Received: 08 May 2023, Accepted: 19 June 2023

Review Article

Journal of Advanced Veterinary Research
(2023) Volume 13, Issue 7, 1459-1463

Toxic Metal in Fish and Fish products: Accumulation and Human Health-A Review

Mohamed A. Hussein, Abdallah F. Mahmoud, Samar A. Morgan*

Food Control Department, Faculty of Veterinary Medicine, Zagazig University, 44511 Zagazig, Egypt.

***Correspondence**
Corresponding author: Samar A. Morgan
E-mail address: samaralarby2@gmail.com

Abstract

In the aquatic environment, pollution with heavy metals is a major issue. Some of them are essential heavy metals because they play biological roles for aquatic organisms. Other heavy metals, however, are regarded as dangerous even at low concentrations. Heavy metal levels that are harmful may be caused by industrial, mining, and agricultural operations. Water contamination and changes to the physicochemical properties of the aquatic environment will result from this. The harmful toxic consequences of this pollution on fish raise questions about its possible impacts on human health. The most prevalent heavy metals are arsenic, cadmium, lead, and mercury, which are systemic toxicants and have an impact on human health. These metals are classified as carcinogens by the United States Environmental Protection Agency and the international agency for research on cancer because they cause organ damage even at low exposure levels. This review was created to contribute to the understanding of the environmental impact, toxicology, and consequences of heavy metals on fish.

KEYWORDS
Fish, Fish products, Lead, Cadmium, Arsenic, Mercury.

INTRODUCTION

Fish is becoming more popular as a human food source because a large portion of the world's population finds it delicious, nutritious, and high in animal protein. They are the most widely consumed foods in both developed and developing countries, owing to their contribution to resolving the issue of a lack of animal meat, particularly in the last ten years (Ahmed *et al*., 2013; Morshdy *et al*., 2013; Hussein *et al*., 2019; Morshdy *et al*., 2022). Heavy metals pose a risk on many different levels and pose a major threat to both human life and the lives of other living things. Mines and volcanic dust are two major contributors to these variables, but in addition to these, people themselves may contribute to the release of heavy metals in a variety of ways, including through the dyeing industry, metal plating, and battery manufacturing (Sattari *et al*., 2020). Large quantities of these metals naturally reach the sea from a number of causes, such as mine erosion, wind, dust particles, volcanic activity, rivers, and groundwater. These metals are naturally present in saltwater. What is troubling, however, is the rise in these metals' concentrations as a result of human industrial activities, such as the expansion of industrial effluents and wastes, oil pollution, poisons, pests, and so forth. On the one hand, these pollutants lower the amount of oxygen that is water soluble, while on the other, the presence of toxins has a direct impact on fish and results in their losses. Metal mining businesses are another source of water pollution since they discharge a lot of harmful metals when mining. Some of these waters have a pH that is slightly acidic, increasing the solubility of metals. For instance, the high acidity of coal mine drainage water causes metals in the mine bed to dissolve (Sattari *et al*., 2019). Heavy metals cannot be biodegraded; instead, bioaccumulation can increase their concentration (Mitra *et al*., 2012; Morshdy *et al*., 2019). As a result, metals may accumulate in the food chain and pose a risk to the consumer's health (Frantzen *et al*., 2015; Morshdy *et al*., 2021a). It is believed that variations in the absorption and depuration times of specific metals are the primary cause of metal bioaccumulation in fish. Many factors, including the time of year, the physical and chemical properties of the water, industrial development, fertilizers, livestock manure, air pollution, mining, and excessive pesticide use, can lead to metal accumulation in different fish tissues (Tucker, 1997). Human is mainly exposed for such toxic metals through ingestion of contaminated food and water, which accounted for more than 90 % compared to inhalation and other exposure routes (Loutfy *et al*., 2006). There are a number of harmful effects that heavy metals have on human health. For instance, Pb is one of the heavy metals that has been associated with numerous cases of child fatalities, such as those in China and Zambia (Xu *et al*., 2014; Yabe *et al*., 2015). Additionally, the effects of Pb on mental health and intelligence are harmful. Heavy metal cadmium (Cd) has no known physiological purpose. Itai-Itai disease, which has been linked to heavy fish consumption in Japan, is primarily caused by cadmium. Such a condition is characterized by osteomalacia and kidney dysfunction. (Nishijo *et al*., 2017). Besides, Cd is considered a group B1 carcinogen (IARC, 2016). Arsenic is another heavy metal that has been linked to multiple organ damage, carcinogenesis with unknown mechanisms, and skin irritation (Reichard and Puga, 2010).

