



Element concentrations of cultured fish in the Black Sea: selenium-mercury balance and the risk assessments for consumer health

Dilara Kaya Öztürk¹

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Abstract

Fish are a powerful model for risk–benefit analyses to explore the impact of elements on human health among all accessible species. The sea bream (*Sparus aurata*), sea bass (*Dicentrarchus labrax*), turbot (*Scophthalmus maximus*), and weights of > 1 kg large rainbow trout registered as “Turkish Salmon,” (*Oncorhynchus mykiss*) are four economically important cultured species in the Black Sea. In this research, it is aimed (1) to determine the value of the elements, (2) to determine total Hg and Se concentrations, Se/Hg molar ratios, and the HBVSe index, and (3) to calculate the consumer’s possible health risk in the edible tissues of cultivated four economically important Black Sea fish species. Fish and diet samples from all species were obtained in 2020 from aquaculture locations in the Black Sea (Sinop, Samsun, and Trabzon cities of Turkey). At the end of the study, the elements in all edible tissues and all the parameters analyzed [Se/Hg, estimated daily intake (EDI), target hazard quotient (THQ), maximum allowable consumption rate (CR_{lim} and CR_{mm})] in cultured fish tissues were below permissible values. Additionally, when compared with the data of the World Health Organization and The National Academy of Sciences, it determined that consuming cultured fish in the Black Sea adequately meets the daily elemental requirement.

Keywords Cultured fish · Se/Hg molar ratio · Risk assessment · Black Sea · Biomagnification factor

Introduction

Turkish farmed fish represented approximately 44.6% of total production for sea bass, sea bream, rainbow trout, and other species in 2020 (Anonymous 2021a). Despite the fact that aquaculture production is so high, the prejudice of consumers towards these products is still a matter of debate. In fact, many studies have been conducted comparing the meat yield of cultured fish and natural fish to overturn this prejudice (Erdem et al. 2009; Baki et al. 2015; Kaya Öztürk et al. 2019a, 2020). However, there are few publications on the potential risk to human health of cultured fish (Anonymous 2021b). According to recent research on contamination levels in farmed fish populations, they have a higher risk of cancer than wild fish stocks when consumed often (Hites

et al. 2004). Fish farms have been criticized for their environmental impacts, but the possible human health consequences of eating farmed fish have not been well investigated (Connor 2000). In fact, because fish meat is high in fatty and amino acids, as well as minerals and vitamins, eating enough fish on a weekly basis has been linked to a lower risk of cardiovascular disease, some cancers, and various inflammatory responses and conditions (Sidhu 2003; Mozaffarian and Rimm 2006; Lall and Milley 2008).

The 29 of the 90 naturally occurring inorganic elements are regarded as necessary for all farmed fish species (Lall and Milley 2008). Micro elements such as calcium, potassium, magnesium, sodium, and phosphorus, as well as copper, iron, manganese, selenium, and zinc, are essential components for fish and must be included in diets for cultivated species (National Research Council (NRC) (2011)). An adequate amount of elements in feed ensures the healthy growth of cultured fish and it is presented to the consumer as a better quality and balanced product. Some elements, on the other hand, are poisonous and biodegradable environmental pollutants that can cause significant harm to the many systems in the human body when they accumulate in tissues

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✉ Dilara Kaya Öztürk
dilara.kaya55@gmail.com

¹ Faculty of Fisheries, Department of Aquaculture, Sinop University, Sinop, Turkey

and reach high levels (Stankovic et al. 2014; Bayrakli 2021). Although some elements such as copper, iron, and zinc are required for metabolic activities, high amounts of these elements may have toxic effects (Mol et al. 2010). Therefore, metals such as lead, cadmium and mercury, which can be found in aquatic organisms, can cause completely toxic effects (Mol et al. 2010; Bat et al. 2021). Increasing population and industrial pollutants have been found to have a negative impact on aquatic species with restricted mobility (Hwang et al. 2017). Although they move as they wish in the water column, it is not possible for the cultured fish to escape from their environment when exposed to possible pollution, since aquaculture is done in fixed places. Therefore, in order to estimate the critical level of the elements in the risk group in terms of human health and to establish safe food standards, some internationally valid coefficients should be calculated especially for cultured fish (Anonymous 2021b).

For many years, it has been known that selenium (Se) provides protection against the fatal consequences of excessive mercury exposures and those high mercury (Hg) exposures significantly reduced Se levels (Pařízek and Ošťádalová 1967). In numerous studies was reported that when Se and Hg are coadministered, insoluble, and biologically unavailable HgSe complexes formed in body (Naganuma and Imura 1980), and then that Hg sequesters Se and thereby inhibits the activities of enzymes (Chen and Berry 2003; Schweizer et al. 2004; Ralston and Raymond 2010). The Se health benefit value, or Se-HBV, is a newly established risk assessment criteria that was created to allow for the simultaneous evaluation of Hg exposures and dietary Se intakes, particularly in relation to maternal consumption during pregnancy (Kaneko and Ralston 2007). Dietary Se and Hg have opposing effects on Se status and brain enzyme activities. For this reason, this equation is utilized to generate an index (Se-HBV) that may be used to forecast the consequences of maternal Hg exposure from seafood intake (Ralston 2008). Hg/Se molar ratios must be evaluated in order to understand the consequences of Hg exposure in terms of food safety and risk assessment of fish consumption, according to the International Bioindicators Roundtable (Ralston 2008). The Se/Hg molar ratios above 1 provide protection against Hg toxicity and reduce adverse effects of Hg, and the

molar ratio must be the critical value for risk assessment rather than the level of Hg in fish (Ulusoy et al. 2019). The US Environmental Protection Agency created the Se-HBV, another indication of fish dietary safety. For risk assessment related to Methyl Hg exposure, this indication was shown to be more trustworthy (Ralston 2008; Ulusoy et al. 2019).

