CARPATHIAN JOURNAL OF FOOD SCIENCE AND TECHNOLOGY

journal homepage: **http://chimie-biologie.ubm.ro/carpathian_journal/index.html**

IMPACTS OF HEAVY METALS IN SEED CROPS AND OIL SEED ON HUMAN HEALTH: A TREAT TO FOOD SAFETY- REVIEW

Firouzeh Nazari[1], Adel Mirza Alizadeh[2], Mahsa Alikord[3], Rana Dizaji[4], Zahra Torki[4], Shahram Shoeibi[5], Mir-Jamal Hosseini[6,✉], Talat Ghane[5], Roya Khosrokhavar[5,✉]

[1] Food and Drug Administration, Iran University of Medical Sciences, Tehran, Iran.
[2] Student Research Committee, Department of Food Technology, Faculty of Nutrition Sciences and Food Technology/National Nutrition and Food Technology Research Institute, Shahid Beheshti University of Medical Sciences, Tehran, Iran.
[3] Department of Environmental Health, Food Safety Division, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran.
[4] Department of Food Safety and Hygiene, School of Public Health, Zanjan University of Medical Sciences, Zanjan, Iran.
[5] Food and Drug Laboratory Research Center, Food and Drug Administration, MOH & ME, Tehran, Iran.
[6] Department of Pharmacology and Toxicology, School of Pharmacy, Zanjan University of Medical Sciences, Zanjan, Iran.
✉ jamal_hossini@yahoo.com; mhosseini@zums.ac.ir; khosrokhavar_r@yahoo.com

https://doi.org/10.34302/crpjfst/2023.15.2.10

Article history:
Received:
12 December 2022
Accepted:
12 May 2023

Keywords:
Heavy Metals;
Potentially Toxic Elements;
Vegetable Oils and Fats;
Contamination;
Human.

ABSTRACT

The dramatic distribution of heavy metals in the 21st century is one of the most important concern in human health and the environment. A wide range of heavy metals has been detected in various environmental and food matrices due to their bio-accumulative and persistent properties. To prevent any health problems and toxicity from heavy metals in human due to their worldwide consumption, guidelines on the maximum residue level (MRL) in oilseeds have been established. This review has been done to assess vegetable and seed oil/fat and their benefits, nutritional value and applications, as well as sources and occurrence of heavy metals in vegetable and seed oil/fat, effects of heavy metals on nutrient quality of oilseed and impact on human health. The most common heavy metals, which can found in oil and oilseeds/fats, are arsenic (As), lead (Pb), cadmium (Cd), mercury (Hg), nickel (Ni) and chromium (Cd). Coexistence of heavy metals in the food commodities may lead to synergistic toxic interactions among heavy metals. In this regard, to minimize the health effects of heavy metals by consumption of plant and seed oil/fat, besides increasing regular surveillance and monitoring, revising the maximum permissible level of heavy metals is necessary.

1. Introduction

1.1. Major concern of toxic metals in foods

Food contamination has come to be a major concern and importance in food safety for human health. Food contamination can result from a number of events occurring among the food chain such as external environmental pollution, naturally occurring phytotoxins , bacterial toxins, the addition of chemicals during processing techniques, as well as emerging chemical hazards such as the potentially toxic elements (PTEs) (Kuswandi, Futra, & Heng, 2017). Heavy metals come in elemental, organic and inorganic forms. The exposure of heavy metals has become a global concern in recent years due to the global, stability, non-biodegradability and bioaccumulation potential. The presence of these metals in agricultural soils and consequently their accumulation in plants are considered one of the most serious environmental problems in the world. Undeniably, the distinguished less amount of some metals as essential metals is important for biological activity; and they play important roles in vital metabolic pathways such as copper (Cu), iron (Fe), manganese (Mg) and zinc (Zn) but exposure to more amount of these metals might be highly toxic. Also, the presence of non-essential metals such as arsenic (As), cadmium (Cd), lead (Pb), nickel (Ni), chromium (Cr) and mercury (Hg), which have been identified as contaminants by the world organizations, is not only needed for natural biological function, but also rapidly lead to toxicity (Rai, Lee, Zhang, Tsang, & Kim, 2019).

Heavy metals can be released into environments from either natural sources such as explosive volcanoes and burning forests or through human activities (Zhang, Huang, Dong, Hu, & & Akhtar, 2017). Obviously, human resources have a greater share of these contaminants. Human activities include mining, steel and iron metallurgy industries, vehicular pollution, applying the fertilizer and pesticides in agriculture, mercury-cadmium or cadmium-nickel batteries, lead-containing ceramics and glass, mercury thermometers, etc (El-Kady & Abdel-Wahhab, 2018). Characterizations of metals, they have adverse effects on human and vital organisms (their non-biodegradable characterization, their long biological half-lives and accumulation in body organs) (Tang, Huang, & Pan, 2014). It seems mitochondrial dysfunction and oxidative stresses are suggested as important mechanisms of metal toxicity and triggering the programmed cell death pathway (Hassani, et al., 2015; M-J Hosseini, et al., 2016; Mir-Jamal Hosseini, Shaki, Ghazi-Khansari, & Pourahmad, 2013). As dietary intake is the main route of exposure to heavy metals for most people via handling and processing of foods as well as from the farm to the point of consumption, maximum levels for heavy metals in foodstuffs have been set by different regulatory international organizations such as European Union (EU), Codex Alimentarius Commission (CAC) and U.S. Food and Drug Administration (FDA). These regulations establish maximum permission levels (MLs), tolerable weekly intake (TWI), or provisional tolerable weekly intake (PTWI) for these metals in a type of vegetable oils and fats. Heavy metal uptake by oil seeds might pose a threat to human health. The objective of the present study is to highlight the impact of heavy metals in plant and seed oil/fat and human health. In this regard, this paper covers plant and seed oil/fat and their benefits, nutritional value and applications, sources and occurrence of heavy metals in them. Furthermore, the effects of heavy metals on nutrient quality of seed oil/fat and impact on the health of human are discussed.

1.2. Plant and Seed Oil/Fat in Human Diet

Edible oils that are originated from plants and seeds including coconut oil, corn oil, cottonseed oil, olive oil, palm oil, peanut oil, rapeseed/canola oil, safflower oil, sesame oil, soybean oil and sunflower oil are generally used in industrial food manufacturing and household consumption universally. Edible oil of seeds and plants are known as important in the food technology. The statistics show that global production of vegetable oils has been increasing from since the early 2000s and reached about 207.5 million tons worldwide in 2019-2020. However, as with all food products, there is the possibility for potentially toxic contaminants to occur in oils such as heavy metals.

2. Can Heavy Metals Accumulate in Plant and Seed Oils/Fat?

Oil of seeds and plants have well-organized mechanisms to absorb essential nutrients from the soil. The root system of plants, along with chelating agents, can dissolve and absorb micronutrients and heavy metals even at very low concentrations.

Transmission of pollutants is diffused through the process of evapotranspiration and translated from the roots to other parts. Heavy metals uptake by the plant use four mechanisms of phytoestruction, phytoacetylation, rhizofiltration and phyto-volatilization (Salido, Hasty, Lim, & Butcher, 2003). Heavy metal accumulation occurs more often in the edible parts of plants, which may reduce yield and quality of crops and is dangerous to human and animal health. Some heavy metals such as Pb, Al, and Cd are suggested to cause damage in some body organs even at very low concentrations, and healthy plants may sometimes contain heavy metal concentrations that are toxic to mammals (F. Chen, et al., 2007). Plant tolerance for various heavy metals involves processes of detoxification of internal metals that may be through intracellular or complex with cellular ligands such as organic acids, cysteine and low molecular weight thiols (Mnasri, et al., 2015). Species and cultivar characteristics have been studied in the process of uptake and distribution of heavy metals in plant organs. Like the accumulation of more Pb in the root than in the stem and leaves in the sunflower or the accumulation of Cd and Zn in the leaf more than the seed, but the opposite holds for Cu and Ni (Dhiman, et al., 2017). In another study, Cu, Zn, Cd and Pb were higher in sunflower seeds and in another study of heavy metal contamination, the amount of Cd in sunflower seeds was higher (Dhiman, et al., 2017). Several studies reveal that oilseeds might be an accumulator for some toxic trace elements which could enter into plants and their oil (Manzoor, Sharma, & Wani, 2018). The origin of metals in the oil could be from plant growth media, like heavy metal contaminated soil. Heavy metals with natural source are not available to the plant, however, excess heavy meals due to presence of industrial factories, near agricultural area and disposal of industrial wastes, pesticide contamination residues, sewage sludge are available to living organisms (Rizwan, et al., 2017).

