



Heavy Metals Contamination of Canned Fish and Related Health Implications in Iran

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Abstract

Samples of some popular brands of canned *Thunnus albacares*; *Clupeonella cultriventris caspia*; *Euthynnus affinis*; and *Thunnus tonggol* in the Iranian market were analyzed for determination of Cr, Cu, Fe, Mn and Ni after digestion with 10 ml of 1 N nitric acid by inductively coupled plasma–optical emission spectrometer. The results showed that the concentrations of metals ($\mu\text{g/g}$ wet weight) with an average of 2.66 for Cr, 0.92 for Cu, 54.68 for Fe, 0.33 for Mn and 0.22 for Ni were lower than the Maximum Permissible Limits (MPL) established by WHO. Also, The Health Risk Index (HRI) values were within the safe limits (<1), and there is no potential health risk for adults and children via consumption of canned fish. Despite the fact that our canned fish samples does not significantly contribute to total body burden of analyzed metals, But due to the increased discharge of pollutants into the environment, especially the marine ecosystem, and consider that various species of fish retain substantial amounts of heavy metals during their lifespan, the monitoring of heavy metals concentrations in food is important. Therefore, the study of heavy metal distribution on a temporal basis is recommended.

Keywords: Canned fish, health risk index, heavy metals, food safety.

Introduction

Aquatic environment makes up the major part of our resources and environment, hence, its safety is directly related to human health. Excessive contamination of these ecosystems has raised major environmental and health concerns worldwide (Omar, Zaghoul, Abdel-Khalek & Abo-Hegab, 2013).

Many elements that are present in seafood are essential for human life at low concentrations (Sobhanardakani, Tayebi, Farmany & Cheraghi, 2012; Hosseini *et al.*, 2013a; Sobhanardakani *et al.*, 2017). However, other elements such as As, Cd, Cr, Hg, and Pb have no known essential function in biological systems and are toxic even at low concentrations (Isibor, 2017; Isibor, Imoobe & Ohiokhioya, 2017). It should be noted that the skin and gills, and also the intake of contaminated food or drinking water as the main resources can cause enter the heavy metals into the fish body. Therefore, accumulation of heavy metals in fish tissues is dependent on the concentration of the metal in the aquatic ecosystem and period of exposure to contaminants in the water (Pourang, Tanabe, Rezvani, & Dennis, 2005; Sobhanardakani, Tayebi & Farmany, 2011; Hosseini *et al.*, 2013a; Hosseini *et al.*, 2013b)

Fish are healthful for human due to provide a source of dietary protein, low saturated fat, and omega-3(n-3) fatty acids and for this reason they are widely consumed around the world. Also, several studies have documented the long-term cardioprotective and the reproductive benefits of eating fish. However, benefits may be offset by the presence of pollutants, especially heavy metals (Burger, & Gochfeld, 2004; Hosseini *et al.*, 2013a).

The human health risk assessment is the process requires identification, collection, and integration of information on the toxins and chemicals health hazards, exposure of human to the chemical and relationships between exposure, dose and adverse health effects in polluted environmental. On the other hand, a human potential health risk assessment includes hazard identification, dose-response assessment, exposure assessment and risk characterization steps (Sobhanardakani, 2017).

Canned fish is largely eaten in many countries that located on different continents especially Libya, USA, Portugal, the Kingdom of Saudi Arabia, Turkey, and Iran (Hosseini *et al.*, 2013a). Because of the concern for the adverse health effects of heavy metals particularly organ failure/damage (e.g., kidney and liver), this study was done to human health risk

assessment of Cr, Cu, Fe, Mn and Ni through consumption of different brands commonly consumed canned tuna fish in Iran.

Materials and Methods

Sample Collection

One hundred and twenty samples of four different brands of canned fish, including 30 samples for each species (yellowfin tuna, *Thunnus albacares*; common Kilka, *Clupeonella cultriventris caspia*; Kawakawa, *Euthynnus affinis*; and longtail tuna, *Thunnus tonggol*; were purchased from different markets in Tehran and used for analysis of concentration of heavy metals (Cr, Cu, Fe, Mn, and Ni).

Chemical Analyses

After opening, each can content was homogenized thoroughly in a food blender using stainless steel cutters (Boadi, Twumasi, Badu, & Osei, 2011). Then, samples were digested with 10 ml of 1 N HNO₃ in closed Teflon vessels in a microwave oven (CEM MARS-5 closed vessel microwave digestion system) according to the method introduced by Sobhanardakani (2017). After digestion, blank solutions were prepared in the laboratory in a similar manner to the field samples. All metal concentrations (µg/g, wet weight) were determined with three replications using inductively coupled plasma–optical emission spectrometer (Optima 2100 DV, Perkin Elmer) (Turkmen, Turkmen, Tepe, Tore & Ates, 2009). Standard solutions were prepared from stock solutions (Merck, multi-element standard). All the instrumental conditions applied for Cr, Cu, Fe, Mn, and Ni concentration determinations were set in accordance with general recommendations (wavelength for Cr, Cu, Fe, Mn and Ni: 267.72 nm, 324.75 nm, 258.59 nm, 257.61 nm, and 231.6 nm, respectively). Also, the Limits of Detection (LOD) and Limits of Quantification (LOQ) were assessed according to the method introduced by Nascimento *et al.* (2008) and both are presented in Table 1.

