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Research article

Toxic heavy metals of agricultural products in developing countries and its human health risk assessment: A study from Iran

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A R T I C L E I N F O

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A B S T R A C T

Food toxicity through heavy metals, particularly from cereal consumption, poses significant threats to human health. This study studied various toxic heavy metals (Pb, As, Cr, Cd, Co, Hg, and Ag) in cereal products and their human health risk assessment in Ilam province, Iran.

This study analyzed 30 samples of the most commonly cultivated cereals (wheat, rice, corn, pea, and lentil) in Ilam province. ICP-MS was used to measure the concentrations of selected toxic heavy metals.

According to the obtained results, only the rice samples had concentrations of As and Pb that exceeded Iran's national standards. Monte Carlo simulation showed that the 95th percentile (P95th) values of hazard quotient (HQ) for As in wheat and rice, Hg in wheat, and Pb in rice were above 1. Moreover, P95th values of incremental lifetime cancer risk (ILCR) for As in wheat and rice were above 10^{-4}

The findings showed that the consumption of wheat and rice in the Ilam province was a potential source of exposure to As, Pb, and Hg. This study recommends the necessity of monitoring heavy metals in cereal products to protect human health.

1. Introduction

Food safety and health are important issues for governments, producers, and consumers [1]. Food safety means the absence of harmful substances for the consumer's health or the presence of an acceptable level of it in food [2,3]. This issue is so important that the World Health Organization (WHO) has chosen its theme for 2021 as "Safe Food Today for a Healthy Tomorrow". Currently, many countries in the world are facing a severe food crisis. According to the Global Report on Food Crisis (GRFC), 155 million people in 55 countries/territories underwent acute food crisis in 2020. Of this population, 29.4 million live in the Middle East [4]. Nowadays, agricultural products play a vital role in human nutrition and health. With industrial development in the last few decades, food products especially agricultural ones have been affected by various pollutants through contaminated water, soil, fertilizers, and

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pesticides [5,6]. Heavy metals (HMs) are a group of metallic and metalloid minerals in the periodic table of elements that have a high density (at least 5 g/cm^3) and are very toxic to human health even in ppb concentrations [7,8]. HMs are a group of metallic and metalloid minerals in the periodic table of elements that have a high density (at least 5 g/cm^3) and are very toxic to human health even in ppb concentrations [9–11].

The carcinogenic properties of certain HMs, such as lead and cadmium, have been established, linking them to the development of gastrointestinal cancers [9,12]. Other health effects of HMs include high blood pressure, kidney and neurological problems, and behavioral and cardiovascular disorders [4,5]. Food contamination with HMs can lead to significant food chain issues. The stability, non-biodegradable nature, bioaccumulative properties, and toxic effects of HMs contribute to these problems [13]. However, the entrance of HMs to the human body is from different ways such as digestive, respiratory, and skin systems, more than 90 % of them enter the body through food consumption [14]. Environmental and agricultural product pollution by HMs happens through natural sources such as soil and water and artificial sources such as fertilizers, industrial wastewater, pesticides, etc. [15,16]. These contaminants are easily introduced to the plants through the roots and finally accumulate in the leaves and fruits [4]. In developing countries, due to the indiscriminate use of polluted water, fertilizers, and pesticides, the quality of agricultural products in terms of various pollutants, especially HMs, is disputed [17–19].

So far, many investigations have been done on the HMs amount in agricultural products in Iran. Some studies have reported a significant amount of HMs in the various products of vegetables [20,21] rice [22,23], red grape [24], saffron [25], wheat [26], pumpkin, sunflower, and watermelon [27], tomato and cucumber [28] lentil, peas, corn, and bean [29]. In this study, the concentrations of HMs including Pb, As, Cr, Cd, Co, Hg, and Ag in the most common agricultural products (wheat, rice corn, pea, and lentil) in Ilam province, Iran were determined. Moreover, HM consumption's carcinogenic and non-carcinogenic health risks were assessed.

