Quantitative Measurement of Toxic Metals and Assessment of Health Risk in Plant-based Food from Markazi Province of Iran

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Abstract

The aim of current study is to measurement and investigate the toxic metals levels in plant-based food collected in Markazi province and human health risk by using inductively coupled plasma - optical emission spectrometry (ICP-OES). The levels of arsenic (As) and cadmium (Cd) in all samples were lower than LOD, while level of Cd in potato samples were lower than permitted limit of European commission (EC). The highest mean of toxic metals were observed for lead (Pb) in legume samples (562.17 µg kg$^{-1}$). Mercury (Hg) and Pb levels in all samples were higher than LOD, while Pb level in wheat samples were lower than of EC. The rank order of Hg and Pb levels in all samples based on target hazard quotient (THQ) value was wheat > potato > legume. The 95% THQ index of Hg and Pb for adults in wheat samples were 2.59E+00 and 7.19E-01, in potato samples were 2.07E-01 and 1.64E-01; in legume samples were1.41E-01 and 6.61E-02 respectively, while in the case of children, the 95% THQ index of Hg and Pb in wheat samples were 8.90E+00 and 2.44E+00; in potato samples were 1.17E+00 and 5.81E-01; in legume samples were4.77E-01 and 2.20E-01 respectively. The high hazard index values were estimated, indicating a high health risk from consumption of wheat and potato.

1. Introduction

Plant-based foods contain plant-derived substances, such as cereals, legumes, kernel seed, vegetables and fruits. Plant-based foods are an important part of the human daily diet that can be contaminated with toxic metals such as Hg, Cd, Pb and As, therefore plant-based foods are considered a serious concern for human health (Stefanović et al. 2008) (Dodangeh et al. 2018). The contamination of plant-based food with toxic metals can be related to either natural resources or human activities such as industrial processing, mining, waste disposal and application of wastewater as well as sewage sludge to irrigation of cultivated plant-based food or even application of fertilizers (especially phosphate type) and pesticides (Tadesse et al. 2015; Marrugo-Negrete et al. 2015; Shariatifar et al. 2020; Shariatifar et al. 2017). It is worthy to note that the atmospheric deposition could be accounted as the primary sources of soil, and water contaminations and consequently further contaminations in the food chain (Fakhri et al. 2017). In this regard, plants can absorb toxic metals from the soil, water and air and furthermore concentrate them in different parts such as roots, leaves, and grains (Qu et al. 2012).

Toxic metals as the non-essential compounds for the human body could cause several adverse health effects, even in trace amounts (Yılmaz et al. 2010). Due to their non-degradable nature, they could biologically accumulate in different tissues (kidney, liver, bone, and brain) after their intake through diet as well as inhalation pathways (Bjerklund et al. 2017). For instance, the consumption of contaminated food with Cd can cause bone pain, cardiovascular diseases, and kidney damages (Cheng et al. 2017). Pb can accumulate in the bone and can cause gastrointestinal colitis, hypertension, kidney damages, leukemia, brain dysfunctions, and thrombotic illnesses in human (Fang et al. 2014).

Hg is one of the major pollutants that can cause to brain problems such as hearing, vision and tactile disorders (Raj and Maiti 2019). It has been noted that the developmental disorders in infants and children such as lowering intelligence quotient (IQ) can be correlated with Hg and Pb (Raj and Maiti 2019; Marrugo-Negrete et al. 2015).

In this context, the International Agency for Research on Cancer (IARC) categorized Pb as (group 2B) and Cd as (group 1) a human carcinogenic compound (Cancer 1993). As may cause cancer in human in various organs including the lung, skin, blood and skeleton. (Sarkar and Paul 2016).