Statistical Analysis

The statistical analysis of the obtained results consisted of a first Kolmogorov-Smirnov normality test, followed by the study of the variance homogeneity using an ANOVA parametric test with a DMS post hoc and Duncan multiple range test. The mean levels of heavy metals were compared with international standard using a one-sample test. Probabilities less than 0.05 were considered statistically significant (P<0.05). The statistical calculations were done using SPSS version 17.0 (SPSS Inc., Chicago, IL, USA) statistical package.

Potential Health Risk Assessment

For computing potential health risk assessment the average Daily Intake of Metal (DIM) was calculated according to the Equation 1 (Guo, Yue, Li & Yuan, 2016):

$$DIM = \frac{C_{metal} \times C_{factor} \times D_{food\ intake}}{B} \quad (1)$$

Where C_{metal} , C_{factor} , and $D_{food\ intake}$ represent the heavy metal concentrations in canned fish (µg/g), conversion factor, and average daily intake of analyzed canned fish for adult and children (3.5E0-3 kg per person per day) respectively. B indicated that average body weight (70.0 kg for adult and 15.0 kg for children). The conversion factor (0.085) is used to convert fresh weight into dry weight (Falco, Ilobet, Bocio, & Domingo, 2006; Omar *et al.*, 2013; Guo *et al.*, 2016; Tang, Cheng, Zhao & Wang, 2015).

The Health Risk Index (HRI) for the local population through the consumption of canned fish was assessed using the Equation 2 (Guo *et al.*, 2016):

$$HRI = \frac{DIM}{RfD} \quad (2)$$

Here, DIM and RfD represent the daily intake of metal and reference dose of metal, respectively. The oral reference doses (mg/kg/day) of metals were 1.50 for Cr, 0.04 for Cu, 0.643 for Fe, 0.014 for Mn and 0.02 for Ni (Harmanescu, Alda, Bordean, Gogoasa, & Gergen, 2011; Xue, Liu, Liu, & Yan, 2012; Omar *et al.*, 2013; Liang, Xue, Wang, Sun, Yang, & Liu, 2015; Zeng, Wang, Wang, Guo, Chen, & Zhuang, 2015; Sobhanardakani, 2016). In this regard, the HRI <1 means the exposed population is assumed to be safe.

The Total HRI (THRI) of heavy metals for the canned fish was calculated according to the Equation 3 (Guo *et al.*, 2016):

$$THRI = HRI (\text{toxicant } 1) + HRI (\text{toxicant } 2) + \dots + HRI (\text{toxicant } n) \quad (3)$$

Results

The concentrations of Cr, Cu, Fe, Mn and Ni in the analyzed canned fish samples are presented in Table 1. Among the analyzed canned fish samples, Cr was detected in amounts ranging from 1.65 µg/g to 3.24 µg/g, Cu ranged from 0.73 µg/g to 1.18 µg/g, Fe ranged from 34.02 µg/g to 77.53 µg/g, Mn ranged from 0.04 µg/g to 1.01 µg/g and Ni ranged from 0.14 µg/g to 0.37 µg/g, respectively.

Comparing the heavy metal concentrations in studied canned fish with the maximum permissible limits (µg/g) (8.0 for Cr, 30.0 for Cu, 100.0 for Fe, 1.0

Table 1. Concentrations and analysis of LOD and LOQ of metals in canned fish samples ($\mu\text{g/g}$, wet weight)

Metal	Min.	Max.	Mean	Std.	LOD	LOQ
Cr	1.65	3.24	2.66d*	0.73	0.048	0.150
Cu	0.73	1.18	0.92c	0.19	0.037	0.115
Fe	34.02	77.53	54.68e	18.89	0.072	0.222
Mn	0.04	1.01	0.33b	0.46	0.075	0.220
Ni	0.14	0.37	0.22a	0.10	0.029	0.085

* The letters (a, b, c, d, e) represent the statistical significant differences ($P < 0.05$) in the contents of analyzed metals between canned fish samples.

for Mn, and 1.0 for Ni) established by Agency for Toxic Substances and Disease Registry (ATSDR), Food and Agricultural Organization/World Health Organization (FAO/WHO), Food and Drug Administration (FDA), European Union (EU), and WHO (WHO, 1989;1996; FDA, 2001; ATSDR, 2004;2005,2012a,b; EU, 2005; FAO/WHO, 2009), indicated that the concentration of all analyzed metals were lower than MPL. Therefore, canned fish's contribution to the total body burden of Cr, Cu, Fe, and Ni can be considered as negligibly small.

