluminum intake as 7 mg kg^{-1} body weight in 2008 (EFSA 2008). In this study, the mean aluminum concentration found in muscle tissue of *S. porcus* was 0.28 mg kg^{-1} and aluminum concentrations detected in the tissues were increased in following order; L > G > S > M. In all of the studied tissues, aluminum was the mostly found heavy metal. Similarly, aluminum was the second element after iron which was found at most in all the tissues (G, L, M) in the species of groovy mullet, *Liza dumerelii* gathered from Mhlathuze Estuary (South Africa) (Mzimela et al. 2003). The aluminum concentrations in muscle tissues of Cod *Gadus morhua*, Saithe *Pollachius virens*, Mackerel *Scomber scombrus* and Ocean perch *Sebaster* spp. were determined as 0.076, 0.099, 0.074, 0.096 mg kg^{-1}, respectively (Ranau et al. 2001) which were lower than the values found in our study. As higher values than the ones found in our study, 0.51, 0.84 and 1.61 mg kg^{-1} of aluminum levels were determined in Brushtooth lizardfish *Saurida undosquamis*, gilt-head (sea) bream *Sparus aurata* and red mullet *Mullus barbatus* respectively in a study conducted in the Northeastern Mediterranean Sea (Türkmen et al. 2005). Likewise, the aluminum concentrations determined in muscle tissues of three species (İndian mackerel *Rastrelliger kanagurta*, ilish *Tenualosa ilisha* and narrow-barred Spanish mackerel *Scomberomorus commerson*) obtained from fishermen in Persian Gulf were 3.896, 3.762, 0.249 mg kg^{-1} respectively (Pilehvarian et al. 2015). In all the studies above, the values found were under weekly aluminum intake rate specified by EFSA.

Table 7 The average trace element daily intake amounts taken with the consumption of the studied fish species (muscle tissue) (μg day^{-1})

	Al	Hg	Cu	Ni	As	Cd	Pb	U
1-year-olds	0.53	0.019	0.13	0.019	0.27	nd	0.08	7×10^{-4}
3-year-olds	0.35	0.013	0.09	0.013	0.18		0.05	4×10^{-4}
6-year-olds	0.27	0.009	0.07	0.009	0.13		0.04	3×10^{-4}
12-year-olds	0.12	0.004	0.03	0.004	0.06		0.02	2×10^{-4}
Adult	0.08	0.003	0.02	0.003	0.04		0.01	9.5×10^{-5}
Reference values	7 mg kg^{-1} body weight $week^{-1}$ = 70 mg day^{-1}	300 μg $week^{-1}$ = nearly 43 μg day^{-1}	30 mg day^{-1}	5 μg day^{-1}	120 μg day^{-1}	60 μg day^{-1}	210 μg day^{-1}	42 μg day^{-1}
	PTWI		TDI					

PTWI provisional tolerable weekly intake amount, *TDI* tolerable daily intake amount, *nd* not detected (FAO 1983; UK Department of Health 1991; WHO 1982a,b; Ysart et al. 2000; EFSA 2008; EFSA 2009)

Food is a principal source of copper exposure for humans. Liver and other meats, seafood, nuts and seeds (including whole grains) are good sources of dietary copper (IOM 2001). The concentrations of Cu in samples were lower than the permitted limit (10 mg kg^{-1}) recommended by FAO (1983). In this study, copper amount obtained from muscle tissue (0.07 mg kg^{-1}) was below limit value. In a study done in Sinop (Turkey) by other authors (Bat et al. 2012) on scorpionfish the amount of copper was found as 0.88 mg kg^{-1}, in another study done in Sevastopol (Russia) (Rudneva et al. 2011) the amount was found as 0.60 mg kg^{-1} and the study done in Aegean Sea (Uluozlu et al. 2007) the amount was found as 0.73 mg kg^{-1}. These amounts of copper were higher than the amounts found in this study. The highest amount of copper concentration in muscle tissue was found in grey mullet *Mugil cephalus* as 4.41 mg kg^{-1} in another study done in the Northeastern Mediterranean Sea (Canli and Atli 2003). In *S. porcus*, the distribution order of copper was in an increasing order of L > S > M > G. In a study done in the coast of Mauritania, researchers found the highest copper accumulation (49.1 mg kg^{-1}) in the liver of four different pelagic fish species as in this study (Roméo et al. 1999).