In recent years, there has been a significant increase in the study of the effects of soil contamination on plants as well as the effect of production stages on heavy metal content in plant and seed oil. Indisputably, the high exposure of these metals have been confirmed to have negative effects to human health. In one of the first studies conducted by Garrido et al. (1994) on level of metals (Na, K, Ca, Mg, Cu, Zn and Fe) in some Spanish edible oils, the samples showed higher values than the maximum permitted by FAO/WHO (for Cu and Fe, respectively, 18.3% and 2.8%)(Garrido, Frías, Díaz, & Hardisson, 1994). Mendil et al. (2009) investigated the concentration of some metals (Fe, Mn, Zn, Cu, Pb, Co, Cd, Na, K, Ca and Mg) in olive oil, hazelnut oil, sunflower oil, margarine, butter and corn oil samples produced in Turkey by using Atomic absorption spectrometry (AAS) technique. The concentrations of trace element in the samples were found to be 291.0-52.0, 1.64-0.04, 3.08-1.03, 0.71-0.05, 0.03-0.01, 1.30-0.50, 84.0-0.90, 50.1-1.30, 174.2-20.8 and 20.8-0.60 µg/g for Fe, Mn, Zn, Cu, Pb, Co, Na, K, Ca, and Mg, respectively. Cd was found to be 4.57-0.09 µg/kg. The high heavy metal and mineral accumulation levels in the samples were found in olive oil for Cu, Pb, Co, margarine for Fe, K, corn oil for Zn, Mn, butter for Na, Mg, sunflower oil for Ca and hazelnut oil for Cd, respectively (Mendil, Uluözlü, Tüzen, & Soylak, 2009). In another study, Szyczewski et al. (2016) evaluated the level of Cu, Zn, Mn, Fe, Pb and Cd in linseed oil, rapeseed oil and soybean oil. In addition, the effect of technological production processes on metals concentration was also investigated. The significant concentrations of Fe, Mg and Zn were observed in oilseeds. Determination of the concentrations of some toxic elements in plant and seed oil in Zaria, northern Nigeria have shown the level of metals (Na, Cd, Pb, Cr, Al, Cu, Mn, and Ni) in the different varieties of oils. The highest and lowest metal concentrations were observed in Na and Cu in all samples respectively. The concentrations ranged from 19.10-110.6, 0.34-2.77, 0.01-0.34, 0.05-0.84, 0.02-0.25, 0.01-0.08, 0.14-0.91, 0.34-0.97 mg/kg of Na, Cd, Pb, Cr, Al, Cu, Mg and Ni

(Ogabiela, et al., 2010). Pehlivan et al. (2008) evaluated some inorganic metals (Cu, Fe, Mn, Co, Cr, Pb, Cd, Ni, and Zn) in edible oils by inductively coupled plasma atomic emission spectroscopy (ICP-OES). The highest metal concentrations were measured as Cu in almond oil (0.0850 mg/kg), Fe in corn oil (0.0352 mg/kg), Mg in soybean oil (0.0220 mg/kg), Co in sunflower oil and almond oil (0.0040 mg/kg), Cr in almond oil (0.0010 mg/kg), Pb in virgin olive oil (0.0074 mg/kg), Cd in sunflower oil (0.0045 mg/kg), Ni in almond oil (0.0254 mg/kg) and Zn in almond oil (0.2870 mg/kg) (Pehlivan, Arslan, Gode, Altun, & Özcan, 2008). Farzin and Moassesi (2014) have determined the metal contents of four edible oils (olive oil, canola oil, and sunflower oil and soybean oil) produced in Iran by using microwave-assisted acid digestion. The results have shown that the concentration of Ni, Mg, Zn, Cu, Fe, Ca and Mg were in the range of 0.91–2.17, 0.14–1.76, 3.58–9.54, 0.18–0.68, 7.78- 28.93, 21.42–78.52, 5.34–36.49 µg/g, respectively. Result of Pb and Cd were found to be 4.56– 15.82 and 1.87–8.58 µg/kg (Farzin & Moassesi, 2014). Mohammadpourfard et al. (2015) have analyzed the heavy metals in apricot and almond oils. The results showed the average of the most important toxic metals detected in apricot oil samples was as follows 721.72 µg/kg for Al, 15 µg/kg for Cd, 18 µg/kg for Pb, 14 µg/kg for As and <1 µg/kg for Hg. Furthermore, the average of heavy metals detected in almond oil samples was as follows 1019.73 µg/kg for Al, 10 µg/kg for Cd, 21 µg/kg for Pb and 11 µg/kg for As and <1 µg/kg for Hg. Also, in the studied samples, Al had the highest concentrations among all metals (Mohammadpourfard, Shariatifar, Jahed-Khaniki, & Ebadi-Fathabad, 2015). Ashraf and Khobar (2014) determined Cu, Zn, Fe, Mn, Cd, Pb and As in different varieties of edible oils consumed in Saudi Arabia. The concentrations of Cu, Zn, Fe, Mg, Pb and As were observed in the range of 0.035 - 0.286, 0.955 - 3.10, 17.3 - 57.8, 0.178 - 0.586, 0.011 - 0.017 and 0.011 - 0.018 µg/g, respectively. Cadmium was found to be in the range of 2.36 - 6.34 ng/g (Muhammad Waqar Ashraf & Khobar, 2014). Torki et al. (2018) investigation in seeds of Iran from 331 seed samples such as sunflower, pumpkin, watermelon, & jabooni (red watermelon seeds) revealed that that Pb was detected in 33% of the samples with a median and mean level of 66 and 77 ± 28 µg/kg, respectively. The level of Pb in 39% of positive samples was higher than 100 µg/kg. The highest frequency of lead contamination was detected in the pumpkin seeds (52%), followed by the sunflower seeds (30%), the watermelon seeds (25%), and the jabooni seeds (15%) (Torki, Mehrasebi, Nazari, Kamali, & Hosseini, 2018). Furthermore, Cd was found in 17% of the samples with an average level of 264 ± 177.3 µg/kg. In addition, none of the watermelon and jabooni seed samples was contaminated with Cd. The highest concentration (731 µg/kg) and incidence (35%) of Cd were recorded in the sunflower seeds (Torki, et al., 2018).

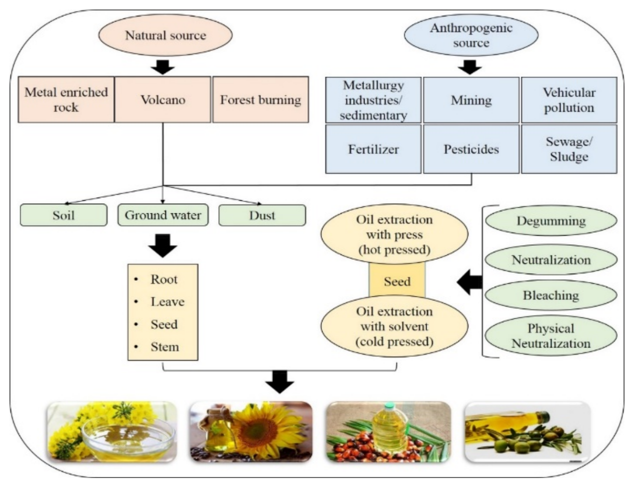

Figure 1. Sources of heavy metals contaminant in oilseed and mechanism entrance

In the following, more details about the source of pollution and toxicity of some of the most important heavy metals will be given. In addition to natural agents, oil production processes can also increase or decrease the amount of heavy metals in the final product. Refining edible oil treated processes, including degumming, neutralization, bleaching, and deodorizing and inevitably contact with the corrosion milling equipment surface at high temperature, storage and packaging excess oil heavy metal contents (Ansari, et al., 2009) (**Figure 1**).

2.1. Lead in Seed or Edible Oil

According to European Food Safety Authority (EFSA) in 2012, the mean concentration of Pb in poppy, sesame, sunflower and pumpkin seed samples was reported between 37-42, 21-30, 34-39 and 32-40 µg/g, respectively (EFSA, 2012b). Another study in the Swedish market showed mean concentrations of Pb in sunflower and pumpkin seeds were 3.1 and 7.9 µg/g, respectively (Rodushkin, Engström, Sörlin, & Baxter, 2008). In Brazil, Pb level in cotton, sunflower and soybean seeds were 22±1, 11±3 and 20±8 µg/g respectively (Chaves, et al., 2010). Another study in Bulgaria showed Pb mainly accumulates in peanut and corn seeds especially in regions around a metal smelter with higher concentration range between 5200 and 9600 µg/g (Stefanov, Seizova, Yanishlieva, Marinova, & Popov, 1995). The result data of research by Chen et al. (2010) showed a different Pb level in seeds with the highest and lowest amount in sunflower and cotton seeds, respectively (Z. F. Chen, et al., 2010). Pb concentration in 9 varieties of edible oils in China was reported in ranges of 9-18 µg/g. Also, Pb concentration in soybean, corn, peanut, sesame, cottonseed, olive and sunflower oil was 15±1,9 ±1, 12 ±1, 18 ±2,11±1,13±1, 10 ±1 µg/g, respectively (Zhu, Fan, Wang, Qu, & Yao, 2011). In Turkey, Pb level in sunflower, hazelnut, canola, corn and olive oils was reported 99-134 µg/kg (Bakircioglu, Kurtulus, & Yurtsever, 2013). One more investigation in some oil samples from Spain and Morocco showed different levels of Pb in two countries in the range of 3.1-92.5 µg/kg (Bakkali, Martos, Souhail, & Ballesteros, 2012) (**Table 1**).