2. Materials and methods

2.1. Study area

Ilam province, with coordinates of 33.6384°N 46.4226°E, is located in the west of Iran with an area of 20,164.11 km^2 and elevation from the sea level of 136–1450 m. According to the national census of 2016, the population of the province was 580,158 people. The province consists of 10 counties (Ilam, Chardavol, Sirvan, Ivan, Malekshahi, Badreh, Abdanan, Darrehshahr, Mehran, Dehloran). The province undergoes different climatic variations in winter (cold) and summer (hot and dry) with an average annual rainfall of 446.8 mm. Fig. 1 shows the location of Ilam province and its counties in Iran. About 68 % and 32 % of the population live in urban and rural areas, respectively. The main occupation of the people in the rural areas is agriculture and animal husbandry. Ilam province has 340,000 ha of agricultural land which is used by farmers every year.

2.2. Crops sampling

This cross-sectional investigation was done in 2020. According to the proposed list of the Ilam Agricultural Organization, wheat, rice, corn, pea, and lentil are the 5 main types of cereals and bean products that are cultivated in this province. Table 1 lists the agricultural products that are produced in the counties. Therefore, this study focused on these products. All of these products were

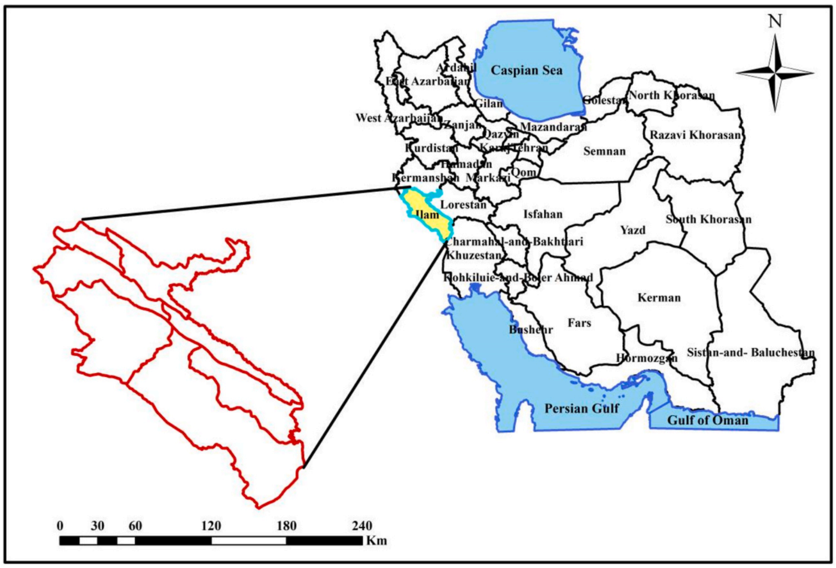

Fig. 1. The location of Ilam province and its counties in Iran.

collected from randomly selected 30 points (local farms and stores) throughout the province for HM measurement. Each sample consisted of 3–5 subsamples. The weight of the collected samples was 200–500 g. The samples were subsequently transported to the laboratory using shopping plastics and stored in a refrigerator at a temperature of 4 °C to maintain their integrity for the experiments.

2.3. Sample preparation

All of the used chemicals in this investigation were analytical grade without further purification. The glass containers that were used in the research were soaked in 10 % HNO_3 solution for 24 h and continuously rinsed with distilled water to ensure the reliability of the findings. To prepare samples, firstly, all the agricultural products were washed with tap water and then dried. Then, it was used to extract the toxic HMs (Pb, As, Cr, Cd, Co, Hg, and Ag). The wet digestion method was used to extract toxic HMs from the samples. The digestion procedure was conducted as follows: First, 0.5 g of the prepared sample was weighed and 1 mL of distilled water was added dropwise to moisten the sample. Then, 25–30 mL of HNO_3/H_2SO_4 digestion solution (1/2 v/v) was added to the sample. The mixture was left under the hood at room temperature for about 1 h. In continue the mixture was digested using a hot plate at 110 °C. Then 1 mL of concentrated HNO_3 was added into the mixture and the temperature was gradually raised and heating continued until white SO_3 fumes and a bright yellow, colorless, or pale sulfuric acid solution were observed. Finally, after cooling, the residue was dissolved in 2.5 mL of concentrated HCl made up to 50 mL with distilled water, and transferred to the Falcon tubes for analysis [30].