Nickel is required for normal growth and reproduction in animals and human beings, but has a carcinogenic effect when consumed in high amount (Vaseem and Banerjee 2013). Export Inspection Council of India states that in fish and fish products, nickel concentration level should not be more than 80 mg kg^{-1} (IEIC 2002). In this study, the nickel levels (0.01 mg kg^{-1}) determined in the muscle tissues of fish samples did not exceed this limit. The nickel results for each tissue in this study were close to each other, the maximum nickel concentration was found in the gills and the minimum nickel concentration was found in the liver and skin. In a study on scorpionfish done in Aegean Sea, nickel level found in muscle tissue (3.63 mg kg^{-1}) was much more than this (Uluozlu et al. 2007). In a study done in Black Sea, nickel amounts were found as 0.01, 0.06, below 0.001 and 0.03 mg kg^{-1} in muscle tissues of anchovy *Engraulis encrasicholus*, rainbow trout *Oncorhyncus mykiss*, bluefin *Trachurus mediterraneus* and whiting *Merlangius merlangus* respectively (Korkmaz et al. 2012). These results were in line with those of our study.

Arsenic is a widely distributed metalloid, occuring in rock, soil, water and air. General population is exposed to arsenic via intake of food and drinking water (Stancheva et al. 2013). There is not any certain recommended legal limit for arsenic in Turkish Food Regulations and European Community No 1181/2006. Nevertheless, the maximum arsenic level permitted is 1.00 mg kg^{-1} according to Australian Standards (FSANZ 1998). The mean concentration of arsenic in the mucle tissues in this study (0.14 mg kg^{-1}) was lower than the permitted arsenic level (1.00 mg kg^{-1}). With regard to the mean concentration, the order of arsenic in tissues was

Table 8 THQ and TTHQ values for children and adults

		THQ								TTHQ
		Al	Cu	Ni	As	Hg	Pb	U	Cd	
Children	Age 1	5.3×10^{-4}	3.3×10^{-3}	9.5×10^{-4}	0.88	6.3×10^{-2}	1.9×10^{-2}	2.2×10^{-4}	nd	<1
	Age 3	3.5×10^{-4}	2.2×10^{-3}	6.3×10^{-4}	0.59	4.2×10^{-2}	1.3×10^{-2}	1.5×10^{-4}		
	Age 6	2.7×10^{-4}	1.7×10^{-3}	4.7×10^{-4}	0.44	3.2×10^{-2}	9.5×10^{-3}	1.1×10^{-4}		
	Age 12	1.2×10^{-4}	7.5×10^{-4}	2.2×10^{-4}	0.20	1.4×10^{-2}	4.3×10^{-3}	5.0×10^{-5}		
Adult		7.6×10^{-5}	4.7×10^{-4}	1.4×10^{-4}	0.13	9.0×10^{-3}	2.7×10^{-3}	3.2×10^{-5}		