2.2. Cadmium in Seed or Edible Oil

The results of one investigation reported that the mean Cd concentration in soybeans was 0.006–0.028 mg / kg [34]. The average concentration of Cd in the olive oil, corn oil and sunflower oil-containing food product was between 1.1-7.1, 4.0-5.9 and 4.1-7.2µg/kg respectively (Mataveli, Pohl, Mounicou, Arruda, & Szpunar, 2010). Determination of Cd concentration in edible oil produced in Turkey by Bakircioglu et al. (2013) show that the concentration of chromium concentration is between 0.030 to 0.053 mg/kg for Hazelnut and Sunflower (FDA, 2020). Other studies have been performed on Cd in oilseeds and edible oils, which can be regarded in **Table 1**. In the study in Brazil, mean concentrations of Cd in cotton, sunflower , Tung and soybean seeds were reported <0.006 µg/kg, 0.038 µg/kg, <0.006 and <0.006µg/g, respectively (Chaves, et al., 2010).

2.3. Arsenic in Seed or Edible Oil

The investigation of EFSA, in 17 European countries, showed that mean concentrations of inorganic As in 119 samples of linseed, 90 samples of poppy seed, 139 samples of sesame seed, 170 samples of sunflower seed, 200 samples of rape seed, 15 samples of mustard seed and 129 samples of pumpkin seed were 20.8, 32.6, 20.1, 25.1, 33.2, 33.7 and 10.5 µg/g, respectively. In Swedish market, mean concentrations of As in sunflower, pumpkin seeds and peanut were 6.1, 5.1 and 6.6 µg/g, respectively (Rodushkin, et al., 2008). The compression of suggested previous studies showed the different levels of arsenic contamination in seeds in different regions and countries, which could relate to the use of agricultural, fertilize industrial waste, mining activities and pesticides. The mean occurrence level of inorganic As content in olive oils and other edible oil was 0.8 µg/kg (Cubadda, D'Amato, Aureli, Raggi, & Mantovani, 2016). Determination of metal content in oil samples in Spain and Morocco shows As concentration range is between 0.56-6.2 µg/kg (Bakkali, et al., 2012) (**Table 1**).

2.4. Mercury in Seed or Edible Oil

Mercury (Hg) has long been recognized as a dangerous metal related to its naturally occurrence in the environment, bioaccumulation and transportation in a variety of foods (EFSA, 2012c). Although major Hg has been detected in marine foods, which sometimes contain small amounts of inorganic Hg. In several countries, foodstuffs have shown that plant samples typically contain low concentrations of Hg (Khanna, 2011). From 2002 to 2011, 20 European countries submitted approximately 60,000 analytical results of Hg concentrations; 98 % of the data were on total Hg with mean concentrations 3.7 µg/g in 556 samples of Oilseeds (Alexander, et al., 2012). Rodushkin et al. (2008) result on the Swedish market showed that mean concentrations of Hg in sunflower and pumpkin seeds were 0.13 and 0.19 µg/g, respectively (Rodushkin, et al., 2008) (**Table 1**).

2.5. Chromium in Seed or Edible Oil

EFSA database in 2012 supposed that a concentration of Cr (III) was 214 -227.3 µg/g in 455 oilseed samples (EFSA, 2014b). Also, the study in 2008 on the Swedish market, reported the mean concentrations of Cr in sunflower, pumpkin seeds and peanut were 5.3, 11 and 12 µg/g, respectively (Rodushkin, et al., 2008). Average concentration of Cr in soybean based edible product was between 560-5880 µg/kg (Barbosa, et al., 2015). Determination of Cr concentration in edible oil that was produced in Turkey by Bakircioglu et al. (2013) shows that chromium concentration range is between 0.126 and 7.106 mg/kg (Bakircioglu, et al., 2013) (**Table 1**).

2.6. Nickel in Seed or Edible Oil

The results of investigation in 15 different European countries showed the high mean levels Ni were in 'Legumes, nuts and oilseeds' (~ 2000 µg/g), certain types of chocolate (Cocoa) products (3800 µg/g), and 'Cocoa beans and cocoa products' (9500 µg/g) among 18885 food and 25700 drinking water samples (Davide. Arcella, Gergelova, Innocenti, López-Gálvez, & Steinkellner, 2019). In Swedish market, mean concentrations of Ni in sunflower, pumpkin seeds and peanuts were 2500, 3100 and 850 µg/g, respectively (Rodushkin, et al., 2008). In the study in Brazil, mean concentrations of Ni in cotton, sunflower and soybean seeds were reported 310±20, 1010±380 and 1640±1070 µg/g, respectively (Chaves, et al., 2010). Determination of nickel in Nigerian foods shows Ni content in some oils (groundnut oil and vegetable oil) was (570 and 330 µg/kg). It is related to food processing, the natural geochemistry of the soils and chemicals used as fertilizer and pesticide (Onianwa, Lawal, Ogunkeye, & Orejimi, 2000). Bakkali et al. (2012) performed a study for heavy metal determination in vegetables and oils and Ni content in oils was between (1.0-25.6 µg/kg) (Bakkali, et al., 2012) (**Table 1**).

3. Co-existence of heavy metals and anions

Epidemiologic studies have shown that co-exposure to heavy metals has been investigated by different researches. It is reported that renal dysfunction of Cd and Pb co-exposure can induce additive or synergistic interactions or even new adverse effects which are not observed following single exposure of toxic metals on occupational workers (X. Chen, et al., 2019). Agrawal et al. (2015) concluded that co-exposure of mercury, arsenic and lead resulted in a significant increase in oxidative stress in kidneys and liver (Agrawal, Bhatnagar, & Flora, 2015). The finding of data in animal study indicated co-exposure to non-toxic levels of Cd and fluoride can potentiate their individual hepatotoxicity through disruption of the cellular redox status, inflammation, and apoptosis pathway (Arab-Nozari, et al., 2020).

Table 1. Mean concentration of heavy metals in seeds and oilseeds

Heavy Metals	Seed/Oils	Mean Concentration	Range (µg/kg)	Country	Year	Ref.
Pb	Olive oil	29.2 µg/kg	4.4-92.5	Spain	2012	(Bakkali, et al., 2012)
	Corn oil	8.52 µg/kg	3.1-13	Spain	2012	(Bakkali, et al., 2012)
	Sunflower oil	18.42 µg/kg	6.4-39.4	Spain	2012	(Bakkali, et al., 2012)
	Types of vegetable oils	0.003 mg/kg	-	French	2012	(Arnich, et al., 2012)
	Sunflower oil	0.056 mg/kg	-	Turkey	2013	(Bakircioglu, et al., 2013)
	Hazelnut oil	0.059 mg/kg	-	Turkey	2013	(Bakircioglu, et al., 2013)
	Canola oil	0.073 mg/kg	-	Turkey	2013	(Bakircioglu, et al., 2013)
	Corn oil	0.048 mg/kg	-	Turkey	2013	(Bakircioglu, et al., 2013)
	Olive oil	0.071 mg/kg	-	Turkey	2013	(Bakircioglu, et al., 2013)
	Soybean	-	<29–110	Brazil	2015	(Barbosa, et al., 2015)
	Cotton seed	0.022µg/kg	-	Brazil	2010	(Chaves, et al., 2010)
	Sunflower	0.011µg/kg	-	Brazil	2010	(Chaves, et al., 2010)
	Tung	<0.006 µg/kg	-	Brazil	2010	(Chaves, et al., 2010)
	Soybean	0.02 µg/kg	-	Brazil	2010	(Chaves, et al., 2010)
	Curcas bean	0.062 µg/kg	-	Brazil	2010	(Chaves, et al., 2010)
	Fodder turnip	0.025 µg/kg	-	Brazil	2010	(Chaves, et al., 2010)
	Castor bean	0.043 µg/kg	-	Brazil	2010	(Chaves, et al., 2010)
	Olive oil flavored with pepper	0.984 µg/g	-	Iran	2019	(Ziarati, et al., 2019)
	Olive oil flavored with fungi	12.33 µg/g	-	Iran	2019	(Ziarati, et al., 2019)
	Olive oil flavored with vegetable	10.76 µg/g	-	Iran	2019	(Ziarati, et al., 2019)
	Olive oil	10.111 µg/g	-	Iran	2019	(Ziarati, et al., 2019)
	Vegetable oils	-	11-17	KSA	2014	(M. W. Ashraf, 2014)
	Rapeseed oil	0.09 mg/kg	-	Poland	2016	(Szyczewski, et al., 2016)
	Soybean oil	0.08 mg/kg	-	Poland	2016	(Szyczewski, et al., 2016)
	Linseed oil	< 0.06 mg/kg	-	Poland	2016	(Szyczewski, et al., 2016)
Cd	Olive oil	23.35 µg/kg	1.1-7.1	Spain	2012	(Bakkali, et al., 2012)
	Corn oil	3.62 µg/kg	4.0-5.9	Spain	2012	(Bakkali, et al., 2012)