The purpose of this study were (1) to determine the value of the elements, (2) to determine total Hg and Se concentrations, Se/Hg molar ratios, and the HBVSe index, and (3) to calculate the consumer's possible health risk in the edible tissues of cultivated four economically important Black Sea fish species

Materials and methods

Fish samples

All fish species were collected from aquaculture sites in the Black Sea (Sinop, Samsun, and Trabzon), in 2020. In the study, sea bass (*Dicentrarchus labrax*), sea bream (*Sparus aurata*), turbot (*Scophthalmus maximus*), and weight of > 1 kg registered as “Turkish Salmon,” (*Oncorhynchus mykiss*) large rainbow trout were used. All collection sites are located in the Black Sea and species information, fish number, and site location are shown in Table 1. It was preferred that the cultured fish used in the study should be at least in portion weight in order to give clear results to the consumers. Turkish salmon, sea bream, and sea bass were produced in cage systems, and while the turbot was produced in a recirculating aquaculture system. The fish were sampled by the operating personnel while they were harvested, therefore this manuscript does not need an ethical approval. Fish and diet samples were transported to the laboratory of the Faculty of Fisheries and Aquaculture, Scientific and Technological Research Center (University of Sinop) by cold chain conditions and stored in a deep freezer (WiseCryo/WUF-D500-80°C) until analysis. After biometric measurements were made in the laboratory, skinless and boneless fillets of fish were analyzed.

Table 1 The length-weights, numbers, and locations of the sampled fish

Fish species	Weight (g)	Length (cm)	Number of samples	Location	Diet types
Sea bream	759.36 ± 32.40	36.25 ± 1.67	10	41°40'53.12"N 35°28'22.48"E	D3
Sea bass	533.18 ± 56.76	36.50 ± 1.35	10	41°40'53.12"N 35°28'22.48"E	D3
Turkish salmon	1556.36 ± 140.81	46.43 ± 1.87	10	41°54'44.15"N 35°10'55.92"E	D1
Turbot	761.30 ± 42.56	35.27 ± 0.94	3	40°58'17"N 39°50'30"E	D2

Element analysis

Element analysis was determined in the laboratories of Sinop University Scientific and Technological Researches Center (SUBITAM). Fish fillet samples digested using a microwave digestion system (Milestone Systems, Start D 260) with Suprapur® HNO₃ (nitric acid) according to meat, texture, fish, and similar samples HPR-FO-67 method (Milestone). Element analysis of fish fillet samples were performed using Inductively Coupled Plasma-Mass Spectrometer (ICP-MS) (Agilent Technologies, 7700X) method by accredited SEM laboratory. Data quality was checked by the analysis of standard reference materials (UME CRM 1201-UME CRM 1204).

Molar ratio (Se/Hg) and selenium health benefit value

The molar ratio (Se/Hg) ($\mu\text{mol g}^{-1}$) was calculated individually for each fish species dividing Se and Hg concentrations by their respective molecular weights (Hg: 200.59; Se: 78.96). The selenium health benefit value (Se-HBV) was calculated using the molar concentrations of two elements according to the following equation (Ralston et al. 2016). A positive value of Se-HBV is considered healthy, whereas a negative value indicates health risks associated with Hg exposure.

$$\text{Se HBV} = [(\text{Se} - \text{Hg})/\text{Se}] \times (\text{Se} + \text{Hg}).$$

Potential risk to human health

The estimated daily intake, target hazard quotient, and highest daily intake values were calculated for potential risk to human health. The potential risk to human health was determined using the fish consumption amount (6.3 kg/year) from the Turkish Statistical Institution for 2019 (Anonymous 2021c) and Reference doses (RfD) of elements [Al (1 mg/kg day⁻¹), Cu (0.04 mg/kg day⁻¹), Fe (0.7 mg/kg day⁻¹), Mn (0.14 mg/kg day⁻¹) Zn (0.3 mg/kg day⁻¹) Hg (0.0003 mg/kg day⁻¹), Cd (0.001 mg/kg day⁻¹), and Pb (0.004 mg/kg day⁻¹) Se (0.005 mg/kg day⁻¹)] from the EFSA (2010), Official Gazette (2011), US EPA (2013), and Anonymous (2021d).

Estimated daily intake

The estimated daily intake (EDI, mg kg⁻¹ bw/day) was calculated with the following equation (Bat et al. 2022):

$$\text{EDI} = [C \times \text{AvC}]/\text{bw}$$

where C (mg kg⁻¹ ww of fish) is the mean metal concentration in muscle tissue, AvC is the average consumption of fish per day, and bw is the average body weight for adult (70 kg) and child (16 kg).

Target hazard quotient

Target hazard quotient (THQ) was estimated for each length class of the five selected species by dividing the EDI by the RfD (Onsanit et al. 2010). In the end, values below 1 indicate that even for more sensitive groups (such as pregnant women and children) consumption of these species/size classes represents no danger in terms of health effects. In contrast, values above 1 indicate a high probability for long term health effects (Copat et al. 2012).

$$\text{THQ} = \text{EDI}/\text{RfD}$$

$$\text{TotalTHQ}(\sum \text{THQ}) = \text{THQ}_1 + \text{THQ}_2 + \text{THQ}_3 + \text{THQ}_4$$

Maximum allowable consumption rate

The maximum amount of edible tissue that can be consumed by one person without representing a health risk (CR_{lim}) was calculated according to the method of the US EPA (2000) and was evaluated to consider an additive interaction among the contaminants (Yu et al. 2012). The CR_{lim} was arrived at according to the equation given below (US EPA 2000):

$$\text{CR}_{\text{lim}} = \text{RfD} \times \text{BW}/C \text{ (kg person}^{-1}\text{day}^{-1}\text{)}$$

The maximum allowable daily consumption limits calculated in this study were converted to the number of allowable meals per month (US EPA 2000).

It was calculated as: $\text{CR}_{\text{mm}} = (\text{CR}_{\text{lim}} \times T_{\text{ap}})/\text{MS}$ (Yu et al. 2014)

where CR_{mm} is the maximum allowable fish consumption rate (meals/month), T_{ap} is time averaging period (365.25 days/12 months = 30.44 days per month), and MS is meal size (0.227 kg for adults and 0.114 kg for children).

Biomagnification factor

The biomagnification factor (BMF) is the ratio between the concentration of an element in a fish fillet and the concentration of this element in its diet. The BMF was calculated by the following equation (Kelly et al. 2008):

$$\text{BMF} = C_{\text{fish}}/C_{\text{diet}}$$

where C_{fish} is a heavy metal concentration in fish edible tissues and C_{diet} is a metal concentration in used in fish feeding.