ISSN: 2090-6277/2090-6269/

ACCUMLATION OF TOXIC METAL IN FISH AND FISH PRODUCTS

Heavy metals can enter aquatic biota through a variety of sources, including food, sediments, and water. Fish living in fresh and marine water bodies are exposed to many harmful heavy metals from both anthropogenic and natural sources. Because it puts fish in danger and endangers consumers' health, heavy metal contamination of fish has gained importance on a global scale (Rahman *et al*., 2012). It is crucial to evaluate the bioaccumulation of heavy metals in various aquatic fish species. Fish consumption by humans and the management of aquatic ecosystems depend on the assessment of heavy metal levels in fish tissues (Ariyaee *et al*., 2015). Fish are low in cholesterol and abundant in unsaturated fatty acids. They are a significant protein source (Hussein *et al*., 2019). Eating edible fish is advantageous for humans and is hence advised as part of a balanced diet. However, the consumption of fish, particularly by more vulnerable segments of the population like women, children, and those at risk of diseases from other causes, has been questioned due to the risk that toxic heavy metal contamination of fish poses to human health. Freshwater fish's bioaccumulation of heavy metals is influenced by a number of elements, including the fish's individual traits and external environmental conditions. Fish-related aspects include age, size (length and weight), food preferences, and body physiology, whilst environmental factors outside the fish's control include metal concentrations and bioavailability in the water column, physicochemical characteristics of water, and other climate variables. Depending on the structure and function of the tissues, there are generally differences for accumulation in the various fish tissues. In general, metabolically active tissues like the gills, liver, and kidneys accumulate more heavy metals than less metabolically active tissues like the skin and muscles. The induction/occurrence of metal-binding proteins termed metallothioneins (MTs) in these tissues following exposure to heavy metals typically accounts for the somewhat larger heavy metal accumulation in metabolically active tissues of fish. The target tissue for accumulation and removal of heavy metals like Ni has been discovered to be the fish gills (Mansouri *et al*., 2012). Although fish muscles have poor heavy metal accumulation (Khaled *et al*., 2009), they are significant in terms of human consumption. Fish muscles often bioaccumulate trace metals in a species-specific manner (Kumar *et al*., 2010).

Fish muscles have been the subject of the majority of studies on the bioaccumulation of heavy metals in fish because they are edible and the most pertinent to human health. Important environmental, ecological, and social consequences of the bioaccumulation of toxic heavy metals in freshwater fish include implications for people and other fish that consume carnivorous wildlife (Ali *et al*., 2019; Ahmed *et al*., 2020). Fish contain waterborne heavy metals that reach the human body through the food chain and have an effect on health (Dwivedi *et al*., 2015). Addi-

Table 1. Heavy metal residues mg/kg in muscle from fish and fish product.