	Sunflower oil	5.5 µg/kg	4.1-7.2	Spain	2012	(Bakkali, et al., 2012)
	Oilseeds	371 µg/kg	-	Europe	2012	(EFSA, 2012a)
	Types of vegetable oils	0.0014mg/kg	-	French	2012	(Arnich, et al., 2012)
	Sunflower	0.053 mg/kg	-	Turkey	2013	(Bakircioglu, et al., 2013)
	Hazelnut	0.030 mg/kg	-	Turkey	2013	(Bakircioglu, et al., 2013)
	Canola	0.040 mg/kg	-	Turkey	2013	(Bakircioglu, et al., 2013)
	Corn	0.036 mg/kg	-	Turkey	2013	(Bakircioglu, et al., 2013)
	Olive	0.036 mg/kg	-	Turkey	2013	(Bakircioglu, et al., 2013)
	Soybean	-	<6–28	Brazil	2015	(Barbosa, et al., 2015)
	Cotton seed	<0.006 µg/kg	-	Brazil	2010	(Chaves, et al., 2010)
	Sunflower	0.038 µg/kg	-	Brazil	2010	(Chaves, et al., 2010)
	Tung	<0.006 µg/kg	-	Brazil	2010	(Chaves, et al., 2010)
	Soybean	<0.006 µg/kg	-	Brazil	2010	(Chaves, et al., 2010)
	Curcas bean	<0.006 µg/kg	-	Brazil	2010	(Chaves, et al., 2010)
	Fodder turnip	0.053 µg/kg	-	Brazil	2010	(Chaves, et al., 2010)
	Castor bean	<0.006 µg/kg	-	Brazil	2010	(Chaves, et al., 2010)
	Olive oil flavored with pepper	Not detected	-	Iran	2019	(Ziarati, et al., 2019)
	Olive oil flavored with fungi	1.004 µg/g	-	Iran	2019	(Ziarati, et al., 2019)
	Olive oil flavored with vegetable	0.078 µg/g	-	Iran	2019	(Ziarati, et al., 2019)
	Olive oil	0.096 µg/g	-	Iran	2019	(Ziarati, et al., 2019)
	Vegetable oil		2.36 - 6.34	KSA	2014	(M. W. Ashraf, 2014)
	Rapeseed oil	0.03 mg/kg	-	Poland	2016	(Szyczewski, et al., 2016)
	Soybean oil	0.01mg/kg	-	Poland	2016	(Szyczewski, et al., 2016)
	Linseed oil	0.03 mg/kg	-	Poland	2016	(Szyczewski, et al., 2016)
As	Olive oil	51.25 µg/kg	0.38-7.2	Spain	2012	(Bakkali, et al., 2012)
	Corn oil	4.1 µg/kg	5.1-6.2	Spain	2012	(Bakkali, et al., 2012)
	Sunflower oil	15.62 µg/kg	2.3-6.5	Spain	2012	(Bakkali, et al., 2012)

	Types of vegetable oils	0.014 mg/kg	-	French	2012	(Arnich, et al., 2012)
	Soybean	-	<7–40	Brazil	2015	(Barbosa, et al., 2015)
	Olive oil	0.8 ng/ g	-	Italy	2016	(Cubadda, et al., 2016)
	Vegetable oils	0.8 ng/ g	-	Italy	2016	(Cubadda, et al., 2016)
	Olive oil flavored with pepper	0.00020	-	Iran	2019	(Ziarati, et al., 2019)
	Olive oil flavored with fungi	0.00040 µg/g	-	Iran	2019	(Ziarati, et al., 2019)
	Olive oil flavored with vegetable	0.00030 µg/g	-	Iran	2019	(Ziarati, et al., 2019)
	Olive oil	0.00040 µg/g	-	Iran	2019	(Ziarati, et al., 2019)
	Vegetable oil	-	11-18	KSA	2014	(M. W. Ashraf, 2014)
Ni	Olive oil	25.57 µg/kg	3.4-17.9	Spain	2012	(Bakkali, et al., 2012)
	Corn oil	32.72 µg/kg	2.3-25.6	Spain	2012	(Bakkali, et al., 2012)
	Sunflower oil	9.82 µg/kg	1.0-21.5	Spain	2012	(Bakkali, et al., 2012)
	Types of vegetable oils	0.039 mg/kg	-	French	2012	(Arnich, et al., 2012)
	Soya oil	4.462 µg/kg	-	EFSA	2019	(Davide. Arcella, et al., 2019)
	Sunflower oil	1.566 µg/kg	-	EFSA	2019	(Davide. Arcella, et al., 2019)
	Rape seed	762 µg/kg	-	EFSA	2019	(Davide. Arcella, et al., 2019)
	Linseed	-	0–300	EFSA	2019	(Davide. Arcella, et al., 2019)
	Sunflower	1.490 mg/kg	-	Turkey	2013	(Bakircioglu, et al., 2013)
	Hazelnut	1.420 mg/kg	-	Turkey	2013	(Bakircioglu, et al., 2013)
	Canola	1.097 mg/kg	-	Turkey	2013	(Bakircioglu, et al., 2013)
	Corn	0.772 mg/kg	-	Turkey	2013	(Bakircioglu, et al., 2013)
	Olive	0.836 mg/kg	-	Turkey	2013	(Bakircioglu, et al., 2013)
	Soybean	-	740–4780	Brazil	2015	(Barbosa, et al., 2015)
	Cotton seed	0.31 µg/kg	-	Brazil	2010	(Chaves, et al., 2010)
	Sunflower	1.01 µg/kg	-	Brazil	2010	(Chaves, et al., 2010)
	Tung	1.97 µg/kg	-	Brazil	2010	(Chaves, et al., 2010)
	Soybean	1.64 µg/kg	-	Brazil	2010	(Chaves, et al., 2010)
	Curcas bean	0.90 µg/kg	-	Brazil	2010	(Chaves, et al., 2010)

	Fodder turnip	0.60 µg/kg	-	Brazil	2010	(Chaves, et al., 2010)
	Castor bean	1.30 µg/kg	-	Brazil	2010	(Chaves, et al., 2010)
	Olive oil flavored with pepper	Not detected	-	Iran	2019	(Ziarati, et al., 2019)
	Olive oil flavored with fungi	10.230 µg/g	-	Iran	2019	(Ziarati, et al., 2019)
	Olive oil flavored with vegetable	12.340 µg/g	-	Iran	2019	(Ziarati, et al., 2019)
	Olive oil	14.180 µg/g	-	Iran	2019	(Ziarati, et al., 2019)
Hg	Edible oils	0.005 mg/kg	-	French	2012	(Arnich, et al., 2012)
	Sunflower	0.13 µg/g	-	Sweden	2008	(Rodushkin, et al., 2008)
	Pumpkin	0.19 µg/g	-	Sweden	2008	(Rodushkin, et al., 2008)
Cr	Sunflower	2.780 mg/kg	-	Turkey	2013	(Bakircioglu, et al., 2013)
	Hazelnut	0.428 mg/kg	-	Turkey	2013	(Bakircioglu, et al., 2013)
	Canola	0.450 mg/kg	-	Turkey	2013	(Bakircioglu, et al., 2013)
	Corn	0.224 mg/kg	-	Turkey	2013	(Bakircioglu, et al., 2013)
	Olive	0.646 mg/kg	-	Turkey	2013	(Bakircioglu, et al., 2013)
	Soybean	-	1040-1120	Brazil	2015	(Barbosa, et al., 2015)
	Olive oil	2. 85 µg/kg	-	Spain	2012	(Bakkali, et al., 2012)
	Corn oil	5.05 µg/kg	-	Spain	2012	(Bakkali, et al., 2012)
	Sunflower oil	5.32 µg/kg	-	Spain	2012	(Bakkali, et al., 2012)

4. Regulation, Incidence and Human Health Effects of Heavy Metals in Vegetable Oils/Fats

The ability of heavy metals to accumulate in seeds can pose serious health risk issues, such as gastrointestinal cancer (El-Kady & Abdel-Wahhab, 2018), immunological mechanisms, mental retardation (Raj & Maiti, 2019) and malnutrition (Dickin, Schuster-Wallace, Qadir, & Pizzacalla, 2016), as well as accumulated through diet in bones or adipose tissue, leading to the loss weakened immunological defenses (Davide. Arcella, et al., 2019). It is also reported, that some heavy metals (e.g. Al, Cd, Mn and Pb) are capable of causing intrauterine growth retardation (A. Khan, Khan, Khan, Qamar, & Waqas, 2015). In this regard, maximum residue limited levels (MRLs) have been developed by various organizations for the maximum permission level of heavy metals in oils (**Table 2**).