Results and discussion

The mean $\pm$ SE contents of elements concentration (mg kg^{-1}) of edible tissues of cultured fish in the Black Sea (Turkish salmon, turbot, sea bass, and sea bream) and these fish diets (D1: Turkish salmon diet, D2: turbot diet, and D3: Sea bass and bream diet) are presented in Table 2. According to the research, the most abundant essential elements in all three diets were P, Ca, K, Na, and Mg, respectively. The value of Ni, a non-essential element, was in the D1 diet at most. Heavy metal Pb and Hg concentrations in diets were $D3 > D2 > D1$ and $D3 = D2 > D1$ correspondingly. The presence of Ni, Hg, and Pb concentrations

determined in diets is thought to be caused by the ingredients (fish meal and oil, soybean meal etc.) used in feed production. Adeniji and Okedeyi (2017) reported that the elemental concentrations of diet components directly affect the fish diets and indirectly the fish element concentrations. For this reason, it is important that the ingredients used by fish feed manufacturers are regularly monitored and evaluated by local, national, or international authorities in terms of element concentrations, especially for heavy metal contents.

Fish have the ability to absorb some ions from the water they are in, not from the feed as terrestrial animals. Therefore, ion exchange through the gill and skin makes it extremely difficult to determine the mineral needs of fish. Common dietary element requirements are Ca, Na, Cl, K, S, P, Fe, Cu, Cr, I, Mn, Mg, Zn, and Se for fish species (NRC 2011). These elements regulate osmotic balance and aid in bone

Table 2 Elemental values of diets and cultured fish of the Black Sea

Elements	Turkish salmon	D1	Turbot	D2	Sea bream	Sea bass	D3
Essential (mg/kg)							
Sodium (Na)	452.45 $\pm$ 2.9	3594.82 $\pm$ 20.8	1268.09 $\pm$ 8.3	3644.32 $\pm$ 28.5	420.92 $\pm$ 4.1	645.01 $\pm$ 6.71	6420.30 $\pm$ 51.6
Magnesium (Mg)	321.11 $\pm$ 2.0	2763.77 $\pm$ 18.9	217.67 $\pm$ 1.1	2548.13 $\pm$ 24.0	344.98 $\pm$ 2.4	392.84 $\pm$ 6.2	2497.94 $\pm$ 17.1
Phosphorus (P)	2695.98 $\pm$ 19.1	13,866.31 $\pm$ 101.61	1830.78 $\pm$ 8.4	12,149.77 $\pm$ 93.5	3017.31 $\pm$ 20.9	3056.50 $\pm$ 36.7	19,999.67 $\pm$ 142.3
Potassium (K)	5654.37 $\pm$ 23.2	9971.97 $\pm$ 54.0	4263.56 $\pm$ 18.6	14,930.61 $\pm$ 101.2	6520.64 $\pm$ 49.7	7184.52 $\pm$ 65.8	13,761.59 $\pm$ 80.3
Calcium (Ca)	93.02 $\pm$ 0.6	14,467.12 $\pm$ 66.8	81.80 $\pm$ 1.2	13,600.31 $\pm$ 84.9	137.98 $\pm$ 0.7	106.15 $\pm$ 1.3	28,059.70 $\pm$ 165.0
Manganese (Mn)	0.16 $\pm$ 0.01	50.21 $\pm$ 0.50	0.39 $\pm$ 0.01	100.45 $\pm$ 0.38	0.13 $\pm$ 0.01	0.18 $\pm$ 0.01	70.93 $\pm$ 0.23
Iron (Fe)	6.25 $\pm$ 0.02	575.51 $\pm$ 1.94	5.27 $\pm$ 0.02	423.12 $\pm$ 1.69	6.80 $\pm$ 0.03	6.43 $\pm$ 0.06	693.15 $\pm$ 1.35
Zinc (Zn)	5.80 $\pm$ 0.02	171.16 $\pm$ 0.61	11.78 $\pm$ 0.02	368.18 $\pm$ 0.40	6.49 $\pm$ 0.06	6.06 $\pm$ 0.03	215.62 $\pm$ 0.55
Copper (Cu)	0.74 $\pm$ 0.01	15.41 $\pm$ 0.04	0.32 $\pm$ 0.01	27.73 $\pm$ 0.12	0.74 $\pm$ 0.01	0.68 $\pm$ 0.01	9.77 $\pm$ 0.02
Non-essential (mg/kg)							
As	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cadmium (Cd)	BDL	0.26 $\pm$ 0.01	BDL	0.01 $\pm$ 0.01	BDL	BDL	0.26 $\pm$ 0.01
Nickel (Ni)	0.02 $\pm$ 0.01	3.79 $\pm$ 0.01	0.24 $\pm$ 0.01	2.04 $\pm$ 0.02	0.23 $\pm$ 0.01	0.22 $\pm$ 0.01	2.29 $\pm$ 0.01
Other (mg/kg)							
Aluminium (Al)	1.07 $\pm$ 0.02	105.14 $\pm$ 0.14	1.76 $\pm$ 0.03	478.86 $\pm$ 0.71	1.38 $\pm$ 0.04	5.83 $\pm$ 0.05	414.44 $\pm$ 2.23
Chrome (Cr)	0.07 $\pm$ 0.01	3.10 $\pm$ 0.01	0.42 $\pm$ 0.01	0.87 $\pm$ 0.01	0.09 $\pm$ 0.01	0.11 $\pm$ 0.01	2.56 $\pm$ 0.02
Selenium (Se)	0.21 $\pm$ 0.01	1.13 $\pm$ 0.05	0.25 $\pm$ 0.01	2.16 $\pm$ 0.01	0.26 $\pm$ 0.02	0.22 $\pm$ 0.01	1.63 $\pm$ 0.06
Mercury (Hg)	0.06 $\pm$ 0.01	0.07 $\pm$ 0.01	0.11 $\pm$ 0.01	0.09 $\pm$ 0.01	0.12 $\pm$ 0.01	0.19 $\pm$ 0.01	0.09 $\pm$ 0.01
Lead (Pb)	BDL	0.10 $\pm$ 0.10	0.01 $\pm$ 0.01	0.19 $\pm$ 0.01	BDL	0.02 $\pm$ 0.01	0.23 $\pm$ 0.01

BDL below detection limit, D1 large rainbow trout diets, D2 turbot diets, D3 sea bass and sea bream diets

formation, integrity and are required in small amounts as components in enzyme and hormone systems. Antony Jesu Prabhu et al. (2016) reported that the factors that may affect the minimal dietary levels of mineral and trace elements to fish can be one or a combination as biological factors (species, life stage, sex, trophic level, feeding habits, and the nutritional status of the fish), dietary factors (diet composition, availability, and nutrient interactions), and environmental factors (water mineral concentration, salinity, and temperature of the rearing system). The element values of diets determined in the study were similar to the literature and were at a level to meet the needs of the fish (Maage and Julshamn 1993; Watanabe et al. 1997; Liang et al. 2012; Chanda et al. 2015; Antony Jesu Prabhu et al. 2016; Amin 2018).