Fish species or product	Lead	Cadmium	Mercury	Arsenic	Country	Authors
Upeneus vittatus	0.062±0.00	0.008±0.00	-	-	Nigeria	Ajiboye *et al.* (2011)
Anchovilla commersonii	1.569±1.41	0.114±0.14	-	-		
Pomadasys maculates	1.066±1.49	0.006±0.00	-	-		
Lutjanus adetii	0.861±0.14	0.004±0.00	-	-		
Ambassis commersoni	1.264±1.48	0.012±0.01	-	-		
Cyprinus carpio	0.087- 0.066	0.023 - 0.042	-	-	China	Rajeshkumar and Li (2018)
Pelteobagrus fluvidraco	0.036 - 0.052	0.023 - 0.028	-	-		
Fenneropenaeus indicus	BDL	0.23±0.01	-	0.59±0.01	Kingdom Saudi Arabia	Aljabryn (2022)
Chaceon quinquedens	BDL	0.16±0.02	-	4.30±0.10		
Lethrinus nebulosus	1.51±0.06	BDL	-	0.23±0.02		
Scomberomorus commerson	0.89±0.14	BDL	-	0.18±0.01		
Pampus argenteus	1.69±0.04	BDL	-	0.19±0.02		
Plectropomus pessuliferus	5.05±0.86	BDL	-	0.22±0.01		
Epinephelus summana	2.80±0.35	BDL	-	0.21±0.01		
Smoked mackerel	0.05	0.01	-	-	Poland	Winiarska-Mieczan *et al.* (2018)
Smoked salmon	0.06	0.01	-	-		
Smoked spart	0.00	0.00	-	-		
Smoked eel	0.0 3726	0.01	-	-		
Trout dish	0.00	0.06	-	-		
Fish salad	0.06	0.01	-	-		
Fish spreads	0.05	0.01	-	-		
Marinated fish	0.06	0.00	-	-		
Nile tilapia	0.70	-	0.05	0.51	Egypt	Sallam *et al.* (2019)
Grey mullet	0.64	-	0.01	0.62		
African catfish	0.64	-	0.02	0.57		
Canned sardines	1.17±0.28	0.09±0.02	0.05±0.01	4.23-7.79	Egypt	Morshdy *et al.* (2021b)
Canned tuna	0.72±0.13	0.05±0.02	0.03±0.01	5.66-10.41		
Canned anchovies	0.32±0.08	0.04±0.01	0.02±0.01	1.69-3.45		
Tilapia spp	BDL	1.45±0.9	BDL	BDL	Philippines	Mendoza *et al.* (2023)

BDL: Below detection limit.

tionally, harmful heavy metals have an impact on the health and wellbeing of fish. According to reports, stress caused by heavy metal-containing effluent in the river made the freshwater fish Channa punctatus feeble and more susceptible to illness (Javed and Usmani, 2015). One of the potential reasons for the population decreases of freshwater fish and other aquatic species in freshwater habitats is heavy metal contamination. The quantity and variety of fish and other aquatic species in the River Indus in Pakistan have reportedly decreased as a result of rising pollution (Al-Ghanim *et al*., 2016). In canned fish, corrosion of the can material might lead to leaching of Sn into the fish flesh, and subsequently into the human body (Morshdy *et al*., 2021b).

PREVALENCE OF HEAVY METAL IN FISH AND FISH PRODUCTS

Aquatic organisms generally accumulate chemical contaminants from the surrounding environment and therefore have been widely used in aquatic contamination monitoring programmes (Hussein *et al*., 2022). In India, an atomic absorption spectrometer was used to assess the concentration of heavy metals in economically significant species of fish, shellfish, and fish products from fish markets in and around the Cochin region. Cd, Pb, Hg, Cr, As, Zn, Cu, Co, Mn, Ni, and Se concentrations ranged from 0.07 to 1.32, 0.05 to 3.65, 0.06 to 165, 0.15 to 24, 0.02 to 0.85, 0.08 to 9.2, 0.032-1.38, and 0.03-1.35 mg/kg, respectively, in the samples (Sivaperumal *et al*., 2007). Another study in India, reported that the concentrations of heavy metals significantly varied ($P< 0.05$). The findings of this investigation revealed the strongest conclusive relationships between the hazardous heavy metals found in the fish samples. Metals such as Cd, Pb, Cu, and Zn were found in the fish samples at varying concentrations. The residual concentrations of harmful heavy metals were below the criteria established by the World Health Organization, European Union, and Food and Agriculture Organization for human consumption. Since they are considered safe for human consumption, the fish species found in the Thondi fish landing and their fishery products can be exported anywhere in the world (Arulkumar *et al*., 2017).