nd not detected

Table 9 Estimated THQ and DIR values of heavy metals from recent studies

	THQ (mg kg^{-1})				EDI (mg day^{-1} 65 kg^{-1} body weight)				References
	Cd	Pb	As	Hg	Cd	Pb	As	Hg	
Fish species									
Cyprinus carpio	3.8E-02	1.5E-01	6.3E-01	–	1.1E-03	3.7E-02	1.1E-02	–	Islam et al. 2015
Rutilus rutilus	7.7E-05	9.9E-05	3.0E-04	–	7.7E-05	2.0E-04	9.2E-05	–	Alipour et al. 2015
Fish	2.3E-01	6.5E-01	7.03E-02	–	2.3E-04	2.6E-03	2.1E-05	–	Saha and Zaman, 2013
Engralus encrasicolus[a]	–	–	1.9[b]	–	3.0E-03	1.6E-02	5.1E-0-1[b]	–	Copat et al. 2013
Istiophorus platypterus	1.0E-01	1.5E-02	5.0E-01[b]	5.0E-01	2.1E-01	1.6E-01	5.0E-0-1[b]	9.0E-01	Soto-Jimenez et al. 2010
Ostrea plicatula	1.1E-01	3.5E-02	–	4.7E-02	2.1E-01	1.3E-01	–	5.0E-03	Li et al. 2013
Carassius auratus	–	–	1.1E-01	3.1E-01	–	–	–	–	PuYamg et al. 2015
Mullus barbatus	2.0E-02	1.0E-02	–	1.1	2.0E-02	2.5E-02	–	1.1E-01	Storell and Barone, 2013
Scorpaena porcus	–	2.7E-03	1.3E-01	9.0E-03	–	1.0E-02	4.0E-02	3.0E-03	This study

[a] EDI is calculated as per meal size (μg kg^{-1} daily^{-1})

[b] As calculations were made by assuming the inorganic As the 3 % of the total concentration

found as L > M > G > S. Arsenic concentration determined in muscle tissue of scorpionfish gathered from the coast of Sevastopol, Black Sea was 0.80 mg kg^{-1} and higher than the values found in our study (Rudneva et al. 2011). Arsenic contamination in females and males in the species of sardine, chub mackarel, horse mackarel sold in fish markets in Porto Metropolitan area (NW Portugal) were studied seperately. Arsenic concentrations determined in males of Chub mackarel and horse mackarel were 1.0637 and 1.3389 mg kg^{-1} respectively (Vieira et al. 2011) and these concentrations exceeded the limit value (1.00 mg kg^{-1}).

Cadmium is a highly toxic element for all mammals and fishes. Accumulation of cadmium in living organisms is a major ecological concern, especially because of its ability to be accumulated very quickly (Beširovič et al. 2010). People are exposed to cadmium through nutrition mostly due to aquacultural products like fish. The European community No 1881/2006 and Turkish Food Regulation recommend the maximum levels permitted for Cd in fish as 0.05 mg kg^{-1} (EC 2006; The Official Gazette 2008). In this study, cadmium concentration in muscle tissue, gill and skin was under the limit of detection, while cadmium concentration in liver tissues was 0.02 mg kg^{-1}. There was not any threat to public health in terms of cadmium. In a study carried out at Aegean Sea, cadmium concentration was found as 0.80 mg kg^{-1} for scorpionfish (Uluozlu et al. 2007). On the other hand, in a study done in Sinop on scorpionfish, cadmium level (0.02 mg kg^{-1}) was found much lesser than reccomended limit (0.05 mg kg^{-1}) (Bat et al. 2012).

Acute mercury exposure may give rise to lung damage. Chronic poisoning is characterized by neurological and psychological symptoms. The general population is primarily exposed to mercury via food, fish being a major source of methyl mercury exposure (Järup 2003). The maximum acceptable level set by Turkish Food Codex and EC 1881/2006 is 0.50 mg kg^{-1} (EC 2006; The Official Gazette 2008). Mercury was not detected in gill and liver tissues, while the mean mercury concentration in muscle and skin tissues was 0.01 mg kg^{-1}. The mean mercury concentration determined in the scorpionfish caught in Sevastopol was 0.06 mg kg^{-1} (Rudneva et al. 2011). There was not any danger in consuming scorpionfish caught from Sevastopol and Sinop in terms of mercury. In a study done in New Jersey (USA), mercury was found at the levels of 0.60 and 0.30 mg kg^{-1} in tuna fish *Thunnus albacaras* and bluefish *Pomatomus saltatrix* respectively (Burger et al. 2004). Also, in a study carried out in Brasil, the highest mercury concentration (2.84 mg kg^{-1}) in the fish sold in markets was determined in *Pellona castelnaeana* known as Apapá fish (Bourdineaud et al. 2015). The amount found in tuna fish and Apapá fish exceeded the limit value (0.50 mg kg^{-1}). In addition to these studies Total Hg (HgT) concentrations found in various fish species from other areas are presented in Table 10.