Although they were fed with the same feed, Mg, P, and K elements were determined at high values in sea bass, Ca, Fe and Cu elements in sea bream. In the study, Na, Mn, and Zn values of turbot were found to be higher than other species. Ni values of Turkish salmon was less than other species and As and Cd elements in all fish fillets were found below the detection limit. While the Pb value was below the detection limit in Turkish salmon and sea bream, it was 0.01 ± 0.01 and 0.02 ± 0.01 mg kg⁻¹ in turbot and sea bass, respectively. The Hg values of turbot, sea bream and bass were higher than the diets (D2 and D3) used. In the study, Na, Mn, and Zn values of turbot were found to be higher than other species.

The Ni values of Turkish salmon were less than other species and As and Cd elements in all fish fillets were found below the detection limit. Current European Commission Regulation (2006) and Turkish Food Codex (2008) allowed the maximum Hg, Cd, and Pb limits in the edible tissues of fish as 0.5, 0.05, and 0.3 mg kg⁻¹, respectively. European Commission Regulation (2006) has no legislation for essential metals, but Turkish Food Codex (2008) states the maximum permitted limits of Cu and Zn as 20 and 50 mg kg⁻¹, respectively. In the present study, none of the metals in all edible tissues of cultured fish were above the permissible values.

The evaluations regarding selenium and mercury are shown in Table 3. The mean Hg and Se

concentrations of the all samples species ranged from 0.06 ± 0.01 to 0.19 ± 0.01 µg g⁻¹ and from 0.21 ± 0.01 to 0.26 ± 0.01 µg g⁻¹, respectively. The Se contents of cultured fish included in this study were in molar excess of the Hg that was also present.

The calculated mean Hg/Se and Se/Hg molar ratios were ranked from low to high Turkish salmon, turbot, sea bream, and sea bass. The calculated Se-HBV values were positive in fish culture in the Black Sea, the highest value was in Turkish salmon, and the lowest value was in sea bass. While the tolerable daily intake level for Selenium has been reported between 0.40 and 0.80 mg day⁻¹ in different sources (Yang and Zhou 1994; Johnson et al. 2003), the maximum individual safe Se intake level has been reported as 0.60 mg day⁻¹. The amount of Se in cultured fish in the current study is in accordance with previous literature. These results corroborate that cultured fish such as wild species tend to be rich dietary sources of Se.

The molar ratios of Se to Hg were favorable, indicating substantial Se was available to counter the Hg that was also present in almost culture fish. Se: Hg molar ratio and Se-HBV findings were taken into account in this study to highlight the dangers of Hg exposure in terms of consumer health. If the Se/Hg molar ratio is > 1 and the Se-HBV result is positive, is reported that Se and Hg in the studied fish have a protective effect on human health (Squadrone et al. 2015; Ralston et al. 2019).

The Se/Hg ratio determined in the edible tissues of the studied fish was higher than 1 and the calculated Se-HBV values were positive in the current study. As a result of this study it was concluded that the cultured fish of the Black Sea, especially Se, have a protective effect against the effects of Hg on human health.

The estimated daily intake (EDI), target hazard quotient (THQ) and maximum allowable consumption rate CR_{lim} and CR_{mm} values of selected element in culture fish of Black Sea are given Table 4. Cultured fish species, as wild fish species, are excellent food sources for human health in terms of rich fatty acids, amino acids, minerals, and vitamin contents (Baki et al. 2015, 2017; Kaya Öztürk et al. 2019b, 2020). Aquatic species with limited mobility have been shown to be negatively affected by increasing population and industrial pollution (Hwang et al. 2017).

Table 3 Mass and molar concentrations and molar ratios of mercury and selenium of cultured fish in the Black Sea

Fish species	Hg content		Se content		Molar ratios		Free Se (Se–Hg) µmol/kg	Se-HBV (calculated)
	µg/g	µmol /kg	µg/g	µmol /kg	Se/Hg	Hg/Se		
Sea bream	0.12 ± 0.01	0.60 ± 0.01	0.26 ± 0.02	3.27 ± 0.24	5.44	0.11	2.67	1.37 ± 0.21
Sea bass	0.19 ± 0.01	0.93 ± 0.01	0.22 ± 0.01	2.73 ± 0.15	2.92	0.32	1.80	0.47 ± 0.06
Turkish salmon	0.06 ± 0.01	0.30 ± 0.01	0.21 ± 0.01	2.62 ± 0.07	8.65	0.04	2.32	1.77 ± 0.07
Turbot	0.11 ± 0.01	0.56 ± 0.01	0.25 ± 0.01	3.16 ± 0.07	5.64	0.10	2.60	1.36 ± 0.06

Table 4 The estimated daily intake (EDI), target hazard quotient (THQ), and maximum allowable consumption rate CR_{lim} and CR_{mm} values of selected element in culture fish of Black Sea