2.4. Analysis

HMs analysis was conducted by an inductively coupled plasma optical emission spectrometer (ICP-OES, Spectro Arcos, SPECTRO, Germany) with Torch type of Flared end EOP Torch 2.5 mm. The apparatus was set as follows: RF generator (1405 W), Argon was applied as plasma, auxiliary, and nebulizer gas. The flow of Plasma gas, auxiliary gas, and nebulizer gas were 13.0, 0.7, and 0.7 L/min, respectively. Thence, total sample uptake time, rinse time, and initial stabilization time were 240, 60, and preflush 60 s, respectively. There was no time for delay time and time between replicate analyses. The measurements were replicated three times to ensure accuracy and reliability. The frequency of the RF generator used during the experiments was set at 27.12 MHz, which corresponds to the resonance frequency. Also, the type of detector solid state and the spray chamber cyclonic were CCD and Modified Lichte, respectively [31].

2.5. Health risk assessment

To assess health risks, the ingestion route was considered as the intake route of HMs in the crops. Therefore, the estimated daily intake (EDI) through ingestion was first calculated. Then, the non-carcinogenic and carcinogenic risks were estimated using EDI and toxicity parameters. EDI (mg/kg. day) was calculated using Eq. (1) [32]:

$$\mathrm{EDI} = \frac{\mathrm{C} \times \mathrm{IR} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}} \quad (1)$$

Where C, IR, EF, ED, and BW represent the concentration of the stated metal in the wet weight of crops (mg/kg), rate of ingestion (g/person/day), exposure frequency (365 days/year), exposure duration (year), and body weight (kg), respectively. AT (EF × ED) is the average time exposure. AT for non-carcinogenic risk equals EF × ED, while for carcinogenic risk, it is EF × LE (Life expectancy). The values of these parameters are presented in Table 2. For non-carcinogenic risk assessment, the hazard quotient (HQ) is calculated using Eq. (2): [33].

$$\mathrm{Q} = \frac{\mathrm{EDI}}{\mathrm{RfD}} \quad (2)$$

Where RfD is the oral reference dose (Table 3).

The cumulative non-carcinogenic risk or total HQ (THQ) for all the studied metals is calculated by Eq. (3).

$$\mathrm{THQ} = \sum_{i=1}^{n} \mathrm{HQ}_i \quad (3)$$

Where HQi is HQ for heavy metal i, and n is the total number of HMs studied. Based on the US EPA report, non-carcinogenic risk is a

Table 1
The agricultural products in the Ilam counties.

Products	Counties
Wheat	Ilam, Dehloran, Abdanan, Mehran, Darreh Shahr, Malekshahi, Badreh, Sirvan, Chardavol, Ivan
Rice	Darreh Shahr, Chardavol, Sirvan, Ivan
Corn	Darreh Shahr, Dehloran, Mehran
Pea	Ilam, Chardavol, Sirvan, Ivan, Dehloran, Mehran
Lentil	Ilam, Chardavol, Sirvan, Ivan, Dehloran, Mehran

Table 2
Values of parameters used for health risk assessment [32,34,35].

Parameter	Child	Adult
EF (day/year)	Triangular (180, 345, 365)[a]	
ED (year)	Single value (6)	Single value (30)
BW (kg)[b]	Triangular (6.5, 15, 26.1)	Lognormal (68.4, 4.0)[b]
AT (days)	Single value (2190)	Single value (8760)
LE (year)	Single value (77.4)	Single value (77.4)
Ingestion Rate, IR, (g/person. day)		
Wheat	100	334
Rice	33	110
Corn	0.3	1
Pea	1.3	4
Lentil	1.3	4

[a] Triangular distribution (minimum, likeliest, maximum), Lognormal distribution (mean, standard deviation).