In addition, all the calculated HRI values of heavy metals were within the safe limits ($\text{HRI} < 1$) (Table 2). Furthermore, the THRI values, which varied from— $6.98\text{E-}05$ to $2.06\text{E-}04$ for adults and from $3.26\text{E-}04$ to $9.63\text{E-}04$ for children— and were also within the safe limit ($\text{THRI} < 1$) in this study.

Discussion

Some factors, such as water chemistry, duration of exposure of fish to contaminants in water, concentrations of contaminants in water column, feeding habit of fish, contamination of fish during handling and processing, quality of canned fish and shelf life of canned fish can affect in the level of contaminants in fish. However, the metal levels in canned fishes is influenced by the pH of the canned product, oxygen concentration in the headspace, the quality of the lacquer coatings of canned products, quality of coating and also storage place (Tahán, Sanchez, Granadillo, Cubillan & Romero, 1995; Hosseini *et al.*, 2013a). The metals accumulation varies greatly between both fish species and/or fish tissues. Generally, fish could translocate the large quantities of toxic heavy metals in the liver, gill, and also muscle tissues (Sobhanardakani, Tayebi, Farmany & Cheraghi, 2012). Contaminants in fish can pose a health risk to the fish themselves, to their predators, and to humans who consume them (Burger, & Gochfeld, 2005).

Chromium is an essential mineral in humans that helps the body use protein, lipid, and carbohydrate metabolism (Cefalu, & Hu, 2004). Also, Cr is widely distributed in human tissues in extremely low and variable concentrations (Hosseini, Sobhanardakani, Tahergorabi & Delfieh, 2013c). Chronic exposure to Cr causes damage to the liver, kidney, circulatory and

nerve disorders, as well as skin irritation (Kabata-Pendias, 2010). In this regard, the US National Research Council recommended daily amount of Cr about $60 \mu\text{g/day}$ for a 70 kg person (NRC, 1989). The results showed that the mean concentrations of Cr in canned fish with an average of $2.66 \pm 0.73 \mu\text{g/g}$ were much lower than the MPL. The maximum value of Cr in canned fish samples ($3.24 \mu\text{g/g}$ wet weight) we obtained was higher than values obtained for canned fish ($0.06 \mu\text{g/g}$ w.wt) in the USA (Ikem & Egiebor, 2005), and in canned sardines in Brazil ($1.11 \mu\text{g/g}$ w.wt) (Tarley, Coltro, Matsushita & de Souza, 2001). In another study, Hussein and Khaled (2014) reported that the mean concentrations of Cr in muscle of three tuna species from Alexandria, Egypt were $0.82 \pm 0.07 \mu\text{g/g}$ w.wt. Also, Islam, Bang, Kim, Ahmed, & Jannat, (2010) reported that the mean concentration of Cr ($\mu\text{g/g}$, DW) in canned longtail tuna which was imported from the USA, canned bluefin tuna which was imported from the Thailand and canned bluefin tuna (produced in Korea) were 0.58 ± 0.06 , 0.32 ± 0.002 and 0.25 ± 0.02 , respectively and similar to this study lower than MPL (Islam *et al.*, 2010). A comparison of the Cr concentrations in the canned fish samples marketed in Iran and other selected regions are presented in Table 3.

Copper is an essential element for good health and seafood is known as a good source of dietary copper, but it is very toxic when consumed excessively (Mol, 2011), and for that reason, a maximum limit intake of Cu was set at 30mg/day by WHO (WHO, 1996). Therefore, a high intake of Cu has been recognized to cause adverse health problems such as kidney and liver damage for human (Hussein, & Khaled, 2014; Stancheva, Makedonski & Peycheva, 2014). According to the results of the present study, Cu in canned fish samples with an average of $0.92 \pm 0.19 \mu\text{g/g}$ wet weight was much lower than the MPL. The results of other study showed that the mean concentrations of Cu in the muscle of three tuna species from Alexandria, Egypt were $1.25 \pm 0.43 \mu\text{g/g}$ w.wt (Hussein & Khaled, 2014). Also, Ikem & Egiebor (2005) reported that the mean concentrations of Cu ($\mu\text{g/kg}$ w.wt) in canned fish from Georgia and Alabama were 0.32 for pink salmon, 0.47 for red salmon, 0.25 for tuna, 0.81 for mackerel, 0.83 for sardines and 0.60 for herring. Table 3 shows a comparison of metal concentration in the canned fish from Iran with some other regions