Fish Species	Elements	EDI		THQ		CR_{lim} (kg person ⁻¹ day ⁻¹)		CR_{mm} (meals /month)	
		Children	Adults	Children	Adults	Children	Adults	Children	Adults
Turkish salmon	Zn	0.0063	0.0014	0.0209	0.0048	0.8276	3.6207	524.83	485.52
	Cu	0.0008	0.0002	0.0200	0.0046	0.8649	3.7838	548.47	507.39
	Hg	0.0001	<0.0001	0.2158	0.0493	0.0800	0.3500	50.73	46.93
	Al	0.0012	0.0003	0.0012	0.0003	14.9533	65.4206	9482.87	8772.70
	Fe	0.0067	0.0015	0.0096	0.0022	1.7920	7.8400	1136.43	1051.32
	Mn	0.0006	0.0001	0.0046	0.0011	3.7333	16.3333	2367.56	2190.25
	Se	0.0002	0.0001	0.0453	0.0104	0.3810	1.6667	241.59	223.49
Turbot	Zn	0.0127	0.0029	0.0424	0.0097	0.4075	1.7827	258.40	239.05
	Cu	0.0003	0.0001	0.0086	0.0020	2.0000	8.7500	1268.33	1173.35
	Pb	<0.0001	<0.0001	0.0031	0.0007	5.6000	24.5000	3551.33	3285.37
	Hg	0.0001	<0.0001	0.3955	0.0904	0.0436	0.1909	27.67	25.60
	Al	0.0019	0.0004	0.0019	0.0004	9.0909	39.7727	5765.15	5333.40
	Fe	0.0057	0.0013	0.0081	0.0019	2.1252	9.2979	1347.75	1246.82
	Mn	0.0004	0.0001	0.0030	0.0007	5.7436	25.1282	3642.39	3369.61
Sea bream	Se	0.0003	0.0001	0.0539	0.0123	0.3200	1.4000	202.93	187.74
	Zn	0.0070	0.0016	0.0233	0.0053	0.7396	3.2357	469.03	433.90
	Cu	0.0008	0.0002	0.020	0.0046	0.8649	3.7838	548.47	507.39
	Hg	0.0001	<0.0001	0.4315	0.098	0.0400	0.1750	25.37	23.47
	Al	0.0015	0.0003	0.0015	0.0003	11.5942	50.7246	7352.66	6802.02
	Fe	0.0073	0.0017	0.0105	0.0024	1.6471	7.2059	1044.51	966.29
	Mn	0.0001	<0.0001	0.0010	0.0002	17.2308	75.3846	10,927.18	10,108.84
Sea bass	Se	0.0003	0.0001	0.0561	0.0128	0.3077	1.3462	195.13	180.52
	Zn	0.0065	0.0015	0.0218	0.0050	0.7921	3.4653	502.31	464.69
	Cu	0.0007	0.0002	0.018	0.0042	0.9412	4.1176	596.86	552.16
	Pb	<0.0001	<0.0001	0.0062	0.0014	2.8000	12.2500	1775.67	1642.69
	Hg	0.0002	<0.0001	0.6832	0.1562	0.0253	0.1105	16.02	14.82
	Al	0.0063	0.0014	0.0063	0.0014	2.7444	12.0069	1740.42	1610.08
	Fe	0.0069	0.0016	0.0099	0.0023	1.7418	7.6205	1104.61	1021.89
	Mn	0.0002	<0.0001	0.0014	0.0003	12.4444	54.4444	7891.85	7300.83
	Se	0.0002	0.0001	0.0475	0.0108	0.3636	1.5909	230.61	213.34

Aquaculture is done in fixed locations, so farmed fish cannot flee their habitat when exposed to possible contamination. As a result, certain globally valid coefficients should be established, especially for farmed fish, in order to determine the critical level of the components in the risk group in terms of human health and to create safe food standards (Anonymous 2021b). Reference doses (RfD) of foods used daily have been determined by some international health organizations (EFSA 2010; US EPA 2013).

When the EDI values were evaluated, the levels of Al, Cu, Fe, Hg, and Mn in both adult and child groups were below the RfD standard. THQ is recognized as one of the appropriate metrics for assessing the danger of components in contaminated seafood intake (Bogdanović et al. 2014; Bayraklı 2021) Copat et al. (2012) reported that

THQ values below 1 indicate that even for more sensitive groups consumption of these species/size classes represents no danger in terms of health effects but in contrast, values above 1 indicate a high probability of long term health effects. In the study, THQ values of all fish groups were determined below 1 for both children and adults. Total $\sum$ THQ values of Turkish salmon, turbot, sea bass, and bream were between 0.32–0.07, 0.52–0.12, 0.54–0.12, and 0.80–0.18 for children and adults, respectively. In the current study, these indices (EDI, THQ) values were thoroughly found less than 1 for cultured fish in the Black Sea, which confirmed that these fish are safe to consume and show no potential risk for human. In different studies with cultured fish, THQ and $\sum$ THQ values were less than 1 (Marengo et al. 2018; Varol et al. 2018; Renieri et al.

Table 5 Biomagnification factor (BMF) of selected elements in edible tissues of cultured fish in the Black Sea

Elements	Biomagnification factor (BMF)			
	Turkish salmon	Turbot	Sea bream	Sea bass
Na	0.13	0.35	0.07	0.10
Mg	0.01	0.09	0.14	0.16
P	0.19	0.15	0.15	0.15
K	0.57	0.29	0.47	0.52
Ca	0.01	0.01	0.01	0.01
Mn	0.01	0.01	0.01	0.01
Fe	0.01	0.01	0.01	0.01
Zn	0.03	0.03	0.03	0.03
Cu	0.05	0.01	0.08	0.07
Al	0.01	0.01	0.01	0.01
Cr	0.02	0.48	0.04	0.27
Se	0.19	0.12	0.16	0.13
Hg	0.86	1.22	1.33	2.11
Pb	–	0.05	–	0.09
Ni	0.01	0.12	0.10	0.10

2019; Alkan et al. 2021; Bat et al. 2021) and the current study was similar to the literature.

The maximum allowable consumption rate (CR_{lim}) rate by the person, to estimate the human health risk, was calculated on basis of an average 0.227 kg for adults and 0.114 kg for children of edible tissue consumption per day (US EPA 2008).

For non-carcinogen effects, the maximum allowable daily consumption limits (CR_{lim}) of cultured fish in the Black Sea for selected elements were calculated and found to be quite high enough to ensure human health (Table 5).

For children and adults, the highest CR_{lim} values were in Al element for turbot and Turkish salmon, and Mn element for sea bream and sea bass. In addition, monthly consumption limits (CR_{mm}) were calculated to determine how many meals of cultured fish in the Black Sea can safely be eaten per month with no adverse non-carcinogenic health effects. CR_{mm} values of Turkish salmon, turbot, sea bass, and bream were 50.73, 27.67, 25.37, and 16.02 meals/month, respectively, for children, 46.93, 25.60, 23.47, and 14.82 meals/month respectively for adults. According to US EPA (2000), this is categorized as safe fish consumption (represented by > 16 meals/month). When evaluated according to the US EPA, the CR_{mm} value of the cultured fish in the Black Sea was only in sea bass for adults and at the limit for Hg element.

The element concentrations in commercial diet samples were typically greater than those in farmed fish suggests that biomagnification potential is low (Table 2 and Table 5).