Table 3
Toxicity factors of the studied HMs [36,37].

Metals	RfD (mg/kg day)	CSF (1/(mg/kg day))
Ag	5.00×-10^{-3}	
As	3.00×10^{-4}	1.50×10^{0}
Cd	1.00×10^{-3}	
Co	2.00×10^{-2}	
Cr	1.50×10^{0}	
Hg	3.50×10^{-4}	
Pb	3.50×10^{-3}	

safe level when the value of HQ for the stated contaminant is ≤ 1. For HQ greater than 1, the incidence of non-carcinogenic effects is probable, and the possibility is increased at higher HQ values [32].

Eq. (4) was used to estimate incremental lifetime cancer risk (ILCR) attributed to the As content of crops:

$$ILCR = EDI \times CSF \tag{4}$$

Where CSF is the cancer slope factor. According to USEPA, among the studied HMs, As and Cd may pose carcinogenic risks through inhalation, but As is also carcinogenic through ingestion. Because ingestion is the sole intake route of the HMs in crops, the ingestion of As was selected to assess carcinogenic risk. The proposed CSF for As is presented in Table 3. ILCR is defined as the probability that an individual will develop cancer over a lifetime of exposure to a carcinogen. According to USEPA, the ILCR values of $<10^{-6}$ and $>10^{-4}$ show that the cancer risk is negligible and unacceptable, respectively. The ILCR values between 10^{-6} and 10^{-4} are acceptable or tolerable [32,33]. Non-carcinogenic risks were calculated separately for children and adults, while carcinogenic risks were summed for both childhood and adulthood, as early-life exposure to carcinogens may pose lifetime risks [38,39].

Table 4
Concentration of HMs (mg/kg) in wheat from different counties in Ilam.

Metal	County									Average	Iranian standard (mg/kg)
	Ilam	Chardavol	Sirvan	Dehloran	Abdanan	Malekshahi	Mehran	Ivan	Darreh Shahr		
Ag	0.715	0.272	0.179	0.045	0.044	0.040	0.083	0.136	0.604	0.23 ± 0.25	–
As	0.062	0.062	0.062	0.285	0.062	0.062	0.310	0.062	0.124	0.12 ± 0.10	–
Cd	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003 ± 0.0	0.03
Co	0.285	0.002	0.002	0.099	0.112	0.002	0.112	0.002	0.062	0.07 ± 0.09	–
Cr	0.006	0.006	0.006	127.051	133.382	91.566	134.091	91.872	127.408	78.3 ± 60.3	–
Hg	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062 ± 0.0	–
Pb	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134 ± 0.0	0.15

3. Results and discussion

contamination of foods, particularly cereals, with HMs can lead to various detrimental health effects including anemia, high blood pressure, and adverse effects on bone, kidney, and lung health in both humans and animals [5,22]. This study will discuss several key aspects related to the concentration of toxic HMs (Ag, As, Cd, Co, Cr, Hg, and Pb) in agricultural products (wheat, rice, corn, pea, and lentil) and their implications for human health in Ilam (Iran).

3.1. Heavy metals in wheat

One of the most widely consumed grains around the world is wheat. This grain plays an important role in food security; so about 25 % of the daily caloric intake is provided by wheat. Wheat is widely cultivated in Iran and about 55 % of crops planted in Iran by farmers are allocated to wheat (5–6 million hectares). Wheat consumption per capita in Iran is 2.5 times higher than the world average, which indicates the share of this grain in the supply of calories to the Iranian people. Table 4 lists the HMs content of wheat in various counties of Ilam Province. As shown, the highest and lowest average concentrations of HMs in wheat were related to chromium (78.3 mg/kg) and cadmium (0.003 mg/kg), respectively. The exploration in Ilam province indicated that the HMs concentrations in the wheat grain were in the order of Cr> Ag> Pb> As> Co> Hg> Cd. In terms of total HMs concentration in wheat, Sirvan and Mehran counties had the best and worst quality, respectively. Huang et al. (2008) reported that the content of HMs in the industrialized city of Kunshan, China, decreased as Pb> Cr> Cd> As> Hg [40]. Liu et al. (2020) study on HMs in wheat grain reported that the concentration of Cd, Pb, As, and Cr was 0.012, 0.019, 0.053, and 0.233 mg/kg, respectively [41].