In Poland, Winiarska-Mieczan *et al*. (2018) conducted study aimed to identify whether fishery products from Polish market were safe for human consumption in the regarding of contamination with Cd and Pb. Based on the amount of Cd and Pb present in fisheries products and their contribution to an adult's weekly diet, the safety of these items was assessed. 117 samples of prepared fish-based foods (including salads, spreads, and marinated herring) and 139 samples of smoked fish (including 26 samples of mackerel, 21 samples of salmon, 35 samples of sprat, 38 samples of eel, and 19 samples of trout) were analyzed. The GF AAS technique was used to determine the levels of Cd and Pb. The following can be used to indicate the amount of Cd in 1 kilogram of the product under analysis: Salads come first, followed by smoked eel, salmon, mackerel, trout, and spreads, then marinated herring, and finally smoked sprat. The following chart illustrates the amount of lead in 1 kilogram of the product under analysis: Smoked eel, smoked sprat, and smoked trout are preferred above smoked mackerel and spreads. While the majority of Pb was recorded in salads (on average 56.8 g per kg; range 32.6- 78.9 g) and marinated fish (on average 58.8 g per kg; range 19.8-79.6 g), the majority of Cd was found in salads (on average 10.7 g/kg; range 6.53-14.7 g). Polish customers may get safe fish and fisheries goods.

In China, Rajeshkumar, and Li (2018) found that Freshwater edible fish Cyprinus carpio and Pelteobagrus fluvidraco, which were taken from the Meiliang Bay, Taihu Lake, a large, shallow, and eutrophic lake in China, were tested for the bioaccumulation of heavy metals (Cr, Cu, Cd, and Pb) content. The findings demonstrated that the two fish species' edible sections had substantially lower Cr, Cu, Cd, and Pb contents than suggested by Chinese Food Health Criteria. The results, however, revealed notable changes and discrepancies in the four tested metal contents between the two species and various tissues. Fish livers had the highest levels of Pb, Cd, and Cu, while kidney and liver had the highest concentrations of Cr and kidney had the highest levels of Cu. However, the liver, gills, and muscle had the highest levels of total metal bioaccumulation. Despite the fact that P. fluvidraco had the highest overall accumulations when compared to C. carpio. This study found that fish items in Meiliang Bay, Taihu Lake, were still acceptable for consumption by people, but the amount should be restricted in accordance with the Chinese Food Health Criteria to prevent excessive Pb intake.

In Egypt, Sallam *et al*. (2019) used atomic absorption spectrophotometer to test 600 newly captured fish samples from Manzala Lake in, 200 of which were Nile tilapia, 200 of flathead grey mullet, and 200 of African catfish. All the samples that were examined had metal concentrations of 0.045, 0.0145, and 0.017 ppm for Hg; 0.511, 0.621, and 0.568 ppm for As; 0.704, 0.635, and 0.64 ppm for Pb; and 0.024, 0.006, and 0.020 ppm for Cd in the Nile tilapia, flathead grey mullet, and African catfish, respectively. The three fish species studied had mean Hg, Pb, and Cd concentrations in the following order: Nile tilapia > African catfish > flathead grey mullet. While this was going on, the order of focus was flathead grey mullet, African catfish, and then Nile tilapia. In the three different fish species analyzed, there were noticeable differences in the Hg and Cd contamination levels between summer and winter. Significantly, negative associations between fish size and their residual levels of Hg, Pb, and Cd were seen in both the mullet and catfish tests. According to health-risk assessment indicators, eating these fish from Manzala Lake may pose a health risk to consumers. Also, Egypt, Morshdy *et al*. (2021) carried out a study in four different types of commercially available canned fish products from Zagazig city, Egypt, this study aimed to estimate the residual contents of six heavy metals, including lead (Pb), cadmium (Cd), arsenic (As), mercury (Hg), aluminum (Al), and tin (Sn). We looked at 80 imported samples, comprising 20 samples of each canned fish product, including anchovies, mackerel, sardines, and tuna. Additionally, we determined the estimated daily intakes (EDI), potential health risks, hazard quotient (HQ), and hazard index (HI), of the examined heavy metals linked to the consumption of such fish products among Egyptians. The results showed that residual levels of the tested heavy metals exceeded the Pb maximum permitted limits (MPL) in 20%, 95%, and 100% of the canned anchovies, sardines, and tuna under examination, respectively. While the MPL of As was exceeded in 80%, 100%, 100%, and 100% of the tested canned anchovies, mackerel, sardines, and tuna, respectively. No sample that was analyzed exceeded the MPL for Cd, Hg, Al, or Sn. Based on the daily intakes, the computed HQ and HI for the studied heavy metals indicated values larger than 1.0, suggesting possible dangers to human health. We should thus drastically cut back on the amount of canned fish we consume each day.