Except for Hg, all elements had BMFs of less than one. The BMF of Hg was found to be less than one for

Table 6 Meeting the daily recommended allowances for selected elements by a 100 g portion of cultured fish of the Black Sea

Element	Study Results (mg kg ⁻¹)				RDA/EU (mg day ⁻¹)		Meeting the norm (%)		RDA/TR (mg day ⁻¹)		Meeting the norm (%)		Sea bass	
	Turkish salmon	Turbot	Sea bream	Sea bass			Turkish salmon	Turbot	Sea bream	Sea bass	Turkish salmon	Turbot	Sea bream	Sea bass
Mg	321.11	217.67	344.98	392.84	–	–	–	–	–	–	13.37	9.07	14.37	16.59
P	2695.98	1830.78	3017.31	3056.50	700	38	26	43	43	43	38.51	26.15	43.10	43.67
K	5654.37	4263.56	6520.64	7184.52	2000	28.2	21	32	35	35	–	–	–	–
Ca	93.02	81.80	137.98	106.15	800	1.16	1.02	1.71	1.32	1.32	0.93	0.82	1.38	1.06
Mn	0.16	0.39	0.13	0.18	2	0.80	1.95	0.65	0.90	0.90	–	–	–	–
Fe	6.25	5.27	6.80	6.43	14	4.42	3.76	4.85	4.59	4.59	6.25	5.27	6.80	6.43
Zn	5.80	11.78	6.49	6.06	10	5.80	11.78	6.49	6.06	6.06	5.80	11.78	6.49	6.06
Cu	0.74	0.32	0.74	0.68	1	7.4	3.2	7.4	6.8	6.8	10.57	4.57	10.57	9.71
Se	0.21	0.25	0.26	0.22	0.055	38.25	45.45	47.27	40.00	40.00	52.50	62.50	65.00	55.00

¹RDA Commission Directive 2008/100/EC of 28 October 2008

²RDA Republic of Turkey Ministry of Health General Directorate of Primary Health Care Food Safety Department Community Nutrition Division (2006)

Turkish salmon, between 1 and 1.33 for turbot and sea bream, and above 2 for sea bass. Kelly et al. (2008) determined the BMF value of cultured Atlantic (*Salmo salar*), coho (*Oncorhynchus kisutch*), and chinook (*Oncorhynchus tshawytscha*) salmon to be higher than 1 in Hg only. In terms of essential elements, BMF values of all cultured fish of the Black Sea were to be less than one. Except for Hg, none of the elements were biomagnified by cultivated fish in the Black Sea, according to BMF values.

The World Health Organization's daily nutritional requirements for adults are compared to the values found in this study in Table 6. While according to RDA/EU (2006), consuming 100 g of the Black Sea cultured fish, regardless of species, meets a minimum daily requirement of 40% Se, 21% K, and 26% P; according to RDA/TR (2006), it was calculated that consuming 100 g of cultured fish of the Black Sea meets the daily requirement of a minimum of 52.50% Se, 26.15% P, 9% Mg, 5.27% Fe, and 4.57% Cu. The levels of Zn, Se, K, and Na determined in this study are equal to the amounts that individuals should consume on a daily basis, according to The National Institutes of Health (2021). Larsen et al. (2011) found that fatty fish had greater Se, Zn, Mg, and Ca levels than terrestrial animals.

Conclusion

At the end of the study, the health risk assessment using EDI and THQ showed no health concern associated with the intake of the studied elements via the consumption of cultured fish in the Black Sea. As this result is compatible with the literature, it was concluded that the cultured fish of the Black Sea, especially Se, have a protective effect against the effects of Hg on human health. When compared with the data of the World Health Organization (2005) and The National Institutes of Health (2021), it determined that consuming 100 g of cultured fish in the Black Sea adequately meets the daily elemental requirement.

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Data availability All data generated or analyzed during this study are included in this published article

Declarations

Ethics approval and consent to participate The fish were sampled by the operating personnel while they were harvested, therefore this manuscript does not need an ethical approval. Not applicable.

Consent to publish The author agrees to the study.

Competing interest The author declares no competing interests.

References

- Adeniji CA, Okedeyi OO (2017) Preliminary assessment of heavy metal concentrations in selected fish feed ingredients in Nigeria. *J Fisheries Livest Prod* 5:218. <https://doi.org/10.4172/2332-2608.1000218>
- Alkan N, Alkan A, Polat H (2021) A preliminary assessment of metal/metalloid levels in wild and farmed turbot (*Scophthalmus maximus*) and risks imposed on human health. *Aquac Res*. <https://doi.org/10.1111/are.15068>
- Amin MN (2018) Dietary Requirement of trace elements in fish. A Seminar Paper. (Doctoral dissertation) Bangabandhu Sheikh Mujibur Rahman Agricultural University Salna, Gazipur-1706
- Anonymous (2021a) Republic of Turkey Ministry of Agriculture and Forestry, General Directorate of Fisheries and Aquaculture, Fisheries Statistic <https://www.tarimorman.gov.tr/BSGM/Belgeler/Icerikler/Su%20%C3%9Cr%C3%BCnleri%20Veri%20ve%20D%C3%B6k%C3%BCmanlar%C4%B1/Su-%C3%9Cr%C3%BCnleri-%C4%B0statistikleri.pdf> (accepted date: 07.07.2021a)
- Anonymous (2021b) The risk assessment information system https://rais.ornl.gov/guidance/epa_hh.html (accepted date: 07.07.2021b)
- Anonymous (2021c) Republic of Turkey Ministry of Agriculture and Forestry, Agricultural Economic and Policy Development Institute <https://arastirma.tarimorman.gov.tr/tepge/Belgeler/PDF%20Tar%C4%B1m%20%C3%9Cr%C3%BCnleri%20Piyasalar%C4%B1/2021c-Ocak%20Tar%C4%B1m%20%C3%9Cr%C3%BCnleri%20Raporu/Su%20%C3%9Cr%C3%BCnleri,%20Ocak-2021,%20Tar%C4%B1m%20%C3%9Cr%C3%BCnleri%20Piyasa.pdf> (accepted date: 20.07.2021)
- Anonymous (2021d) United States Environmental Protection Agency <https://semspub.epa.gov/work/HQ/400784.pdf> (accepted date: 30.07.2021d)
- Antony Jesu Prabhu P, Schrama JW, Kaushik SJ (2016) Mineral requirements of fish: a systematic review. *Rev Aquacult*. <https://doi.org/10.1111/raq.12090>
- Baki B, Gonener S, Kaya D (2015) Comparison of food, amino acid and fatty acid compositions of wild and cultivated sea bass (*Dicentrarchus labrax* L. 1758). *Turk J Fish Aquat Sci* 15(1):175–179. https://doi.org/10.4194/1303-2712-v15_1_19
- Baki B, Kaya Öztürk D, Kerim M (2017) Determination of essential amino acid changes related to the growth of sea bass (*Dicentrarchus labrax*). *Turk J Fish Aquat Sc*. https://doi.org/10.4194/1303-2712-v17_6_36
- Bat L, Arıcı E, Öztekin A, Şahin F (2021) Farmed Turkish Salmon: toxic metals and health threat. *Foods Raw Mater*. <https://doi.org/10.21603/2308-4057-2021-2-317-323>
- Bat L, Şahin F, Bhuyan MS, Arıcı E, Öztekin A (2022) Metals in wild and cultured *Dicentrarchus labrax* (Linnaeus, 1758) from fish markets in Sinop: consumer's health risk assessment. *Biol Trace Elem Res*. <https://doi.org/10.1007/s12011-021-03064-8>
- Bayraklı B (2021) Concentration and potential health risks of trace metals in warty crab (*Eriphia verrucosa* Forskal, 1775) from