Table 10 Total Hg (HgT) concentrations of various fish species from other areas

Species	HgT_{muscle} (mg kg^{-1})	Site	References
Engraulis encrasicolus	0.055	Black Sea (Turkey)	Tuzen, 2009
	0.030	Sicily (Catania)	Copat et al. 2012
	0.057	Marsala (Italy)	Bonsignore et al. 2013
	0.150	Aegean Sea (Geece)	Kalogeropoulos et al. 2012
	0.065	Ionian Sea	Copat et al. 2014
Sardina pilchardus	0.033	Lebanon	Harakeh et al. 1985
	0.080	Sicily (Catania)	Copat et al. 2012
	0.082	Augusta (Italy)	Bonsignore et al. 2013
Trachurus trachurus	0.053	Marmara Sea (Turkey)	Keskin et al. 2007
	0.078	Black Sea (Turkey)	Tuzen, 2009
	0.122	Israel	Hornung et al. 1980
	0.090	Ionian Sea	Copat et al. 2014
Diplodus vulgaris	0.378	Marmara Sea (Turkey)	Keskin et al. 2007
	0.643	Augusta (Italy)	Bonsignore et al. 2013
	0.090	Aegean Sea (Turkey)	Yabanli and Alparslan, 2015
Pagellus erythrinus	0.290	Marmara Sea (Turkey)	Keskin et al. 2007
	0.341	Tyrrhenian Sea (Italy)	Papetti and Rossi, 2009
	0.240	Adriatic Sea (Italy)	Gibicar et al. 2009
Mullus barbatus	0.434	Marmara Sea (Turkey)	Keskin et al. 2007
	0.036	Black Sea (Turkey)	Tuzen, 2009
	0.010	Mediterrenian Sea (Spain)	Martorell et al. 2011
	0.281	Ionian Sea	Copat et al. 2014
	0.110	Adriatic Sea (Italy)	Storelli and Barone, 2013
	0.100	Aegean Sea (Turkey)	Yabanli and Alparslan, 2015
Scorpaena scrofa	1.082	Augusta (Italy)	Bonsignore et al. 2013
	0.222	Adriatic Sea (Italy)	Buzina et al. 1995
	0.390	Adriatic Sea (Italy)	Buzina et al. 1995
Scorpaena notata	0.490	Tyrrhenian Sea (Italy)	Gibicar et al. 2009
	1.340	Augusta (Italy)	Bonsignore et al. 2013
Scorpaena porcus	0.06	Black Sea (Russia)	Rudneva et al. 2011
	0.01	Black Sea (Turkey)	This study

Table 11 Comparision of heavy metal concentrations in muscle tissues (mg kg^{-1} ± sd; and for uranium μg kg^{-1} ± sd) with other studies

Area	Al	Cu	Ni	As	Cd	Hg	Pb	U	Reference
Sevastopol (Black Sea)		0.60 ± 0.10		0.80 ± 0.10	0.04 ± 0.01	0.06 ± 0.01	0.16 ± 0.04		Rudneva et al. 2011
Aegean Sea		0.73 ± 0.06	3.63 ± 0.25		0.80 ± 0.06		0.66 ± 0.06		Uluozlu et al. 2007
Sinop (Black Sea)		0.88–1.70			0.02–0.023		0.03–0.07		Bat et al. 2012
Izmir Bay (Aegean Sea)		0.03–0.09			0.005–0.04		0.01–0.08		Sunlu and Egemen 1997
This study	0.28 ± 0.16	0.07 ± 0.009	0.01 ± 0.007	0.14 ± 0.09	nd	0.01 ± 0.00	0.04 ± 0.03	0.35 ± 0.19	This study
Permitted limits		10	80	1.00	0.05	0.50	0.30		in text