Table 2. Maximum permission level of heavy metals in vegetable oils

Heavy Metals	Codex Alimentarius Commission	Ref.	U.S. Food and Drug Administration	Ref.	European Commission Regulation	Ref.
Pb	0.1 mg/kg	(Commission, 1999)	10 mg/kg (Rapeseed oil standard)	(FDA, 2020)	0.1 mg/kg wet weight	(EFSA, 2012a)
Cd	0.05 mg/kg	(Mir Mohammad Makki & Ziarati, 2017)	10 mg/kg (Rapeseed oil standard)	(FDA, 2019)	-	-
As	0.1 mg/kg	(Commission, 1999)	3 mg/kg (Rapeseed oil standard)	(FDA, 2019)	-	-
Hg	-	-	10 mg/kg (Rapeseed oil standard)	(FDA, 2019)	-	-
Ni	Maximum content in Hydrogenated food oils: 0.2 to 1 mg/kg	(Commission, 2012)	0.5 mg/kg (Menhaden oil standard)	(FDA, 2019)	Maximum content in hydrogenated vegetable oils/fats: 20 mg/kg	(Davide. Arcella, et al., 2019)

5. Heavy Metal Impacts on Human Health

Cadmium (Cd) is a natural source in the environment lying under volcanos and rock weathering. In addition, anthropogenic activities increase Cd levels in agricultural soils, air and water. Cd is usually classified as a carcinogenic metal and is usually not found in the pure form, and high concentrations of Cd are found in association with Pb and Zn ores (Satarug, Vesey, & Gobe, 2017). Industrial wastes, rechargeable nickel-cadmium batteries, tobacco and phosphorus fertilizers are major sources of Cd in soil and crops, and industrial wastes are a way for Cd to enter into the aquatic environment and then be accessed by fishes (El-Kady & Abdel-Wahhab, 2018). It is suggested air born Cd is the dominant source of crop contamination around pyrometallurgic smelters (Smolders, 2001) and sewage sludge (D Arcella, Cappe, Fabiansson, di Domenico, & Furst, 2012). Soil contamination by Cd result in increasing Cd uptake by some plants, depending on inherent genetic and physiological characteristics and soil pH (D Arcella, et al., 2012). Some plants such as sunflower accumulate cadmium more than other crops (Vanderpool & Reeves, 2001). Exposure to Cd inhalation stimulates the respiratory tract, which is much higher in tobacco than in cigarettes. But, food is the main source of Cd exposure in the non-smoking general population (Schwarz, Lindtner, Blume, Heinemeyer, & Schneider, 2014). Although Cd absorption through dietary exposure is relatively low (3-5%), it has a very long biological half-life (7-17 years) (D Arcella, et al., 2012). Then, prolonged intake of Cd specifically, accumulates in liver and kidney (Vanderpool & Reeves, 2001). This compound is a non-essential element in foods and exposure may pose adverse health effects, including kidney damage and possibly also bone effects and fractures and increases the risk of lung, endometrial, bladder, and breast cancer (D Arcella, et al., 2012). Cd is classified as ‘carcinogenic to humans’ (group I) by the International Agency for Research on Cancer (IARC) (EFSA, 2012a). In 2010, the Joint FAO/WHO Expert Committee on Food Additives set a provisional tolerable monthly intake of 25 µg/g body weight for Cd several studies determined Cd levels in food stuff (D Arcella, et al., 2012). In terms of the target tissue, this kidney is the most important target tissue in the kidney and it is done by protein proteinuria. Threshold of Cd level that has been reported, is about 200 µg (Zang & Bolger, 2014). Thus, long-term Cd consumption, mainly through foods, leads to serious problems including kidney failure. Consumption of Cd-contaminated food products can cause bone pain (such as Itai-Itai disease), cardiovascular disease and kidney damage (EFSA, 2012a). Osteoporosis, bone malformation, and ultimately kidney dysfunction are symptoms of the disease associated with the mining industry. However, the liver also plays an important role in minimizing Cd toxicity (Baba, et al., 2013). On the other hand, in the long-term exposure, this process reduces metallothionein activity, thereby increasing ROS levels and inducing oxidative stress in brain cells (El-Kady & Abdel-Wahhab, 2018).

Lead (Pb) is a natural environmental contaminant as a result of wide spread anthropogenic activities such as mining, smelting, battery manufacturing. Pb is naturally present in the earth's crust and is used in industry due to its physicochemical properties such as softness, corrosion resistance (Wani, Ara, & & Usmani, 2015). Lead oxide (PbO) is used as a waterproofing layer in earthenware and porcelain, becoming a source of contamination in reaction to acidic foods. In addition, lead acetate is used as a pesticide and color product (Asaduzzaman, et al., 2017). Also, lead nitrate has many applications in packaging, for example, textile printing, oxidizing, sensitizing, and rodenticides (García-Lestón, Méndez, Pásaro, & Laffon, 2010). Pb is now used as a stabilizer in pipes and is a major contributor to the total daily intake of lead in the United States in drinking water (El-Kady & Abdel-Wahhab, 2018). Besides, Pb from fossil fuels and vehicles and its diffusion into the air and into the surface and gradually different parts of plants are other factors in the exposure of this metal. General population exposure to Pb occurs via food, drinking water, air, soil and dust. Although food is the main source of Pb exposure through processing, handling and packaging process chronic toxicity of Pb because of long half-life in the body is of most concern because of the human health risk (EFSA, 2010). The IARC classified inorganic lead as probably carcinogenic to humans (Group 2A) in 2006. In children, there is an association between blood level of Pb and reducing Intelligence Quotient (IQ) score and functions of cognition in a dose-dependent manner. There is an association between elevate blood pressure and kidney dysfunction at relatively low blood lead level (EFSA, 2010). Pb enters the bloodstream after the process of digestion, absorption and accumulates throughout the body organs and soft tissues of the brain. According to previous studies, due to the similarity of Pb^{2+} and Ca^{2+}, Pb is substituted in bone (Tahir, et al., 2017). As a result, Ca deficiency causes more Pb to accumulate in the bone. Elevated levels of Pb in the blood have been observed in children with neurological symptoms, such as lack of concentration and difficulty in communication skills. Pb contamination negatively affects mental development and neurological and cardiovascular diseases in humans, especially children. Also, Pb can accumulate in the bone and can lead to gastrointestinal colitis, leukemia, hypertension, kidney damage, brain disorders and thrombotic diseases (Fang, et al., 2014). High concentrations of Pb (N-methyl-D-aspartate) also play an important role in cognitive functions and eventually impair memory and learning. Pb is also said to be effective in anemia (El-Kady & Abdel-Wahhab, 2018). In addition, Pb has a toxic effect on the reproductive system with increasing abnormal sperm count in males (Brochin, et al., 2008). Besides, lead reduces antioxidant activity (El-Kady & Abdel-Wahhab, 2018). There is a strong association between accumulation and elevated lead levels in humans and the risk of diseases associated with central nervous system disorders such as Parkinson's disease and multiple sclerosis (MS) (Ghoreishi, Mohseni, Amraei, Mirza Alizadeh, & Mazloomzadeh, 2015).

Inorganic arsenic (As) is a human carcinogen and is classified in group I of carcinogenic compounds in humans (EFSA, 2009). The most important pathway of As in humans is contaminated food and drinking water. For example, rice, which is the dominant food in some countries contamination with mineral As, can be a serious risk for contamination with this metal (Praveena & Omar, 2017). Groundwater and contaminated water, obviously, are one of the main ways to absorb the metal in contaminated plants. The toxicity of As depends on its chemical form, route and duration of exposure. The mineral forms of As consist of arsenite, As (III) and arsenate, As (V) are highly toxic compared to organic forms (Feldmann & Krupp, 2011).