3.2. Heavy metals in rice

The annual Rice consumption in Iran is seven times (36.6 kg per capita) more than European Union countries (5.3 kg for EU members), whilst the average per capita consumption of wheat in the world is 57.2 kg. Studies have shown that rice and bread are the dominant products consumed in Iran. As seen in Table 5, the average concentration of the HMs (mg/kg) of rice in different counties of Ilam were as Cr> Pb> Ag> As> Co> Hg> Cd. In addition, the content of As and Pb in rice samples was higher than the Iranian standard. Djahed et al. (2018) study reported the average concentrations of 0.369 ± 0.094, 0.0337 ± 0.039, and 0.123 ± 0.14 mg/kg for As, Cd and Pb in rice, respectively [15]. Furthermore, Zazouli et al. (2010) research expressed that the average Pb concentration was 11.5 mg/kg in rice planted in northern Iran, which was more than the average concentration of the current study [42]. As well as; a study by Naseri et al. (2015) showed that the average values for Pb and Cd in rice samples were significantly higher than the permissible limits set by FAO/WHO [22]. In a similar study in China on the rice samples, As concentration was 0.05 mg/kg, which was meaningfully lower than our study [43].

3.3. Heavy metals in corn

The results revealed that the heavy metal concentrations of corn in different counties of Ilam were in the order of Cr> As> Pb> Hg> Ag> Cd> Co. The highest concentration of Cr was related to the Darrehshahr County (Table 6). Also, the **mean** concentrations of Pb and Cd were lower than the Iranian standard. Zheng et al. (2020) stated that heavy metal contents (mg/kg) in corn samples in China were 0.1, 0.52, 0.23, 0.0014, and 0.014 mg/kg for Cd, Cr, Pb, Hg, and As, respectively [44].

3.4. Heavy metals in pea

The levels of HMs (Pb, As, Cr, Cd, Co, Hg, and Ag) for pea samples are represented in Table 7. The **mean** HMs levels in the cultivated pea in different counties of Ilam varied from 0.003 (Cd) to 59.32 (Cr) mg/kg. In general, the **mean** concentration of metals in pea revealed a following decreasing trend: Cr > Ag > Pb > As > Hg > Cd. However, Cd and Pb concentrations were below the national standard of Iran in all of the counties.

Table 5
Concentration of HMs (mg/kg) in rice from different counties in Ilam.

Metal	County				Mean	Iranian standard (mg/kg)
	Chardavol	Sirvan	Ivan	Darreh Shahr		
Ag	0.766	0.558	0.050	0.156	0.38 ± 0.33	–
As	0.248	0.384	0.062	0.273	0.24 ± 0.13	0.15
Cd	0.003	0.003	0.003	0.003	0.003 ± 0.0	0.06
Co	0.074	0.074	0.002	0.136	0.07 ± 0.05	–
Cr	0.006	124.508	92.553	133.691	87.6 ± 61.0	–
Hg	0.062	0.062	0.062	0.062	0.062 ± 0.0	–
Pb	1.637	1.635	0.134	0.134	0.88 ± 0.86	0.15

Table 6
Concentration of HMs (mg/kg) in corn from different counties in Ilam.