In Bosnia and Herzegovina, 185 samples of the 14 most frequently consumed marine fish, fish products, and exclusively domestically farmed freshwater fish were examined for the presence of mercury (Hg), lead (Pb), cadmium (Cd), and arsenic (As). None of the analyzed fish or fish products had amounts of these heavy metals that were higher than the permissible limit that were established in European Union (Hajrić *et al*., 2022). In comparison to freshwater fish, the mean concentrations of the tested heavy metals were higher in marine fish and their products. According to a research of the eating habits of 527 consumers in Bosnia and Herzegovina, dietary exposure to methylmercury (MeHg), inorganic mercury (IHg), and Cd through fish and fish products was far lower than the tolerated weekly intake (TWI). Dietary exposure to MeHg was nearly at the highest advised TWI among people who consumed too much fish (those in the top 95 percentile). For all freshwater and marine fish species, the worst-case Target Hazard Quotient (THQ) for Hg was much higher than one, indicating a potential risk to excessive consumers. Dietary exposure to Cd was predicted to be considerably below the advised TWI in typical and extreme Bosnia and Herzegovina consumer (Hajrić *et al*., 2022). In Cameroon, Egbe *et al*. (2023) who study that concentrations of heavy metals including As, Cd and Pb, in water, sediment, *Oreochromis niloticus*, and in the endemic and endangered Coptodon kottae in Lake Barombi Kotto were determined to evaluate fish heavy metal bioaccumulation, and heavy metal exposure risk posed to communities consuming these fish species. A similar pattern of metal concentration was recorded Pb> Cd> in both fish species.

HUMAN HEAVY METAL EXPOSURE

The three main ways that humans are exposed to harmful heavy metals in the environment are by ingestion, inhalation, and skin absorption. In underdeveloped nations, people are more likely to be exposed to harmful metals (Eqani *et al*., 2016). In general, especially in poorer nations, individuals lack awareness and understanding regarding heavy metal exposure and its effects on human health (Afrin *et al*., 2015). Heavy metals can be present in the environment and at work, exposing people to them. While exposure to such chemicals in the general environment is referred to as nonoccupational or environmental exposure, occupational exposure refers to human exposure to toxic chemicals at work. In mining and industrial settings, where workers may breathe in dust and particulate matter containing metal particles, workers are exposed to heavy metals. Workers who extract gold via amalgamation are exposed to vaporized mercury. The blood levels of the heavy metals Cr, Ni, Cd, and Pb were considerably greater in welders with occupational lengthy exposure to welding fumes than in controls, and they also had elevated oxidative stress (Mahmood *et al*., 2015). The main way that people are exposed to Cd and other hazardous heavy metals found in tobacco leaves is through cigarette smoking. For the majority of people, ingesting heavy metals through food and water is a primary source of exposure. Industrialization, urbanization, and the global economy's fast growth have all contributed to an increase in industrial and agricultural activity. These operations run the risk of introducing harmful heavy metals into the water, air, and soil. Growing human foods in heavy metal-contaminated medium causes these elements to bioaccumulate in the human food chains, where they eventually make their way into the human body (Järup, 2003).