Chronic oral exposure to inorganic As causes cancers and a wide range of adverse health effects in many organs. Neurotoxicity, immunotoxicity, skin lesions, cardiovascular diseases, toxic effect on developmental stages of life abnormal glucose metabolism, type II diabetes appear to be related to chronic ingestion of As (EFSA, 2014a). Methylation of As exposure is produced and has a direct effect on oxidative stress following exposure (Kesici, 2016). Inorganic, reduced glutathione, glutathione peroxidase and glutathione synthase are released. ROS mitochondrial membrane potential in As poisoning decreases and Ca balance within the cell is disrupted. Thus, it opens the membrane pores and increases the release of cytochrome c, leading to apoptosis (Gao, Li, Xu, Liu, & Liu, 2018).

In various forms of mercury (Hg), half-life of elimination depends on dose, species, strain and sex are different. Absorption and retention have great rates in neonates and children. Methyl mercury in food after absorption in the intestine, binds to plasma proteins in the bloodstream and accumulates in the human brain (EFSA, 2012c). In 2003, the Joint FAO/WHO Expert Committee on Food Additives (JECFA) established the provisional tolerable weekly intake (PTWI) for CH_3Hg in the range of 1.6 μg/kg body weight. Then, in 2010, the JECFA revised the PTWI of 4 μg/g/body weight for inorganic Hg (Arnich, et al., 2012; EFSA, 2012c).

Chromium (Cr) is available to the environment in three states: elemental chromium, trivalent chromium (Cr^{3+}); and hexagonal chromium (Cr^{6+}) (El-Kady & Abdel-Wahhab, 2018). Cr is ubiquitous in food such as oils, fat, meat and cereals (EFSA, 2014b). The panel considered health outcomes of Cr intake and concludes in healthy subjects, Cr has no beneficial effects. Natural presence or emissions from anthropogenic activities are a different environmental source of Cr in food. Additional source of Cr in food could be preparation of food with stainless steel containers, food processors and utensils. Groundwater contamination with chromium is contaminated by hexagonal chromium due to health risks during the process of stainless steel production, textile dyes (Kaprara, et al., 2015). Therefore, irrigation with the wastewater of these industries is the main source of contamination of this heavy metal in the soil. This increases the level of Cr in the soil and subsequently increases its uptake by plants (Liao, et al., 2011). IARC has classified chromium VI as group I of carcinogenic compounds in humans and animals while chromium III was not classifiable as a carcinogen compound to humans (Group III) (Hartwig, 1998). Cd can lead to human cancer through inhalation. Cr^{6+} by NADPH produces hydroxyl radical (OH), which increases p53 elimination in epithelial cells, resulting in apoptosis. Cr is distinct from other metals owing to its capability to interact mainly and directly with DNA to form DNA-DNA cross links and DNA-protein (Nickens, Patierno, & Ceryak, 2010). Target organ for chrome are liver, kidney, spleen with Half-life 35-40 hours. The EFSA panel on contaminants in the food chain established a tolerable daily intake (TDI) of 300 μg Cr (III)/kg body weight per day from the lowest No Observed Adverse Effect Level (NOAEL) identified in a chronic oral toxicity study that amounted to 286 in rats (EFSA, 2014b).

Nickel (Ni) is a widespread natural component of the crust of earth to about 0.01%.

Nickel emission into environment is due to anthropogenic activities, industrial processes and technological sources. Deposition of air born nickel-bearing particles on soil and surface water result in accumulation in plant and animal. In the general population food is the main exposure route for Ni with an average daily intake of about 0.1-0.3 mg (Schaumlöffel, 2012). It is not essential for human, although it is higher in plants and in some animal species is an essential micronutrient (EFSA). Ni toxicological effects to organisms are dependent on species form of diet composition and fasting status as well as exposure way and concentration (Schaumlöffel, 2012). The most stable of the oxidation state forms are divalent form in food and drinking water and mono form of Ni. Ni compounds are classified by IARC as carcinogenic to humans (Group 1) (Chervona, Arita, & Costa, 2012). The WHO established a Tolerable Daily Intake (TDI) of 11 µg Ni /kg body weight per day. (Davide. Arcella, et al., 2019).

6. Effects of heavy metals on nutrient quality of oilseed

Recent studies suggest that seed oils are adversely affected by the heavy metal exposures oil content decrease and fatty acid composition changes in edible oil (R. Khan, Srivastava, Abdin, & Manzoor, 2013). The presence of heavy metals in plant oils may have a negative influence on the quality of oils, causing changes to their taste and smell. Such changes in oil quality, called “taste reversion,” are caused by the occurrence of the following metals: Fe, Cu, Cr, Zn, and Mn, which, through their ability to form radicals, facilitates the process of oxidation of fats (Zioła-frankowsk, Frankowski, & Szyczewski, 2011). Metal contamination of plants leads to oxidative damage of proteins, lipids and nucleic acid, which in turn is responsible for various physiological diseases. The potential toxicity of heavy metals even at low concentrations is due to the stability of their organic and inorganic ligands (Fergusson, 1990).

7. Conclusions

Food safety is a major public concern worldwide and food consumption has been identified as the major pathway for human exposure to contaminants. Vegetable oils and fats are widely used in cooking and alimentary, cosmetic, pharmaceutical and chemical industries, which are beneficial and popular due to their cholesterol-lowering effect. Oilseeds might concentrate some toxic metals, which could enter into vegetables and their oil. The main source of contamination of plant and seed oils and fats with heavy metals is their direct migration from arable land to oil plants. Moreover, during technological processes, the enrichment of oils with heavy metals can occur. The factors that influence the content of heavy metals in plants and seeds also include individual properties of plants used in oil production. Occurrence of heavy metals in food commodities and their uptake can pose toxic effects in human. Hence, the incidence of heavy metals in different vegetable oils and fats was observed practical way to reduce the consumer intake of heavy metals is to increase monitoring. Besides, the co-occurrence of some heavy metals, or heavy metals and some anions in a single food, which can lead to synergistic interactions, indicates the necessity for further investigation of mechanistic toxicity, also, revising the international regulations in foods to minimize the potential health threats through vegetable oils and fats consumption.

8.References

Agrawal, S., Bhatnagar, P., & Flora, S. (2015). Changes in tissue oxidative stress, brain biogenic amines and acetylcholinesterase following co-exposure to lead, arsenic and mercury in rats. *Food and Chemical Toxicology, 86*, 208-216.

Alexander, J., Benford, D., Boobis, A., Eskola, M., Fink-Gremmels, J., Fürst, P., Heppner, C., Schlatter, J., & van Leeuwen, R. (2012). Risk assessment of contaminants in food and feed. *Efsa Journal, 10*(10), s1004.Ansari, R., Kazi, T. G., Jamali, M. K., Arain, M. B., Wagan, M. D., Jalbani, N., Afridi, H. I., &

Shah, A. Q. (2009). Variation in accumulation of heavy metals in different verities of sunflower seed oil with the aid of multivariate technique. *Food Chemistry, 115*(1), 318-323.

Arab-Nozari, M., Mohammadi, E., Shokrzadeh, M., Ahangar, N., Amiri, F. T., & Shaki, F. (2020). Co-exposure to non-toxic levels of cadmium and fluoride induces hepatotoxicity in rats via triggering mitochondrial oxidative damage, apoptosis, and NF-kB pathways. *Environmental Science and Pollution Research*, 1-11.

Arcella, D., Cappe, S., Fabiansson, S., di Domenico, A., & Furst, P. (2012). Cadmium dietary exposure in the European population. *Eur Food Saf Authority (EFSA), 10*, 2551.

Arcella, D., Gergelova, P., Innocenti, M. L., López-Gálvez, G., & Steinkellner, H. (2019). Occurrence data of nickel in feed and animal exposure assessment. *EFSA Journal, 17*(6), e05754.

Arnich, N., Sirot, V., Rivière, G., Jean, J., Noël, L., Guérin, T., & Leblanc, J.-C. (2012). Dietary exposure to trace elements and health risk assessment in the 2nd French Total Diet Study. *Food and Chemical Toxicology, 50*(7), 2432-2449.

Asaduzzaman, K., Khandaker, M. U., Baharudin, N. A. B., Amin, Y. B. M., Farook, M. S., Bradley, D., & Mahmoud, O. (2017). Heavy metals in human teeth dentine: A bio-indicator of metals exposure and environmental pollution. *Chemosphere, 176*, 221-230.

Ashraf, M. W. (2014). Levels of selected heavy metals in varieties of vegetable oils consumed in kingdom of saudi arabia and health risk assessment of local population. *Journal of the Chemical Society of Pakistan, 36*(4), 691-698.

Ashraf, M. W., & Khobar, A. (2014). Levels of selected heavy metals in varieties of vegetable oils consumed in kingdom of Saudi Arabia and health risk assessment of local population. *Journal of Chemical Society Pakistan, 36*, 691-698.

Baba, H., Tsuneyama, K., Yazaki, M., Nagata, K., Minamisaka, T., & Tsuda, T., et al. (2013). The liver in itai-itai disease (chronic cadmium poisoning): Pathological features and metallothionein expression. *Modern Pathology, 26*, 1228-1234.