Metal	County			Mean	Iranian standard (mg/kg)
	Dehloran	Mehran	Darreh Shahr		
Ag	0.067	0.040	0.046	0.05 ± 0.01	–
As	0.062	0.062	0.334	0.15 ± 0.15	–
Cd	0.003	0.003	0.003	0.003 ± 0.0	0.1
Co	0.002	0.002	0.002	0.002 ± 0.0	–
Cr	92.932	88.081	100.480	93.83 ± 6.3	–
Hg	0.062	0.062	0.062	0.062 ± 0.0	–
Pb	0.134	0.134	0.134	0.134 ± 0.0	0.15

Table 7
Concentration of HMs (mg/kg) in pea from different counties in Ilam.

Metal	County						Mean	Iranian standard (mg/kg)
	Ilam	Chardavol	Sirvan	Dehloran	Mehran	Ivan		
Ag	0.768	0.207	0.144	0.069	0.154	0.152	0.25 ± 0.25	–
As	0.062	0.062	0.310	0.173	0.148	0.062	0.13 ± 0.09	–
Cd	0.003	0.003	0.003	0.003	0.003	0.003	0.003 ± 0.0	0.1
Co	0.335	0.002	0.002	0.002	0.186	0.099	0.10 ± 0.13	–
Cr	0.006	0.006	0.006	91.940	134.019	129.954	59.32 ± 66.6	–
Hg	0.062	0.062	0.062	0.062	0.062	0.062	0.062 ± 0.0	–
Pb	0.134	0.134	0.134	0.134	0.134	0.134	0.134 ± 0.0	0.2

3.5. Heavy metals in lentil

The results of HMs concentration in lentil samples are presented in Table 8. As shown, Cr was the highest concentration among the investigated metals. The **mean** concentration of the elements in lentil followed as Cr > Ag > Pb > As > Cd > Hg.

3.6. Health risk of HMs in crops

The results of the probabilistic assessment of the non-carcinogenic and carcinogenic health risk assessment are presented in Table 9. A comparison of HQ values related to exposure to the HMs in two adult and children groups showed that the HQ values for children were more than those for adults. As a result, there is more concern about children for this type of risk in the studied area. Based on the 95th percentile data, the HQ values for As and Hg in both age groups for wheat were higher than 1. In addition, the HQ values for As and Pb in rice were higher than 1 in both age groups. However, the HQ value for Cr (9.06×10^{-1}) in the children group for the wheat samples was near 1. The findings of the health risk assessment showed that long-term consumption of wheat and rice may lead to high non-carcinogenic health risks related to As, Hg, and Pb in consumers. Also, Table 9 shows that there was no non-carcinogenic risk for children and adults based on the HQ in the corn, pea, and lentil bases, i.e., all HQ values were <1. In this regard, the results of Roman-Ochoa et al. (2021) study demonstrated that the HQ value for polished rice was 10^{-1}, representing non-carcinogenic adverse effects. Also, the values of ILCR for As in rice were over the maximum level (1×10^{-4}), indicating an unacceptable cancer risk for a person to develop cancer over a lifetime ([45]). Another study by Pirsaheb et al. (2021) in Iran, reported that the HQ levels for lentils, peas, corn, split peas, beans, rice, and wheat in children were higher than the permissible limit [29]. Similarly, Sharafi et al. (2019) stated that the existence of As in the studied rice samples showed unacceptable health risks [46]. Similar findings were found for wheat by Huang et al. (2008), in which the HQ was 1.09 and 1.20 for rural adults and children in China, respectively [40]. The result of the Djahed et al. (2018) study in Iran demonstrated that only As (5.23 ± 4.01) had non-carcinogenic health risks for investigated elements in rice samples in the Iranshahr city [15].

Table 8
Concentration of HMs (mg/kg) in lentile from different counties in Ilam.