CONCLUSION

Many researches confirm the contamination of fish and its products with lead, cadmium, arsenic and mercury. The pollution increases whenever the place of fish collection is from areas close to populated industrial areas. In addition, the process of converting fish into fish products increases the concentration of heavy metals.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

REFERENCES

Afrin, R., Mia, M.Y., Ahsan, M.A., Akbor, A., 2015. Concentration of Heavy Metals in Available Fish Species (Bain, *Mastacembelus armatus*; Taki, *Channa punctatus* and Bele, *Glossogobius giuris*) in the Turag River, Bangladesh: Heavy Metal Concentration in Bangladesh Fish. PJSIR. 58, 104-110.

Ahmed, A.M, Hussein, M.A., Wahdan, A., Shaheen, H., 2020. Reflection of Environmental Toxins on the Chemical Quality of the African Catfish. EJABF. 24, 497-508.

Ahmed, H.A., Hussein, M.A., El-Ashram, A.M., 2013. Some zoonotic bacteria in Zagazig, Egypt, with the molecular detection of Listeria monocytogenes virulence genes. Vet. Ital. 49, 299-308.

Ajiboye, O.O., Yakubu, A.F., Adams, T.E., 2011., A review of polycyclic aromatic hydrocarbons and heavy metal contamination of fish from fish farms. JASEM, 15, 235-238.

Al-Ghanim, K. A., Mahboob, S., Seemab, S., Sultana, S., Sultana, T., Al-Misned, F., Ahmed, Z., 2016. Monitoring of trace metals in tissues of Wallago attu (lanchi) from the Indus River as an indicator of environmental pollution. Saudi J. Biol. Sci. 23, 72-78.

Ali, H., Ali, W., Ullah, K., Akbar, F., Khan, H., 2019. Assessment of Cu and Zn in water, sediments and in the carnivorous fish, Channa gachua from River Swat and River Barandu, Malakand Division, Pakistan. Iran J Sci Technol Trans A Sci. 43, 773-783.

Aljabryn, D.H., 2022. Heavy metals in some commercially fishery products marketed in Saudi Arabia. Food Sci. Technol. 42.1-8.

Ariyaee, M., Azadi, N. A., Majnoni, F., Mansouri, B., 2015. Comparison of metal concentrations in the organs of two fish species from the Zabol Chahnimeh Reservoirs, Iran BECT. 94, 715-721.

Arulkumar, A., Paramasivam, S., Rajaram, R., 2017. Toxic heavy metals in commercially important food fishes collected from Palk Bay, Southeastern India. Mar. Pollut. Bull. 119, 454-459.

Dwivedi, A.C., Tiwari, A., Mayank, P., 2015. Seasonal determination of heavy metals in muscle, gill and liver tissues of Nile tilapia, *Oreochromis niloticus* (Linnaeus, 1758) from the tributary of the Ganga River, India. Zool. Ecol. 25, 166-171.

Egbe, A.M., Tabot, P.T., Fonge, B.A., Ngole-Jeme, V.M., 2023. Heavy metal exposure risk associated with ingestion of *Oreochromis niloticus* and Coptodon kottae harvested from a lacustrine ecosystem. Environ. Monit. Assess. 195, 427-435.

Eqani, S., Khalid, R., Bostan, N., Saqib, Z., Mohmand, J., Rehan, M., Shen, H., 2016. Human lead (Pb) exposure via dust from different land use settings of Pakistan: A case study from two urban mountainous cities. Chemosphere 155, 259-265.

Frantzen, A., Maage, A., Duinker, A., Julshamn, K., Iversen, S.A., 2015. A baseline study of metals in herring (*Clupea harengus*) from the Norwegian sea, with focus on mercury, cadmium, arsenic and lead. Chemosphere 127, 164–170.