Bakircioglu, D., Kurtulus, Y. B., & Yurtsever, S. (2013). Comparison of extraction induced by emulsion breaking, ultrasonic extraction and wet digestion procedures for determination of metals in edible oil samples in Turkey using ICP-OES. *Food chemistry, 138*(2), 770-775.

Bakkali, K., Martos, N. R., Souhail, B., & Ballesteros, E. (2012). Determination of heavy metal content in vegetables and oils from Spain and Morocco by inductively coupled plasma mass spectrometry. *Analytical Letters, 45*(8), 907-919.

Barbosa, J. T. P., Santos, C. M., Peralva, V. N., Flores, E. M., Korn, M., Nóbrega, J. A., & Korn, M. G. A. (2015). Microwave-assisted diluted acid digestion for trace elements analysis of edible soybean products. *Food chemistry, 175*, 212-217.

Brochin, R., Leone, S., Phillips, D., Shepard, N., Zisa, D., & Angerio, A. (2008). The cellular effect of lead poisoning and its clinical picture. *Georgetown University Journal of Health Sciences, 5*(2).

Chaves, E. S., dos Santos, E. J., Araujo, R. G., Oliveira, J. V., Frescura, V. L. A., & Curtius, A. J. (2010). Metals and phosphorus determination in vegetable seeds used in the production of biodiesel by ICP OES and ICP-MS. *Microchemical Journal, 96*(1), 71-76.

Chen, F., Dong, J., Wang, F., Wu, F., Zhang, G., Li, G., Chen, Z., Chen, J., & Wei, K. (2007). Identification of barley genotypes with low grain Cd accumulation and its interaction with four microelements. *Chemosphere, 67*(10), 2082-2088.

Chen, X., Zhu, G., Wang, Z., Zhou, H., He, P., Liu, Y., & Jin, T. (2019). The association between lead and cadmium co-exposure and renal dysfunction. *Ecotoxicology and environmental safety, 173*, 429-435.

Chen, Z. F., Zhao, Y., Zhu, Y., Yang, X., Qiao, J., Tian, Q., & Zhang, Q. (2010). Health risks of heavy metals in sewage-irrigated soils and edible seeds in Langfang of Hebei province, China. *Journal of the Science of Food and Agriculture, 90*(2), 314-320.

Chervona, Y., Arita, A., & Costa, M. (2012). Carcinogenic metals and the epigenome: understanding the effect of nickel, arsenic, and chromium. *Metallomics, 4*(7), 619-627.

Commission, C. A. (1999). Codex standards for fats and oils from vegetable sources. *Codex-Stan*, 210-1999.

Commission, C. A. (2012). Joint FAO/WHO food standards programme codex committee on food additives. In *Forty Fourth Session. Inventory of Substances used as Processing Aids (IPA), Main List, FA/44 INF/03. 12 – 16 March 2012*). Hangzhou, China: New Zealand

Cubadda, F., D'Amato, M., Aureli, F., Raggi, A., & Mantovani, A. (2016). Dietary exposure of the Italian population to inorganic arsenic: The 2012–2014 Total Diet Study. *Food and Chemical Toxicology, 98*, 148-158.

Dhiman, S. S., Zhao, X., Li, J., Kim, D., Kalia, V. C., Kim, I.-W., Kim, J. Y., & Lee, J.-K. (2017). Metal accumulation by sunflower (Helianthus annuus L.) and the efficacy of its biomass in enzymatic saccharification. *PloS one, 12*(4).

Dickin, S. K., Schuster-Wallace, C. J., Qadir, M., & Pizzacalla, K. (2016). A Review of Health Risks and Pathways for Exposure to Wastewater Use in Agriculture. *Environ Health Perspect, 124*(7), 900-909.

EFSA. (2009). Panel on Contaminants in the Food Chain:Scientific Opinion on arsenic in food. *EFSA Journal, 7*(10), 1351.

EFSA. (2010). Panel on Contaminants in the Food Chain: Scientific Opinion on lead in food. *EFSA Journal, 8*(4), 1570.

EFSA. (2012a). Cadmium dietary exposure in the European population. *Efsa Journal, 10*(1), 2551.

EFSA. (2012b). Lead dietary exposure in the European population. *EFSA Journal, 10*(7), 2831.

EFSA. (2012c). Scientific Opinion on the risk for public health related to the presence of mercury and methylmercury in food. *EFSA Journal, 10*(12), 2985.

EFSA. (2014a). Dietary exposure to inorganic arsenic in the European population. *EFSA Journal, 12*(3), 3597.

EFSA. (2014b). Scientific Opinion on the risks to public health related to the presence of chromium in food and drinking water. *EFSA Journal, 12*(3), 3595.

El-Kady, A. A., & Abdel-Wahhab, M. A. (2018). Occurrence of trace metals in foodstuffs and their health impact. *Trends in Food Science & Technology, 75*, 36-45.

Fang, Y., Z. Nie, F. Liu, Q. Die, He, J., & Q. Huang. (2014). Concentration and health risk evaluation of heavy metals in market-sold vegetables and fishes based on questionnaires in beijing, china. . *Environmental Science and Pollution Research, 21*(19), 11401-11408.

Farzin, L., & Moassesi, M. E. (2014). Determination of metal contents in edible vegetable oils produced in Iran using microwave-assisted acid digestion. *Journal of Applied Chemical Research, 8*(3), 35-43.

FDA. (2019). CFR - Code of Federal Regulations Title 21, Direct Food Substances Affirmed As Generally Recognized As Safe. In CITE: 21CFR184.1555 ed.): US Food Drug Administration.

FDA. (2020). Lead in food, foodwares, and dietary supplements. In): US Food Drug Administration.

Feldmann, J., & Krupp, E. M. (2011). Critical review or scientific opinion paper: arsenosugars--a class of benign arsenic species or justification for developing partly speciated arsenic fractionation in foodstuffs? *Anal Bioanal Chem, 399*(5), 1735-1741.

Fergusson, J. (1990). The Heavy Elements: Chemistry, Environmental Impact and

Health Effects, Pergamon Press, Oxford, p. 551.

Gao, M., Li, C., Xu, M., Liu, Y., & Liu, S. (2018). LncRNA UCA1 attenuates autophagy-dependent cell death through blocking autophagic flux under arsenic stress. *Toxicol Lett, 284*, 195-204.

García-Lestón, J., Méndez, J., Pásaro, E., & Laffon, B. (2010). Genotoxic effects of lead: an updated review. *Environment international, 36*(6), 623-636.

Garrido, M. D., Frías, I., Díaz, C., & Hardisson, A. (1994). Concentrations of metals in vegetable edible oils. *Food Chemistry, 50*(3), 237-243.

Ghoreishi, A., Mohseni, M., Amraei, R., Mirza Alizadeh, A., & Mazloomzadeh, S. (2015). Investigation the amount of copper, lead, zinc and cadmium levels in serum of Iranian multiple sclerosis patients. *Journal of Chemical and Pharmaceutical Sciences, 8*, 40-45.

Hartwig, A. (1998). Carcinogenicity of metal compounds: possible role of DNA repair inhibition. *Toxicology Letters, 102*, 235-239.

Hassani, S., Yaghoubi, H., Khosrokhavar, R., Jafarian, I., Mashayekhi, V., Hosseini, M.-J., & Shahraki, J. (2015). Mechanistic view for toxic effects of arsenic on isolated rat kidney and brain mitochondria. *Biologia, 70*(5), 683-689.

Hosseini, M.-J., Jafarian, I., Farahani, S., Khodadadi, R., Tagavi, S., Naserzadeh, P., Mohammadi-Bardbori, A., & Arghavanifard, N. (2016). New mechanistic approach of inorganic palladium toxicity: impairment in mitochondrial electron transfer. *Metallomics, 8*(2), 252-259.

Hosseini, M.-J., Shaki, F., Ghazi-Khansari, M., & Pourahmad, J. (2013). Toxicity of vanadium on isolated rat liver mitochondria: a new mechanistic approach. *Metallomics, 5*(2), 152-166.

Kaprara, E., Kazakis, N., Simeonidis, K., Coles, S., Zouboulis, A. I., Samaras, P., et al., & (2015). Occurrence of Cr(VI) in drinking water of Greece and relation to the geological background. *Journal of Hazardous Material, 8*, 2-11.

Kesici, G. G. (2016). Arsenic ototoxicity. *Journal of Otology, 11*, 13-17.

Khan, A., Khan, S., Khan, M. A., Qamar, Z., & Waqas, M. (2015). The uptake and bioaccumulation of heavy metals by food plants, their effects on plants nutrients, and associated health risk: a review. *Environ Sci Pollut Res Int, 22*(18), 13772-13799.