Metal	County						Mean	Iranian standard (mg/kg)
	Ilam	Chardavol	Sirvan	Dehloran	Mehran	Ivan		
Ag	1.023	0.370	0.114	0.110	0.050	0.099	0.29 ± 0.37	–
As	0.062	0.062	0.062	0.322	0.062	0.062	0.10 ± 0.10	–
Cd	0.003	0.003	0.003	0.003	0.003	0.003	0.003 ± 0.0	0.1
Co	0.297	0.002	0.002	0.002	0.002	0.002	0.05 ± 0.12	–
Cr	0.045	0.006	0.006	78.240	95.676	91.636	44.27 ± 48.8	–
Hg	0.062	0.062	0.062	0.062	0.062	0.062	0.062 ± 0.0	–
Pb	0.575	0.134	0.134	0.134	0.134	0.134	0.134 ± 0.0	0.2

Table 9
Probabilistic health risk assessment results.

Material	Age Group	Non-carcinogenic Risk														Carcinogenic Risk	
		Ag		As		Cd		Co		Cr		Hg		Pb		As	
		P5th	P95th	P5th	P95th	P5th	P95th	P5th	P95th	P5th	P95th	P5th	P95th	P5th	P95th	P5th	P95th
Wheat	Child	4.47×10^{-2}	9.19×10^{-1}	5.61×10^{-1}	7.19	1.27×10^{-2}	3.25×10^{-2}	2.56×10^{-3}	7.52×10^{-2}	8.10×10^{-2}	9.06×10^{-1}	7.49×10^{-1}	1.92	1.62×10^{-1}	4.14×10^{-1}	9.90×10^{-5}	1.12×10^{-4}
	Adult	3.53×10^{-2}	6.54×10^{-1}	4.51×10^{-1}	4.98	1.21×10^{-2}	1.77×10^{-2}	2.06×10^{-3}	5.36×10^{-2}	6.57×10^{-2}	6.28×10^{-1}	7.13×10^{-1}	1.04	1.54×10^{-1}	2.55×10^{-1}		
Rice	Child	3.93×10^{-2}	4.32×10^{-1}	5.96×10^{-1}	3.93	4.18×10^{-3}	1.07×10^{-2}	1.96×10^{-3}	1.92×10^{-2}	3.37×10^{-2}	3.17×10^{-1}	2.48×10^{-1}	6.33×10^{-1}	9.44×10^{-2}	1.60	1.06×10^{-4}	5.93×10^{-4}
	Adult	3.20×10^{-2}	2.99×10^{-1}	4.91×10^{-1}	2.65	3.97×10^{-3}	5.82×10^{-3}	1.60×10^{-3}	1.32×10^{-2}	7.73×10^{-2}	2.18×10^{-1}	2.35×10^{-1}	3.43×10^{-1}	7.49×10^{-2}	1.11		
Corn	Child	1.25×10^{-4}	3.75×10^{-4}	1.83×10^{-3}	3.21×10^{-2}	4.18×10^{-5}	1.07×10^{-4}	1.39×10^{-6}	3.55×10^{-6}	8.91×10^{-4}	2.22×10^{-3}	2.46×10^{-3}	6.33×10^{-3}	5.33×10^{-4}	1.37×10^{-3}	2.93×10^{-7}	4.72×10^{-6}
	Adult	1.02×10^{-4}	2.01×10^{-4}	1.32×10^{-3}	2.05×10^{-2}	3.61×10^{-5}	5.29×10^{-5}	1.20×10^{-6}	1.76×10^{-6}	7.90×10^{-4}	1.06×10^{-3}	2.00×10^{-3}	3.12×10^{-3}	4.62×10^{-4}	6.75×10^{-4}		
pea	Child	6.41×10^{-4}	1.23×10^{-2}	9.94×10^{-3}	9.27×10^{-2}	1.65×10^{-4}	4.22×10^{-4}	4.74×10^{-5}	1.40×10^{-3}	4.73×10^{-4}	1.05×10^{-2}	9.72×10^{-3}	2.49×10^{-2}	2.10×10^{-3}	5.38×10^{-3}	1.65×10^{-6}	1.36×10^{-5}
	Adult	7.75×10^{-4}	8.10×10^{-3}	7.37×10^{-3}	5.94×10^{-2}	1.45×10^{-4}	2.12×10^{-4}	3.47×10^{-5}	9.12×10^{-4}	3.47×10^{-4}	6.85×10^{-3}	8.54×10^{-3}	1.25×10^{-2}	1.84×10^{-3}	2.70×10^{-3}		
Lentil	Child	5.65×10^{-4}	1.61×10^{-2}	4.78×10^{-3}	8.50×10^{-2}	1.65×10^{-4}	4.24×10^{-4}	8.09×10^{-6}	8.41×10^{-4}	3.64×10^{-4}	7.81×10^{-3}	9.72×10^{-3}	2.49×10^{-2}	9.53×10^{-4}	1.40×10^{-2}	6.27×10^{-7}	1.24×10^{-5}
	Adult	4.20×10^{-4}	1.07×10^{-2}	3.51×10^{-3}	5.47×10^{-2}	1.45×10^{-4}	2.11×10^{-4}	5.77×10^{-6}	5.45×10^{-4}	2.67×10^{-4}	5.12×10^{-3}	8.54×10^{-3}	1.25×10^{-2}	6.96×10^{-4}	8.87×10^{-3}		