The investigation of toxic metals (Cd and Pb) were carried out in the word (all over it) by different analytical methods (Vinás et al. 2000; Salah et al. 2013). Among several method to determine the trace metals in the food samples, the ICP-OES, flame atomic absorption spectrometry (FAAS), and graphite furnace atomic absorption spectrometry (GF-AAS) are the original techniques. Due to saving the time, specificity and more sensitivity of ICP-OES, these technique, it is regarded as better method (Karimi et al. 2012). In various study, agricultural soil is generally considered to be one of the main sources and receptors for heavy metals. However, in Markazi province, the presence of heavy metals in the soil may be from various sources such as industrial activities, lead and zinc mines and fuel combustion, greenhouse gas emissions and municipal waste disposal. Excessive entry of heavy metals and synthetic chemicals into the studied soils may lead to deterioration of the soil biology, thereby altering the physicochemical properties of the soil and causing other environmental problems. Increasing the pollution of air, water and soil caused by highway traffic, mines, various manufacturing industries and industrial waste is a serious problem that negatively affects the public health (Qu et al. 2012; Salama and Radwan 2005; Islam et al. 2020; Proshad et al. 2018; Solgi et al. 2014; Solgi et al. 2012; Ghasemidehkordi et al. 2018b; Ghiyasi et al. 2010; Hani and Karimineja 2010). However, no research has been done to investigate the concentration of toxic metals in foods of plant origin, obtained from the industrial areas of Markazi province as one of the most industrialized regions of Iran. Also, this is the first attempt to measurement and compare toxic metals content in plant-based food in the industrial areas of Markazi province using an inductively coupled plasma-optical emission spectrometry (ICP-OES). Therefore, the present research is devoted to evaluate the toxic metals concentration in selected plant-based food (legumes, potatoes, and wheat) in Markazi Province. Furthermore, the Chronic Daily Intake (CDI) of toxic metals besides the non-carcinogenic risk in children and adult population were estimated.

2. Method And Material

2.1. Sample collection
The sample size was based on the agricultural fields. In this regard, the samples were taken in January 2019 from agricultural products produced in the Markazi Province. A total of 120 samples were examined (60 samples of legume (chickpea \( n = 20 \), lentil \( n = 20 \) and bean \( n = 20 \), 30 samples of potato and 30 samples of wheat were collected). The experiments were conducted in three levels of replication. After coding of samples based on the type and sampling site. They were put in polyethylene (PE) bags. The bean, potato samples were thoroughly washed with water after transfer to the laboratory in order to remove possible contamination.

### 2.2. Chemical reagents

All chemicals (nitric acid 65%, perchloric acid, sulfuric acid, and hydrogen peroxide 70%) and standard stock solutions of toxic metals with analytical grade (purity > 99%) were purchased from Merck (Darmstadt, Germany). Double-deionized water was used in all dilutions.

### 2.3. Sample preparation

In this study closed vessel, acid decomposition in the microwave oven system (Milestone Ethos D closed vessel microwave system with a maximum power of 1400 W, and the maximum pressure in Teflon vessels ~ 100 bar) was used to minimize the effects of the organic matrix as well as to prevent the possibility of sample contamination and loss of analyte. The plant-based food samples were washed with distilled water and dried at 105 °C for 48 h. The dried samples were ground, then homogenized using an agate pestle and sorted in glass bottles until analysis. All of the glass containers used were cleaned by means of soaking, overnight in a 10% nitric acid solution, and then rinsed with deionized water (Türkmen and Dura 2016; Mendil et al. 2004). Triplicate plant-based food samples (0.25 g) were digested with 9 mL of nitric acid (65%) and 1 mL of hydrogen peroxide (70%) in the microwave digestion system for 30 min at a maximum temperature of 300 °C. The residue was then diluted to 10 mL with deionized water in a 10 mL volumetric flask. A blank digest was conduct in the same way (Türkmen and Dura 2016; Torres-Escribano et al. 2010).

### 2.4. Condition of Instrument

All prepared samples (triplicate) were analyzed by the aid of an ICP-OES (Spectro Arcos, SPECTRO, Germany) with Torch type of flared end EOP Torch 2.5 mm. The functioning optimum parameters were: RF generator (1400 W), argon gas grade 6 was used for plasma, nebulizer, and auxiliary gas. The gas flow of plasma, auxiliary, and nebulizer were 14.5, 0.9 and 0.85 (L/min), respectively. Afterward, initial stabilization time, time of rinse, time of sample uptake was 240 seconds total and 45 seconds for prewash. Also, the time between replicate analysis and time of delay was zero. The analysis was a 3-time replicate and the frequency (resonance frequency) of the generator of RF was 27.12 MHz. The type of solid-state, detector and spray chamber were cyclonic, CCD and Modified Lichte, respectively. The type of pump of sample delivery was four-channel, software-controlled; peristaltic pump enables exact sample flows. The Prewash pump speed was 60 rpm (for 15 seconds), 30 rpm (for 30 seconds) and Prewash time was 45 seconds, and finally, the pump speed of sample injection was 30 rpm.