Hajrić, D., Smajlović, M., Antunović, B., Smajlović, A., Alagić, D., Tahirović, D., Poljak, V., 2022. Risk assessment of heavy metal exposure via consumption of fish and fish products from the retail market in Bosnia and Herzegovina. Food Control 133, 108631.

Hussein, M.A., Hammad, O.S., Tharwat, A.E., Darwish, W.S., Sayed-Ahmed, A., Zigo, F., Farkašová, Z., Rehan, I.F., 2022. Health risk assessment of organochlorine pesticide residues in edible tissue of seafood. Front. Vet. Sci. 9, 1042956.

Hussein, M.A., Merwad, A.M., Elabbasy, M.T., Suelam, I.I., Abdelwahab, A.M. Taha, M.A., 2019. Prevalence of Enterotoxigenic Staphylococcus aureus and Shiga Toxin Producing *Escherichia coli* in fish in Egypt: quality parameters and public health hazard. J. Vector Borne Dis.19, 255-264.

IARC (International Agency for Research on Cancer), 2016. Monographs on the identification of carcinogenic hazards to humans. https://monographs.iarc.fr/agents-classified-by-the-iarc/ .

Järup, L., 2003. Hazards of heavy metal contamination. Br. Med. Bull. 68, 167-182.

Javed, M., Usmani, N., 2015. Stress response of biomolecules (carbohydrate, protein and lipid profiles) in fish Channa punctatus inhabiting river polluted by Thermal Power Plant effluent. Saudi J. Biol. Sci. 22, 237-242.

Khaled, A., 2009. Trace metals in fish of economic interest from the west of Alexandria, Egypt. Chem Ecol. 25, 229-246.

Kumar, B., Senthil Kumar, K., Priya, M., Mukhopadhyay, D., Shah, R., 2010. Distribution, partitioning, bioaccumulation of trace elements in water, sediment and fish from sewage fed fish ponds in eastern

Kolkata, India. Environ. Toxicol. Chem. 92, 243-260.

Loutfy, N., Fuerhacker, M., Tundo, P., Raccanelli, S., El Dien, A.G., Ahmed, M.T., 2006. Dietary intake of dioxins and dioxin-like PCBs, due to the consumption of dairy products, fish/seafood and meat from Ismailia city, Egypt. Sci Total Environ. 370, 1–8.

Mahmood, Q., Wang, J., Pervez, A., Meryem, S.S., Waseem, M., Ullah, Z., 2015. Health risk assessment and oxidative stress in workers exposed to welding fumes. Toxicol Environ Chem. 97, 634-639.

Mansouri, B., Ebrahimpour, M., Babaei, H., 2012. Bioaccumulation and elimination of nickel in the organs of black fish (*Capoeta fusca*). Toxicol Ind Health 28, 361-368.

Mendoza, L.C., Nolos, R.C., Villaflores, O.B., Apostol, E.M., Senoro, D.B., 2023. Detection of Heavy Metals, Their Distribution in Tilapia spp., and Health Risks Assessment. Toxics. 11, 286-292.

Mitra, A., Barua, P., Zaman, S., Banerjee, K., 2012. Analysis of trace metals in commercially important crustaceans collected from UNESCO protected world heritage site of Indian Sundarbans. TrJFAS 12, 53-66.

Morshdy, A.E.M., Darwish, W.S., Daoud, J.R.M., Sebak, M.A.M., 2019. Estimation of metal residues in *Oreochromis niloticus* and Mugil cephalus intended for human consumption in Egypt: a health risk assessment study with some reduction trials. J. Cons. Protect. Food Saf. 14, 81-91.

Morshdy, A.E., Darwish, W.S., Hussein, M.A., Mohamed, M.A., Hussein, M.M., 2021a. Lead and cadmium content in Nile tilapia (*Oreochromis niloticus*) from Egypt: a study for their molecular biomarkers. Sci. Afr. 12, 1-8.

Morshdy, A.E., Hafez, A.E., Darwish, W.S., Hussein, M.A., Tharwat, A.E., 2013. Heavy metal residues in canned fishes in Egypt. Jpn. J. Vet. Res. 61, S54-S57.