In the present study, the results showed that the highest cancer risk was attributed to As; because its 95th percentile values of ILCR in the wheat and rice were $>1 \times 10^{-4}$, which is unacceptable. As well as, the results indicated that the potential carcinogenic health impacts from corn, pea, and lentil were unlikely to occur, because their ILCR values were between 1×10^{-4} to 1×10^{-6}, and this is regarded as an acceptable or negligible risk. Djahed et al. (2018) study revealed that the ILCR for As in rice was 2.37×10^{-3} which can cause cancer risk in a lifetime [15]. In contrast, the ILCR value of As was within the safe range in Liu et al. (2020) study, indicating that wheat poses no lifelong carcinogenic risk to children and adults [41]. Furthermore, the ILCR values of As were found more than the tolerable limit ($>10^{-4}$) in wheat from Khairabaad in the Kumar et al. (2021) study [47]. The toxic effects of HMs on living organisms can lead to inhibition of membrane function, oxidative damage, and genetic disorders due to their ability to produce free radicals in the biological system [48]. Exposure to As disrupts the immune system by inhibiting the cellular immune response [49]. Long-term exposure to Pb leads to neurotoxicity, disruption of memory function, and risks of mental retardation especially in children [50]. Given this observation, monitoring of As, Pb, Hg, Cr, and Ag concentration in cereals products is vital especially, in wheat and rice for local governments to address severe environmental problems and human health risks. It is worth noting that, more comprehensive studies should be conducted on the health effects of cereals products consumers in the future.

4. Conclusion

In this study, various toxic HMs (Pb, As, Cr, Cd, Co, Hg, and Ag) in cereals products and their human health risk assessment were investigated in different counties of Ilam province, Iran. The results demonstrated that the Cr concentration in all studied cereals was the highest. Also, the concentration of As and Pb in rice samples was higher than the national standard of Iran. Furthermore, the results of non-carcinogenic risk revealed that the long-term consumption of wheat and rice may lead to high non-carcinogenic health risks related to As, Hg, and Pb in both age groups. The results also demonstrated that ILCR for wheat and rice was above the permissible limit of 10^{-4}, representing an unacceptable carcinogenic risk. Relevant organizations must monitor HM content in cereal products cultivated in the Ilam province. Implementing preventive measures is necessary to mitigate potential health risks associated with exposure to these contaminants. Regular assessments and strict regulations can help ensure the safety of food products and protect public health in the region.

CRediT authorship contribution statement

Ali Amarloei: Project administration. **Heshmatollah Nourmoradi:** Data curation. **Shahrokh Nazmara:** Validation. **Mohsen Heidari:** Writing – review & editing. **Fazel Mohammadi-Moghadam:** Writing – review & editing. **Sajad Mazloomi:** Investigation.

Data availability statement

No data was used for the research described in the article.

Declaration of competing interest

The authors declare that there were no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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