- Southern Coasts of the Black Sea, Turkey. *Environ Sci Pollut Res*. <https://doi.org/10.1007/s11356-020-11563-9>
- Bogdanović T, Ujević I, Sedak M, Listić E, Šimat V, Petričević S, Poljak V (2014) As, Cd, Hg and Pb in four edible shellfish species from breeding and harvesting areas along the eastern Adriatic Coast, Croatia. *Food Chem*. <https://doi.org/10.1016/j.foodchem.2013.09.045>
- Chanda S, Paul BN, Ghosh K, Giri SS (2015) Dietary essentiality of trace minerals in aquaculture—a review. *Agric Rev*. <https://doi.org/10.5958/0976-0741.2015.00012.4>
- Chen J, Berry MJ (2003) Selenium and selenoproteins in the brain and brain diseases. *J Neurochem*. <https://doi.org/10.1046/j.1471-4159.2003.01854.x>
- Connor WE (2000) Importance of n-3 fatty acids in health and disease. *Am J Clin Nutr*. <https://doi.org/10.1093/ajcn/71.1.171S>
- Copat C, Maggiore R, Arena G, Lanzafame S, Fallico R, Sciacca S, Ferrante M (2012) Evaluation of a temporal trend heavy metals contamination in *Posidonia oceanica* (L.) Delile, (1813) along the western coastline of Sicily (Italy). *J Environ Monit*. <https://doi.org/10.1039/C1EM10575B>
- Dietary Guidelines For Turkey (2006) <https://www.fao.org/3/as697e/as697e.pdf> (Date of Access: 07.12.2021)
- Erdem ME, Baki B, Samsun S (2009) Fatty acid and amino acid compositions of cultured and wild sea bass (*Dicentrarchus labrax*, L., 1758) from different regions in Turkey. *J Anim Vet Adv* 8(10):1959–1963
- European Commission Regulation (2006) Commission Regulation (EC) No 1881/2006. Setting maximum levels for certain contaminants in foodstuffs. Official Journal of the European Union 364:5–24
- European Food Safety Authority (EFSA) (2010) Scientific opinion on lead in food. *EFSA J* 8(4):1570
- Hites RA, Foran JA, Carpenter DO, Hamilton MC, Knuth BA, Schwager SJ (2004) Global assessment of organic contaminants in farmed salmon. *Science*. <https://doi.org/10.1126/science.1091447>
- Hwang DW, Choi M, Lee IS, Shim KB, Kim TH (2017) Concentrations of trace metals in tissues of *Chionoecetes* crabs (*Chionoecetes japonicus* and *Chionoecetes opilio*) caught from the East/Japan Sea waters and potential risk assessment. *Environ Sci Pollut Res*. <https://doi.org/10.1007/s11356-017-8769-z>
- Johnson LJ, Meacham SL, Kruskall LJ (2003) The antioxidants-vitamin C, vitamin E, selenium, and carotenoids. *J Agromedicine*. https://doi.org/10.1300/J096v09n01_07
- Kaneko JJ, Ralston NVC (2007) Selenium and mercury in pelagic fish in the central north Pacific near Hawaii. *Biol Trace Elem Res*. <https://doi.org/10.1007/s12011-007-8004-8>
- Kaya Öztürk D, Baki B, Karayücel İ, Öztürk R, Gören GU, Karayücel S (2019a) Determination of seasonal vitamin and mineral contents of sea bream (*Sparus aurata* L., 1758) cultured in net cages in central Black Sea region. *Biol Trace Elem Res*. <https://doi.org/10.1007/s12011-018-1382-2>
- Kaya Öztürk D, Baki B, Öztürk R, Karayücel S, Uzun Gören G (2019b) Determination of growth performance, meat quality and colour attributes of large rainbow trout (*Oncorhynchus mykiss*) in the southern Black Sea coasts of Turkey. *Aquac Res*. <https://doi.org/10.1111/are.14339>
- Kaya Öztürk D, Öztürk R, Baki B, Karayücel İ, Karayücel S (2020) Monthly variation of growth, biochemical composition, fatty and amino acids patterns of gilthead sea bream (*Sparus aurata*) in off-shore cage systems under brackish water conditions in the Black Sea. *Aquac Res*. <https://doi.org/10.1111/are.14833>
- Kelly BC, Ikonomou MG, Higgs DA, Oakes J, Dubetz C (2008) Mercury and other trace elements in farmed and wild salmon from British Columbia, Canada. *Environ Toxicol Chem*. <https://doi.org/10.1897/07-527>
- Lall S, Milley J (2008) Trace mineral requirements of fish and crustaceans. In: Schlegel P, Durosay S, Jongbloed AW (eds) Trace elements in animal production systems. Wageningen, Academic Press, pp 203–214
- Larsen R, Eilertsen KE, Elvevoll EO (2011) Health benefits of marine foods and ingredients. *Biotechnol Adv*. <https://doi.org/10.1016/j.biotechadv.2011.05.017>
- Liang JJ, Yang HJ, Liu YJ, Tian LX, Liang GY (2012) Dietary zinc requirement of juvenile grass carp (*Ctenopharyngodon idella*) based on growth and mineralization. *Aquacult Nutr*. <https://doi.org/10.1111/j.1365-2095.2011.00935.x>
- Maage A, Julshamn K (1993) Assessment of zinc status in juvenile Atlantic salmon (*Salmo salar*) by measurement of whole body and tissue levels of zinc. *Aquaculture*. [https://doi.org/10.1016/0044-8486\(93\)90134-K](https://doi.org/10.1016/0044-8486(93)90134-K)
- Marengo M, Durieux ED, Ternengo S, Lejeune P, Degrange E, Pasqualini V, Gobert S (2018) Comparison of elemental composition in two wild and cultured marine fish and potential risks to human health. *Ecotox Environ Safe*. <https://doi.org/10.1016/j.ecoenv.2018.04.034>
- Mol S, Özden Ö, Oymak SA (2010) Trace metal contents in fish species from Atatürk Dam Lake (Euphrates, Turkey). *Turk J Fish Aquat Sci*. <https://doi.org/10.4194/trjfas.2010.0208>
- Mozaffarian D, Rimm EB (2006) Fish intake, contaminants, and human health; evaluating the risks and benefits. *J Am Med Assoc*. <https://doi.org/10.1001/jama.296.15.1885>
- Naganuma A, Imura N (1980) Bis(methylmercuric) selenide as a reaction product from methyl-mercury and selenite in rabbit blood. *Res Commun Chem Pathol Pharmacol* 27:163–173
- National Research Council (NRC) (2011) Nutrient requirements of fish and shrimp. Animal Nutrition Series, National Research Council of the National Academies, 376. Washington, D.C.
- Official Gazette (2011) Turkish food codex contains regulation, Official Gazette Number: 28157 (3rd reiterated) (in Turkish)
- Onsanit S, Ke C, Wang X, Wang KJ, Wang WX (2010) Trace elements in two marine fish cultured in fish cages in Fujian province China. *Environ Pollut*. <https://doi.org/10.1016/j.envpol.2010.01.012>
- Pařízek J, Oštádalová I (1967) The protective effect of small amounts of selenite in sublimate intoxication. *Experientia* 23:142–143
- Ralston NVC (2008) Selenium health benefit values as seafood safety criteria. *EcoHealth*. <https://doi.org/10.1007/s10393-008-0202-0>
- Ralston NVC, Raymond LJ (2010) Dietary selenium's protective effects against methylmercury toxicity. *J Toxicol*. <https://doi.org/10.1016/j.tox.2010.06.004>
- Ralston NVC, Ralston CR, Raymond LJ (2016) Selenium health benefit values: updated criteria for mercury risk assessments. *Biol Trace Elem Res*. <https://doi.org/10.1007/s12011-015-0516-z>
- Ralston NV, Kaneko JJ, Raymond LJ (2019) Selenium health benefit values provide a reliable index of seafood benefits vs. risks. *J Trace Elem Med Biol*. <https://doi.org/10.1016/j.jtemb.2019.05.009>
- Renieri EA, Safenkova IV, Alegakis AK et al (2019) Cadmium, lead and mercury in muscle tissue of gilthead seabream and seabass: risk evaluation for consumers. *Food Chem Toxicol*. <https://doi.org/10.1016/j.fct.2018.12.020>
- Schweizer U, Bräuer AU, Josef Köhrle J, Nitsch R, Savaskan NE (2004) Selenium and brain function: a poorly recognized liaison. *Brain Res Rev*. <https://doi.org/10.1016/j.brainresrev.2004.03.004>
- Sidhu KS (2003) Health benefits and potential risks related to consumption of fish or fish oil. *Regul Toxicol Pharmacol*. <https://doi.org/10.1016/j.yrtph.2003.07.002>
- Squadrone S, Benedetto A, Brizio P, Prearo M, Abete MC (2015) Mercury and selenium in European catfish (*Silurus glanis*) from Northern Italian Rivers: can molar ratio be a predictive factor for mercury toxicity in a top predator? *Chemosphere*. <https://doi.org/10.1016/j.chemosphere.2014.05.052>