Morshdy, A.E., Hussein, M.A., Darwish, W.S., Yousef, R.E., Tharwat, A.E., 2021b. Residual contents of selected heavy metals in commercial canned fish in Egypt: dietary intakes and health risk assessment. Slov. Vet J. 58, 101-107.

Morshdy, A.E.M., Hussein, M.A., Mohamed, M.A.A., Hamed, E., El-Murr, A.E., Darwish, W.S., 2022. Tetracycline residues in tilapia and catfish tissue and the effect of different cooking methods on oxytetracycline and doxycycline residues. J. Cons. Protect. Food Saf. 17, 387-393.

Nishijo, M., Nambunmee, K., Suvagandha, D., Swaddiwudhipong, W., Ruangyuttikarn, W., Nishino, Y., 2017. Gender-Specific Impact of Cadmium Exposure on Bone Metabolism in Older People Living in a Cadmium-Polluted Area in Thailand. Int. J. Environ. Res. Public Health 14, 401-406.

Rahman, M.S., Molla, A.H., Saha, N., Rahman, A., 2012. Study on heavy metals levels and its risk assessment in some edible fishes from Bangshi River, Savar, Dhaka, Bangladesh. Food Chem. 134, 1847-1854.

Rajeshkumar, S., Li, X., 2018. Bioaccumulation of heavy metals in fish species from the Meiliang Bay, Taihu Lake, China. Toxicol. Rep. 5, 288-295.

Reichard, J. F., Puga, A., 2010. Effects of arsenic exposure on DNA methylation and epigenetic gene regulation. Epigenomics. 2, 87-104.

Sallam, K.I., Abd-Elghany, S.M., Mohammed, M.A., 2019. Heavy Metal Residues in Some Fishes from Manzala Lake, Egypt, and Their Health-Risk Assessment. J. Food Sci. 84, 1957-1965.

Sattari, M., Bibak, M., Vajargah M.F., Faggio C., 2020. Trace and major elements in muscle and liver tissues of Alosa braschnikowy from the South Caspian Sea and potential human health risk assessment. J. Mater. Environ. Sci. 11, 1129-1140.

Sattari M, Namin, J.I, Bibak M, Vajargah, M.F, Faggio C, Haddad, M.S., 2019. Trace and Macro Elements Bioaccumulation in the Muscle and Liver Tissues of Alburnus chalcoides from the South Caspian Sea and Potential Human Health Risk Assessment. J. Environ. Chem. Eng. 4, 13-19.

Sivaperumal, P., Sankar, T.V., Nair, P.V., 2007. Heavy metal concentrations in fish, shellfish and fish products from internal markets of India vis-a-vis international standards. Food Chem. 102, 612-620.

Tucker, B.W., 1997. Overview of current seafood nutritional issues: Formation of potentially toxic products, in: Shahidi F, Jones Y, Kitts DD (Eds.), Seafood safety, processing and biotechnology. Techonomic Publishing Co. Inc., Lancaster, PA (USA).

Winiarska-Mieczan, A., Florek, M., Kwiecień, M., Kwiatkowska, K., Krusiński, R., 2018. Cadmium and lead content in chosen commercial fishery products consumed in Poland and risk estimations on fish consumption. Biol. Trace Elem. Res.182, 373-380.

Xu, J., Sheng, L., Yan, Z., Hong, L., 2014. Blood Lead and Cadmium Levels of Children: A Case Study in Changchun, Jilin Province, China. The West Indian Med J. 63, 29–33.

Yabe, J., Nakayama, S.M., Ikenaka, Y., Yohannes, Y.B., Bortey-Sam, N., Oroszlany, B., Muzandu, K., Choongo, K., Kabalo, A.N., Ntapisha, J., Mweene, A., Umemura, T., Ishizuka, M., 2015. Lead poisoning in children from townships in the vicinity of a lead-zinc mine in Kabwe, Zambia. Chemosphere 119, 941–947.