Khan, R., Srivastava, R., Abdin, M., & Manzoor, N. (2013). Effect of soil contamination with heavy metals on soybean seed oil quality. *European Food Research and Technology, 236*(4), 707-714.

Khanna, P. (2011). Assessment of heavy metal contamination in different vegetables grown in and around urban areas. *Research Journal of Environmental Toxicology, 5*(3), 162.

Kuswandi, B., Futra, D., & Heng, L. Y. (2017). Chapter 15 - Nanosensors for the Detection of Food Contaminants. In A. E. Oprea & A. M. Grumezescu (Eds.), *Nanotechnology Applications in Food*, (pp. 307-333): Academic Press.

Liao, Y.-p., Wang, Z.-x., Yang, Z.-h., Chai, L.-y., Chen, J.-q., & Yuan, P.-f. (2011). Migration and transfer of chromium in soil-vegetable system and associated health risks in vicinity of ferro-alloy manufactory. *Transactions of Nonferrous Metals Society of China, 21*(11), 2520-2527.

Manzoor, J., Sharma, M., & Wani, K. A. (2018). Heavy metals in vegetables and their impact on the nutrient quality of vegetables: A review. *Journal of Plant Nutrition, 41*(13), 1744-1763.

Mataveli, L. R. V., Pohl, P., Mounicou, S., Arruda, M. A. Z., & Szpunar, J. (2010). A comparative study of element concentrations and binding in transgenic and non-transgenic soybean seeds. *Metallomics, 2*(12), 800-805.

Mendil, D., Uluözlü, Ö. D., Tüzen, M., & Soylak, M. (2009). Investigation of the levels of some element in edible oil samples produced in Turkey by atomic absorption spectrometry. *Journal of Hazardous Materials, 165*(1-3), 724-728.

Mir Mohammad Makki, F. S., & Ziarati, P. (2017). Lead And Cadmium Contamination In Flavored Olive Oil. In *3rd international congress on technology - engineering & science*). Kuala Lumpur - Malaysia.

Mnasri, M., Ghabriche, R., Fourati, E., Zaier, H., Sabally, K., Barrington, S., Lutts, S., Abdelly, C., & Ghnaya, T. (2015). Cd and Ni transport and accumulation in the halophyte Sesuvium portulacastrum: implication of organic acids in these processes. *Frontiers in plant science, 6*, 156-156.

Mohammadpourfard, I., Shariatifar, N., Jahed-Khaniki, G. R., & Ebadi-Fathabad, E. (2015). Determination of heavy metals in apricot (Prunus armeniaca) and almond (Prunus amygdalus) oils. *Iranian Journal of Health Sciences, 3*(1), 18-24.

Nickens, K. P., Patierno, S. R., & Ceryak, S. (2010). Chromium genotoxicity: a double-edged sword. *Chemico-biological interactions, 188*(2), 276-288.

Ogabiela, E., Yebpella, G., Ade-Ajayi, A., Mmereole, U., Ezeayanaso, C., Okonkwo, E., Oklo, A., Udiba, U., Mahmood, A., & Gandu, I. (2010). Determination of the level of some elements in edible oils sold in Zaria, northern Nigeria. *Global Journal of pure and applied sciences, 16*(3).

Onianwa, P., Lawal, J., Ogunkeye, A., & Orejimi, B. (2000). Cadmium and nickel composition of Nigerian foods. *Journal of Food Composition and Analysis, 13*(6), 961-969.

Pehlivan, E., Arslan, G., Gode, F., Altun, T., & Özcan, M. M. (2008). Determination of some inorganic metals in edible vegetable oils by inductively coupled plasma atomic emission spectroscopy (ICP-AES). *Grasas y Aceites, 59*(3), 239-244.

Praveena, S. M., & Omar, N. A. (2017). Heavy metal exposure from cooked rice grain ingestion and its potential health risks to humans from total and bioavailable forms analysis. *Food Chem, 235*, 203-211.

Rai, P. K., Lee, S. S., Zhang, M., Tsang, Y. F., & Kim, K. H. (2019). Heavy metals in food crops: Health risks, fate, mechanisms, and management. *Environ Int, 125*, 365-385.

Raj, D., & Maiti, S. K. (2019). Sources, toxicity, and remediation of mercury: An essence review. *Environmental monitoring and assessment, 199*(9), 566.

Rizwan, M., Ali, S., Abbas, F., Adrees, M., Zia-ur-Rehman, M., & Gill, R. (2017). Role of organic and inorganic amendments in alleviating heavy metal stress in oil seed crops. *Oil Seed Crops: Yield and Adaptations Under Environmental Stress, ed. P. Ahmad (Hoboken, NJ: John Wiley & Sons)*, 224-235.

Rodushkin, I., Engström, E., Sörlin, D., & Baxter, D. (2008). Levels of inorganic constituents in raw nuts and seeds on the Swedish market. *Science of the total environment, 392*(2), 290-304.

Salido, A. L., Hasty, K. L., Lim, J. M., & Butcher, D. J. (2003). Phytoremediation of arsenic and lead in contaminated soil using Chinese brake ferns (Pteris vittata) and Indian mustard (Brassica juncea). *Int J Phytoremediation, 5*(2), 89-103.

Satarug, S., Vesey, D. A., & Gobe, G. C. (2017). Current health risk assessment practice for dietary cadmium: Data from different countries. *Food and Chemical Toxicology, 106*, 430-445.

Schaumlöffel, D. (2012). Nickel species: analysis and toxic effects. *Journal of Trace Elements in Medicine and Biology, 26*(1), 1-6.

Schwarz, M. A., Lindtner, O., Blume, K., Heinemeyer, G., & Schneider, K. (2014). Cadmium exposure from food: the German LExUKon project. *Food Additives & Contaminants: Part A, 31*(6), 1038-1051.

Smolders, E. (2001). Cadmium uptake by plants. *International journal of occupational medicine and environmental health, 14*(2), 177-183.

Stefanov, K., Seizova, K., Yanishlieva, N., Marinova, E., & Popov, S. (1995). Accumulation of lead, zinc and cadmium in plant seeds growing in metalliferous habitats in Bulgaria. *Food Chemistry, 54*(3), 311-313.

Szyczewski, P., Frankowski, M., Zioła-Frankowska, A., Siepak, J., Szyczewski, T., & Piotrowski, P. (2016). A comparative study of the content of heavy metals in oils: linseed oil, rapeseed oil and soybean oil in technological production processes. *Archives of Environmental Protection, 42*(3), 37-40.

Tahir, M., Iqbal, M., Abbas, M., Tahir, M. A., Nazir, A., Iqbal, D. N., Kanwal, Q., Hassan, F., & Younas, U. (2017). Comparative study of heavy metals distribution in soil, forage, blood and milk. *Acta Ecologica Sinica, 37*(3), 207-212.

Tang, J., Huang, Z., & Pan, X.-D. (2014). Exposure assessment of heavy metals (Cd, Hg, and Pb) by the intake of local foods from Zhejiang, China. *Environmental geochemistry and health, 36*(4), 765-771.

Torki, Z., Mehrasebi, M., Nazari, F., Kamali, K., & Hosseini, M. (2018). Concentration and exposure assessments of cadmium and lead in pumpkin, sunflower, watermelon, and jabooni seeds collected in Iran. *Fruits, 73*(4).

Vanderpool, R. A., & Reeves, P. G. (2001). Cadmium absorption in women fed processed edible sunflower kernels labeled with a stable isotope of cadmium, 113Cd. *Environmental research, 87*(2), 69-80.

Wani, A. L., Ara, A., & & Usmani, J. A. (2015). Lead toxicity: A review. *Interdisciplinary Toxicology, 8*, 55-64.

Zang, Y., & Bolger, P. M. (2014). Toxic metals: Cadmium. *Encyclopedia of Food Safety, 2*, 346-348.

Zhang, H., Huang, B., Dong, L., Hu, W., & & Akhtar, M. S. (2017). Accumulation, sources and health risks of trace metals in elevated geochemical background soils used for greenhouse vegetable production in southwestern China. *Ecotoxicology and Environmental Safety, 137*, 233-239.

Zhu, F., Fan, W., Wang, X., Qu, L., & Yao, S. (2011). Health risk assessment of eight heavy metals in nine varieties of edible vegetable oils consumed in China. *Food and Chemical Toxicology, 49*(12), 3081-3085.

Ziarati, P., Makki, F. M., Vambol, S., & Vambol, V. (2019). Determination of toxic metals content in iranian and italian flavoured olive oil. *Acta Technologica Agriculturae, 22*(2), 64-69.

Zioła-frankowsk, A., Frankowski, M., & Szyczewski, P. (2011). Determination of heavy metals in vegetable oils. *Laboratorium, 5*(6), 58-60.

Acknowledgment

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.