nd not detected

Lead is a widely common environmental toxic and, being used in manufacture of cans, it is a source of contamination of food by lead (Mol 2011). That is why, monitoring lead in fish and other aquacultural products is very significant for public health. According to our results, the highest mean lead concentration was found in the skin; the lowest lead concentration was found in the liver. A statistically significant difference was determined between concentrations of heavy metals in fish tissues ($p < 0.05$). In this study, the highest lead concentration was found in the skin, the lowest lead concentration was found in the liver. The mean lead amount found in muscle tissues in this study was 0.04 mg kg^{-1} and it did not exceed the maximum permitted lead level (0.30 mg kg^{-1}) determined by Turkish Food Codex and EC 1881/2006 (EC 2006; The Official Gazette 2008). Lead levels found in scorpionfish caught in Sinop were in the range of 0.03–0.06 mg kg^{-1} (Bat et al. 2012). In a study done in Aegean Sea lead levels found in scorpionfish (0.66 mg kg^{-1}) were determined to be higher than recommended limit (Uluozlu et al. 2007).

As Chernobyl Nuclear Power Plant Accident which occured in 1986 affected Black Sea, therefore uranium was included in this study. Uranium is the heaviest element in nature. Uranium penetrates the human body by ingestion with food and drink and inhalation of respirable airborne uranium-containing dust particles or aerosols (Taylor and Taylor 1997; Barillet et al. 2011). The World Health Organization (WHO) has established a tolerable daily intake (TDI) for soluble uranium of 0.6 μg kg^{-1} body weight per day (EFSA 2009). To our knowledge, permission levels for the concentration of uranium in tissues of fish have not been stated. In this study, 0.35 μg kg^{-1} uranium was found in the muscle tissue and this value was below the tolerable daily intake. Uranium concentrations in food samples collected from Catalonia (Spain). They determined uranium concentration at the level of 0.09 mg kg^{-1} in fish and aquaculture products (Bellés et al. 2013). This value was much higher than the value (0.35 μg kg^{-1}) obtained in our study. In this current study, the highest uranium concentration was found in gill, because uranium could be accumulated in gills at a significant level related to their osmoregulation function (Simon and Garnier-Laplace 2005). Likewise, two different studies on uranium levels in the tissues of two fish species, uranium concentrations were found as G > L > S > M (Strømman et al. 2013; Salbu et al. 2013).

The studies on heavy metal determination in muscle tissue of scorpionfish and the permitted limit values are summarized at Table 11. As it can be seen at Table 8, there is not sufficient data about aluminum, nickel and uranium concentrations in scorpionfish in Black Sea. Therefore, it is clear that our study may provide information for researchers.

Conclusions

This study done in an inland port in Black Sea, which is under the influence of many pollutants, contains valuable data especially those about aluminum, nickel and uranium metals which have not been studied in scorpionfish previously. It is stated that the highest heavy metal accumulation is found in the liver. The maximum amount of aluminum and the minimum amount of uranium are determined in the tissues. When the results of heavy metal determination are compared with national and international limits, and when daily heavy metal intake amounts from consumption of scorpionfish is compared with tolerable daily intake amounts, it is seen that there is not any risk for public health. Also, according to determined THQ and TTHQ results, there is not any carcinogenic risk for children and adults in terms of studied heavy metals regarding scorpionfish consumption. Since individual fish consumption is very low (6918 kg person^{-1} year^{-1}) (TURKSTAT,2011), the consumption of scorpion fish does not pose risk for consumer health in terms of studied heavy metals.

However, environmental pollutants can be merged in sea uncontrolledly through factors such as rivers, sewage, industrial decharge and ships. For this reason, it is very important and beneficial that contaminants like heavy metals which affect human health negatively by leaving residues in fish should be monitored and kept under control.

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