- Stankovic S, Kalaba P, Stankovic AR (2014) Biota as toxic metal indicators. *Environ Chem Lett*. <https://doi.org/10.1007/s10311-013-0430-6>
- The National Institutes of Health (2021) (Date of access: 10.11.2021) https://ods.od.nih.gov/Health_Information/Dietary_Reference_Intakes.aspx
- Turkish Food Codex (2008): Communiqué on maximum limits of contaminants in foodstuffs. Official Gazette. 2008; (26879). (In Turkish).
- Ulusoy Ş, Mol S, Karakulak FS, Kahraman AE (2019) Selenium-mercury balance in commercial fish species from the Turkish waters. *Biol Trace Elem Res*. <https://doi.org/10.1007/s12011-018-1609-2>
- United States Environmental Protection Agency (US EPA) (2008) Child-Specific Exposure Factors Handbook (Final Report). EPA/600/R-06/096F. National Center for Environmental Assessment Office of Research and Development, Washington, DC
- US EPA (US Environmental Protection Agency) (2000) Guidance for assessing chemical contaminant data for use in fish advisories, Volume II risk assessment and fish consumption limits. EPA 823-B-00-008. United States Environmental Protection Agency, Washington, DC
- US EPA (United States Environmental Protection Agency) (2013) Regional screening level (RSL) fish ingestion table November 2013
- Varol M, Kaya GK, Alp SA, Sünbül MR (2018) Trace metal levels in rainbow trout (*Oncorhynchus mykiss*) cultured in net cages in a reservoir and evaluation of human health risks from consumption. *Biol Trace Elem Res*. <https://doi.org/10.1007/s12011-017-1156-2>
- Watanabe T, Kiron V, Satoh S (1997) Trace minerals in fish nutrition. *Aquaculture* 151(1–4):185–207
- World Health Organization (2005) Vitamin and mineral requirements in human nutrition, 2nd ed. World Health Organization. <https://apps.who.int/iris/handle/10665/42716>
- Yang G, Zhou R (1994) Further observations on the human maximum safe dietary selenium intake in a seleniferous area of China. *J Trace Elem Electrolytes Health Dis* 8(3–4):159–165
- Yu Y, Zhang D, Zhang X (2012) Correct equations for calculating the maximum allowable fish consumption rate for human health risk assessment considering the noncarcinogenic effects of multiple contaminants in fish. *Environ Sci Technol*. <https://doi.org/10.1021/es3033082>
- Yu Y, Wang X, Yang D, Lei B, Zhang X, Zhang X (2014) Evaluation of human health risks posed by carcinogenic and noncarcinogenic multiple contaminants associated with consumption of fish from Taihu Lake, China. *Food Chem Toxicol*. <https://doi.org/10.1016/j.fct.2014.04.001>

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