Table 2. Daily intakes of metals (DIM, mg) and health risk index (HRI) for individual heavy metal caused by the canned tuna fish

	Cr	Cu	Fe	Mn	Ni
Adults					
DIM	1.13E-05	3.91E-06	2.32E-04	1.40E-06	9.35E-07
STD	3.10E-06	8.07E-07	8.03E-05	1.96E-06	4.25E-07
Min	7.01E-06	3.10E-06	1.45E-04	1.70E-07	5.95E-07
Max	1.38E-05	5.01E-06	3.29E-04	4.29E-06	1.57E-06
HRI	7.54E-06	9.77E-05	3.61E-04	1.00E-04	4.68E-05
STD	2.07E-06	2.02E-05	1.25E-04	1.40E-04	2.13E-05
Min	4.68E-06	7.76E-05	2.25E-04	1.21E-05	2.98E-05
Max	9.18E-06	1.25E-04	5.12E-04	3.07E-04	7.86E-05
Children					
DIM	5.28E-05	1.82E-05	1.08E-03	6.54E-06	4.36E-06
STD	1.45E-05	3.77E-06	3.75E-04	9.12E-06	1.98E-06
Min	3.27E-05	1.45E-05	6.75E-04	7.93E-07	2.78E-06
Max	6.43E-05	2.34E-05	1.54E-03	2.00E-05	7.34E-06
HRI	3.52E-05	4.56E-04	1.69E-03	4.68E-04	2.18E-04
STD	9.65E-06	9.42E-05	5.83E-04	6.52E-04	9.92E-05
Min	2.18E-05	3.62E-04	1.05E-03	5.67E-05	1.39E-04
Max	4.28E-05	5.85E-04	2.39E-03	1.43E-03	3.67E-04

Table 3. Comparison of the heavy metal concentrations ($\mu\text{g/g}$) in canned fish marketed in Iran and other selected regions

Location	Metal					Reference
	Cr	Cu	Fe	Mn	Ni	
Iran	2.66	0.92	54.68	0.33	0.22	Present study
Iran	-	0.17-8.0	0.009-14.21	-	-	(Zarei <i>et al.</i> , 2010)
Ghana	-	-	1.06-21.45	0.006-0.036	-	(Boadi <i>et al.</i> , 2011)
Saudi Arabia	0.38	0.27	-	-	-	(Ashraf, 2006)
Egypt	-	-	139.0-191.4	-	-	(Hussein, & Khaled, 2014)
USA	-	-	0.003-0.016	-	0.00-0.21	(Ikem, & Egiebor, 2005)
USA	-	0.93	107.17	0.58	0.36	(Islam <i>et al.</i> , 2010)
Thailand	-	1.86	35.66	0.32	0.26	(Islam <i>et al.</i> , 2010)
Korea	-	3.13	31.07	0.25	0.12	(Islam <i>et al.</i> , 2010)
Iran	0.38	1.18	-	0.23-1.37	-	(Taghipour, & Aziz, 2010)
Nigeria	0.02	0.01	8.04-48.18	-	0.04-3.26	(Iwegbue <i>et al.</i> , 2009)

reported in the literature.

Iron is an essential mineral and is the most abundant transition element, and probably the most well-known metal in biologic systems especially plays an important role in the human physiology. Iron deficiency causes anemia, reducing cognitive function and also physical work capacity. Whereas, high intake of this element may be the cause of organ failure (Mol, 2011; Hussein, & Khaled, 2014; Stancheva *et al.*, 2014; Wheal, DeCourcy-Ireland, Bogard, Thilsted, & Stangoulis, 2016). Vertebrates (mammals, birds and fish) meat is known good sources of Fe for their high total Fe concentration, as well as presence of haem Fe. It has been proved that haem Fe has greater bioavailability than non-haem Fe due to the different physiological mechanisms of transport across intestinal membranes (Wheal *et al.*, 2016). Accordingly, fish is a major source of Fe for adults and children. The US National Academy of Medicine (NAM) recommends a Recommended Dietary Allowance (RDA) for Fe in elderly men and women-

10000 $\mu\text{g/day}$ (National Academy of Medicine, 2001). The results of the present study showed that the highest mean concentration of Fe with an average of 77.53 $\mu\text{g/g}$ wet weight was found in Kawakawa samples. Iron concentration in the literature was reported between 8.04 $\mu\text{g/g}$ w.wt to 48.18 $\mu\text{g/g}$ w.wt for canned sardines consumed in Nigeria (Iwegbue, Nwajei, Arimoro & Eguavoen, 2009). Table 3 shows a comparison of Fe concentration in the canned fish from Iran with some other regions reported in the literature.

The deficiency of manganese, as an essential element, is very striking ranging from severe convulsions, asthma, skeletal and reproductive abnormalities (Finley & Davis, 1999; Samsel & Seneff, 2015). Daily intake of small amounts of Mn is needed for the good health and growth of children. Children, as well as adults, who lose the ability to remove excess Mn from their bodies, develop nervous system problems. According to the ATSDR, there is no information on the carcinogenicity of this element

(ATSDR, 2012b). The results showed that the mean concentrations of Mn in canned fish samples were $0.33 \pm 0.46 \mu\text{g/g}$. Manganese concentrations in the literature have been reported in the range of $0.51 \mu\text{g/g}$ w.wt to $1.66 \mu\text{g/g}$ w.wt in muscle of three tuna species collected from the Alexandria, Egypt (Hussein, & Khaled, 2014), and also $0.64 \mu\text{g/g}$ w.wt to $1.71 \mu\text{g/g}$ w.wt for canned sardines consumed in Nigeria (Iwegbue *et al.*, 2009). A comparison of our findings with other studies is shown in Table 3.

Trace amounts of Ni act as activator of some enzyme systems but its toxicity at higher levels can cause respiratory problems (bronchial failure) and also is carcinogenic. Its acute toxicity arises from competitive interaction with Ca, Co, Cu, Fe and Zn. Literature review mentioned that the upper tolerable intake level of Ni for children (1-3 years old) and males/females (19-70 years old) is 7000 $\mu\text{g/day}$ and 40000 $\mu\text{g/day}$, respectively (National Academy of Medicine, 2001). Also, the WHO recommends 100-300 μg of this element for daily intake (WHO, 1996). The Ni concentration detected in the present study with an average of $0.22 \pm 0.10 \mu\text{g/g}$ was much lower than the MPL. Also, there was found no significant variability ($P < 0.05$) in the range of Ni when canned fish samples were compared. Nickel concentrations in the literature have been reported in the range of $0.37 \pm 0.0 \mu\text{g/g}$ w.wt in muscle of tuna species samples that collected from the Alexandria, Egypt (Hussein, & Khaled, 2014). Similarly, Malakootian, Tahergorabi, Daneshpajoo, & Amirtaheri (2011) reported the concentration of Ni in canned fish consumed in Iran was detected in amounts ranging from $0.10 \mu\text{g/g}$ w.wt to $0.16 \mu\text{g/g}$ w.wt (Malakootian *et al.*, 2011), and Pourjafar Ghasemnejad, & Noori, (2014) reported Ni concentrations in the range of $0.113 \mu\text{g/g}$ w.wt to $0.589 \mu\text{g/g}$ w.wt (Pourjafar *et al.*, 2014). The results of present study are within the ranges for those reported earlier 0.09 - $0.48 \mu\text{g/g}$ w.wt (Ashraf, 2006). A comparison of our findings with other studies is shown in Table 3.

As shown in Table 2, the average HRI values for adults and children were $1.23\text{E-}04$ and $5.73\text{E-}04$ respectively, and therefore, the non-carcinogenic risks for children are greater than adults. In this regard, Hussein and Khaled (2014) reported that the from the human health point of view, Cr, Cu, and Mn, THQ values were less than 1 and show a situation of no risk for the consumer of the investigated tuna species collected from the Alexandria, Egypt. Also, Ordiano-Flores, Galván-Magaña & Rosiles-Martínez (2011) reported that the estimated THQ values of Hg were < 1 in each population group (children and adults) due to consumption of yellowfin tuna collected from the Eastern Pacific Ocean (Ordiano-Flores *et al.*, 2011).

Conclusion

Based on the results, canned yellowfin tuna, common Kilka, Kawakawa and longtail tuna have

concentrations within permissible limits of Cr, Cu, Fe, Mn and Ni. Also, HRI values of all metals for children and adults were less than safe limits. Therefore, it can be concluded that target population might have no potential significant health risk through only consuming canned tuna fish from the Iran.

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References

- Ashraf, W. (2006). Levels of selected heavy metals in tuna fish. *Arabian Journal for Science and Engineering*, 31(1A), 89-92.
- Agency for Toxic Substances and Disease Registry. (2004). Toxicological profile for copper, U.S. Department of Health and Human Service. Public Health Service, Public Health Service, Agency for Toxic Substances and Disease Registry, Atlanta, 314 pp.
- Agency for Toxic Substances and Disease Registry. (2005). Toxicological profile for nickel, U.S. Department of Health and Human Service. Public Health Service, Public Health Service, Agency for Toxic Substances and Disease Registry, Atlanta, 397 pp.
- Agency for Toxic Substances and Disease Registry. (2012a). Toxicological profile for chromium, U.S. Department of Health and Human Service. Public Health Service, Public Health Service, Agency for Toxic Substances and Disease Registry, Atlanta, 592 pp.
- Agency for Toxic Substances and Disease Registry. (2012b). Toxicological profile for Manganese, U.S. Department of Health and Human Service. Public Health Service, Public Health Service, Agency for Toxic Substances and Disease Registry, Atlanta, 556 pp.
- Boadi, N.O., Twumasi, S.K., Badu, M., & Osei, I. (2011). Heavy metal contamination in canned fish marketed in Ghana. *American Journal of Scientific and Industrial Research*, 2(6), 877-882. <https://dx.doi.org/10.5251/ajsir.2011.2.6.877.882>
- Burger, J., & Gochfeld, M. (2004). Mercury in canned tuna: white versus light and temporal variation. *Environmental Research*, 96, 239-249. <https://dx.doi.org/10.1016/j.envres.2003.12.001>
- Burger, J., & Gochfeld, M. (2005). Heavy metals in commercial fish in New Jersey. *Environmental Research*, 99(3), 403-412. <https://dx.doi.org/10.1016/j.envres.2005.02.001>
- Cefalu, W.T., & Hu, F.B. (2004). Role of chromium in human health and in diabetes. *Diabetes Care*, 27, 2741-2751. <https://dx.doi.org/10.2337/diacare.27.11.2741>
- European Union. (2005). Commission regulation as regards heavy metals. Amending Regulation 466/2001, no 78/2005.
- Falco, G., Ilobet, J., Bocio, A., & Domingo, J.L. (2006). Daily intake of arsenic, cadmium, mercury, and lead by consumption of edible marine species. *Journal of Agricultural and Food Chemistry*, 54, 6106-6112. <https://dx.doi.org/10.1021/jf0610110>

- Finley, J.W. & Davis, C.D. (1999). Manganese deficiency and toxicity: are high or low dietary amounts of manganese cause for concern?. *BioFactors*, 10(1), 15-24. <https://dx.doi.org/10.1002/biof.5520100102>
- Food and Agricultural Organization of the United Nations and World Health Organization. (2009). Codex general standard for food additives, Codex standards, 192-1995, 259 pp.
- Food and Drug Administration. (2001). Fish and fisheries products hazards and controls guidance. U.S. Food and Drug Administration, Center for Food Safety & Applied Nutrition, Chapter 9, Environmental chemical contaminants and pesticides, 26 pp.
- Guo, J., Yue, T., Li, X. & Yuan, Y. (2016). Heavy metal levels in kiwifruit orchard soils and trees and its potential health risk assessment in Shaanxi, China. *Environmental Science and Pollution Research*, 23(14), 14560-14566. <https://dx.doi.org/10.1007/s11356-016-6620-6>
- Harmanescu, M., Alda, L.M., Bordean, D.M., Gogoasa, I. & Gergen, I. (2011). Heavy metals health risk assessment for population via consumption of vegetables grown in old mining area; a case study: Banat County, Romania. *Chemistry Central Journal*, 5, 64. <https://dx.doi.org/10.1186/1752-153X-5-64>
- Hosseini, S.V., Aflaki, F., Sobhanardakani, S., Tayebi, L., Babakhani Lashkan, A., & Regenstein, J.M. (2013a). Analysis of mercury, selenium and tin concentrations in canned fish marketed in Iran, *Environmental Monitoring and Assessment*, 185(8), 6407-6412. <https://dx.doi.org/10.1007/s10661-012-3033-y>
- Hosseini, S.M., Sobhanardakani, S., Batebi Navaei, M., Kariminasab, M., Aghilinejad, S.M. & Regenstein, J.M. (2013b). Metal content in caviar of wild Persian sturgeon from the southern Caspian Sea. *Environmental Science and Pollution Research*, 20(8), 5839-5843. <https://dx.doi.org/10.1007/s11356-013-1598-9>
- Hosseini, S.V., Sobhanardakani, S., Tahergorabi, R. & Delfieh, P. (2013c). Selected heavy metals analysis of Persian sturgeon's (*Acipenser persicus*) caviar from Southern Caspian Sea. *Biological Trace Element Research*, 154, 357-362. <https://dx.doi.org/10.1007/s12011-013-9740-6>
- Hussein, A. & Khaled, A. (2014). Determination of metals in tuna species and bivalves from Alexandria, Egypt. *Egyptian Journal of Aquatic Research*, 40, 9-17. <https://dx.doi.org/10.1016/j.ejar.2014.02.003>
- Ikem, A. & Egiebor, N.O. (2005). Assessment of trace elements in canned fishes (mackerel, tuna, salmon, sardines and herrings) marketed in Georgia and Alabama. *Journal of Food Composition and Analysis*, 18, 771-787. <https://dx.doi.org/10.1016/j.jfca.2004.11.002>
- Isibor, P.O. (2017). Heavy metals, nutrients, total hydrocarbons and zooplankton community structure of Osse River, Edo State, Nigeria. *Jordan Journal of Biological Sciences*, 10(2), 109-116.
- Isibor, P.O., Imoobe, T. & Ohiokhioya, T. (2017). Comparative analysis of contaminability between *Clarias gariepinus* and *Tilapia mariae*. *Annual Research and Review in Biology*, 16(5), 1-14. <https://dx.doi.org/10.9734/ARRB/2017/34920>
- Islam, M.M., Bang, S., Kim, K.W., Ahmed, M.K. & Jannat, M. (2010). Heavy metals in frozen and canned marine fish of Korea. *Journal of Scientific Research*, 2(3), 549-557. <https://dx.doi.org/10.3329/jsr.v2i3.4667>
- Iwegbue, C.M.A., Nwajei, G.E., Arimoro, F.O., & Eguavoen, O. (2009). Characteristic levels of heavy metals in canned sardines consumed in Nigeria. *Environmentalist*, 29, 431-435. <https://dx.doi.org/10.1007/s10669-009-9233-5>
- Kabata-Pendias, A. (2010). Trace Elements in Soils and Plants, Fourth Edition. Florida, USA, CRC Press., 548 pp.
- Liang, Q., Xue, Z.J., Wang, F., Sun, Z.M., Yang, Z.X., & Liu, S.Q. (2015). Contamination and health risks from heavy metals in cultivated soil in Zhangjiakou City of Hebei Province, China. *Environmental Monitoring and Assessment*, 187(12), 754. <https://dx.doi.org/10.1007/s10661-015-4955-y>
- Malakootian, M., Tahergorabi, M., Daneshpajooh, M., & Amirtaheri, K. (2011). Determination of Pb, Cd, Ni, and Zn concentrations in canned Fish in Southern Iran. *Sacha Journal of Environmental Studies*, 1(1), 94-100.
- Mol, S. (2011). Levels of Heavy Metals in Canned Bonito, Sardines, and Mackerel Produced in Turkey. *Biological Trace Element Research*, 143, 974-982. <https://dx.doi.org/10.1007/s12011-010-8909-5>
- Nascimento, R.S., Mendes, D.B., Matos, J., Silva, J., Ciminelli, V.S., & Neto, W.B. (2008). Determination of trace elements in Brazilian human milk by quadrupole inductively coupled plasma mass spectrometry and microwave-assisted digestion. *Atomic Spectroscopy*, 29(3), 77-81.
- National Academy of Medicine. (2001). Dietary reference intakes for vitamin A, vitamin K, arsenic, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium, and zinc. National Academies Press (US); Washington, D.C.
- National Research Council. (1989). National Research Council recommended dietary allowances. 10th ed. Washington: National Academy Press.
- Omar, W.A., Zaghoul, K.H., Abdel-Khalek, A.A. & Abo-Hegab, S. (2013). Risk assessment and toxic effects of metal pollution in two cultured and wild fish species from highly degraded aquatic habitats. *Archives of Environmental Contamination and Toxicology*, 65(4), 753-764. <https://dx.doi.org/10.1007/s00244-013-9935-z>
- Ordiano-Flores, A., Galván-Magaña, F. & Rosiles-Martínez, R. (2011). Bioaccumulation of mercury in muscle tissue of yellowfin tuna, *Thunnus albacares*, of the Eastern Pacific Ocean. *Biological Trace Element Research*, 144(1-3), 606-620. <https://dx.doi.org/10.1007/s12011-011-9136-4>
- Pourang, N., Tanabe, S., Rezvani, S., & Dennis, J.H. (2005). Trace elements accumulation in edible tissues of five sturgeon species from the Caspian Sea. *Environmental Monitoring and Assessment*, 100(1-3), 89-108. <https://dx.doi.org/10.1007/s10661-005-7054-7>
- Pourjafar, H., Ghasemnejad, R., & Noori, N. (2014). Heavy metals content of canned tuna fish marketed in Tabriz, Iran. *Iranian Journal of Veterinary Medicine*, 8(1), 9-14. <https://dx.doi.org/10.22059/ijvm.2014.50557>
- Samsel, A. & Seneff, S. (2015). Glyphosate, pathways to modern diseases III: Manganese, neurological diseases, and associated pathologies. *Surgical Neurology International*, 6, 45. <https://dx.doi.org/10.4103/2152-7806.153876>
- Sobhanardakani, S. (2016). Potential health risk assessment of Cr, Cu, Fe and Zn for human population via

- consumption of commercial spices; a case study of Hamedan City, Iran. *International Archives of Health Sciences*, 3(3), 119-124.
<https://dx.doi.org/10.18869/IAHS.3.3.119>
- Sobhanardakani, S. (2017). Tuna fish and common kilka: Health risk assessment of metal pollution through consumption of canned fish in Iran. *Journal of Consumer Protection and Food Safety*, 12(2), 157-163. <https://dx.doi.org/10.1007/s00003-017-1107-z>
- Sobhanardakani, S., Tayebi, L., & Farmany, A. (2011). Toxic Metal (Pb, Hg and As) Contamination of muscle, gill and liver tissues of *Otolithes rubber*, *Pampus argenteus*, *Parastromateus niger*, *Scomberomorus commerson* and *Onchorynchus mykiss*. *World Applied Sciences Journal*, 14(10), 1453-1456.
- Sobhanardakani, S., Tayebi, L., Farmany, A., & Cheraghi, M. (2012). Analysis of trace elements (Cu, Cd and Zn) in muscle, gill and liver tissues of some fish species using anodic stripping voltammetry. *Environmental Monitoring and Assessment*, 184(11), 6607-6611.
<https://dx.doi.org/10.1007/s10661-011-2445-4>
- Sobhanardakani, S., Hosseini, S.V., Kolangi Miandare, H., Faizbakhsh, R., Harsij, M., & Regenstein, J.M. (2017). Determination of Cd, Cu, Mn and Zn concentrations in Iranian Caspian Sea caviar of *Acipenser persicus* using anodic stripping voltammetry. *Iranian Journal of Science and Technology Transaction A: Science*, 41(1), 139-144.
<https://dx.doi.org/10.1007/s40995-017-0217-x>
- Stancheva, M., Makedonski, L., & Peycheva, K. (2014). Determination of heavy metal concentrations of most consumed fish species from Bulgarian Black Sea coast. *Bulgarian Chemical Communications*, 46(1), 195-203.
- Tahán, J.E., Sanchez, J.M., Granadillo, V.A., Cubillan, H.S., & Romero, R.A. (1995). Concentration of total Al, Cr, Cu, Fe, Hg, Na, Pb, and Zn in commercial canned seafood determined by atomic spectrometric means after mineralization by microwave heating. *Journal of Agricultural and Food Chemistry*, 43, 910-915. <https://dx.doi.org/10.1021/jf00052a012>
- Tang, W., Cheng, J., Zhao, W., & Wang, W. (2015). Mercury levels and estimated total daily intakes for children and adults from an electronic waste recycling area in Taizhou, China: Key role of rice and fish consumption. *Journal of Environmental Sciences*, 34, 107-115. <https://dx.doi.org/10.1016/j.jes.2015.01.029>
- Tarley, C.R.T., Coltro, W.K.T., Matsushita, M. & de Souza, N.E. (2001). Characteristic levels of some heavy metals from Brazilian canned sardines (*Sardinella brasiliensis*). *Journal of Food Composition and Analysis*, 14, 611-617.
<https://dx.doi.org/10.1006/jfca.2001.1028>
- Turkmen, M., Turkmen, A., Tepe, Y., Tore, Y. & Ates, A. (2009). Determination of metals in fish species from Aegean and Mediterranean seas. *Food Chemistry*, 113, 233-237.
<https://dx.doi.org/10.1016/j.foodchem.2008.06.071>
- Wheal, M.S., DeCourcy-Ireland, E., Bogard, J.R., Thilsted, S.H. & Stangoulis, J.C.R. (2016). Measurement of haem and total iron in fish, shrimp and prawn using ICP-MS: Implications for dietary iron intake calculations. *Food Chemistry*, 201, 222-229.
<https://dx.doi.org/10.1016/j.foodchem.2016.01.080>
- World Health Organization. (1989). Heavy metals-environmental aspects, Environment Health Criteria. No. 85. Geneva, Switzerland.
- World Health Organization. (1996). Health criteria other supporting information, Guidelines for Drinking Water Quality. WHO, Geneva. 1996.p. 318-88.
- Xue, Z.J., Liu, S.Q., Liu, Y.L. & Yan, Y.L. (2012). Health risk assessment of heavy metals for edible parts of vegetables grown in sewage-irrigated soils in suburbs of Baoding City, China. *Environmental Monitoring and Assessment*, 184, 3503-3513.
<https://dx.doi.org/10.1007/s10661-011-2204-6>
- Zeng, X., Wang, Z., Wang, J., Guo, J., Chen, X. & Zhuang, J. (2015). Health risk assessment of heavy metals via dietary intake of wheat grown in Tianjin sewage irrigation area. *Ecotoxicology*, 24(10), 2115-2124.
<https://dx.doi.org/10.1007/s10646-015-1547-0>