### 2.5. Validation of the analytical method

The validation of the analytical method for the quantitative analysis of elements present in toxic metals and its aqueous extracts was performed by evaluating selectivity, working and linear ranges, limit of detection (LOD), limit of quantification (LOQ), repeatability and reproducibility (precision). Matrix effects were evaluated by standard addition method by adding 200 µL of standard mixed solutions to the original samples. (Mix standard CRM: 92091 Supelco LOT BCCB9855, TraceCERT®, 33 elements, 10 mg/L in nitric acid, Hg standard CRM:28941 Supelco, LOT BCCB8927, 1000 mg/L<sup>−1</sup>, Hg in nitric acid). The recoveries all the studied elements were 93%-105%.

### 2.6. Health risk assessment

The Monte Carlo Simulation (MCS) is the most applied to the health risk assessment concerning uncertainty while the MCS approach usually deals with the parameters affecting uncertainties (Jahanbakhsh et al. 2019; EPA 2005). Therefore, the MCS method presents better human health risk identification. The Crystal Ball software (version 11.1.2.4.600, Oracle, Decisioneering, Denver, CO, USA) was utilized to perform simulation calculations (Zhu et al. 2019; Liao et al. 2011). The number of repetitions for each model was at 10,000, Also probability distributions of parameters in MCS was Log-normal (LN) distribution (Qu et al. 2012).

The Chronic Daily Intake (CDI) of detection of toxic metals due to ingestion of toxic metals via consumption of food products was calculated using the following Equation (Heshmati et al. 2018; Jahanbakhsh et al. 2019):

$$\text{CDI} = \frac{C \times \text{IR} \times \text{EDi} \times \text{EFI}}{\text{BW} \times \text{AT}}$$  \hspace{1cm} (Equation 1)

In this study, “C” is the toxic metals concentration (mg kg<sup>−1</sup>); “IRi” ingestion rate was set as (legume 19 g day<sup>−1</sup>, wheat 320 g day<sup>−1</sup> and potato 58 g day<sup>−1</sup>) (Abdollahi et al. 2014; Kalantari et al. 2005); “EDi” is the duration of toxic metals ingestion (6 years for children and 24 years adults); “EFI”, is the exposure frequency (350 days year<sup>−1</sup> for both age groups) (Yousefi et al. 2018); “BW”, body weight average (for children and adults is between 20 and 70 Kg, respectively (Yousefi et al. 2018; Nazaroff and Alvarez-Cohen) and “AT” is the mean exposure years (365 days year<sup>−1</sup> ×
number of exposure years) (EPA 2015). The THQ was used for the non-carcinogenic risk assessment of toxic metals according to Eq. 2 (Dadar et al. 2017; Madani-Tonekaboni et al. 2019):

\[ THQ = \frac{CDI}{RfD} \]  

(Equation 2)

Where, CDI is chronic daily intake (mg kg\(^{-1}\) per day); RfD is the oral reference dose that for Hg, Pb and Cd is 0.0001, 0.0035 and 0.0005 mg kg\(^{-1}\) per day (Dadar et al. 2017; Madani-Tonekaboni et al. 2019; EPA 2015).

The actual TTHQ act in the both A and B zones was also calculated by using Eq. 3:

\[ TTHQ_{\text{act}} = [THQ_{\text{Hg}} + THQ_{\text{Pb}}]_{\text{Legume}} + [THQ_{\text{Hg}} + THQ_{\text{Pb}}]_{\text{Wheat}} + [THQ_{\text{Cd}} + THQ_{\text{Hg}} + THQ_{\text{Pb}}]_{\text{Potato}} \]  

(Equation 3)

If THQ > 1 value, the exposed population is at considerable health risk, but if TTHQ \( \leq \) 1, the health risk is not likely (Dadar et al. 2017; Ghasemidehkordi et al. 2018b).

### 2.7 Statistical analysis

The statistical analysis was conducted with SPSS v.24 using analysis of variance (ANOVA) and Chi-square tests. All experiments were performed in triplicate. The considered significant level was \( p < 0.05 \).

### 3. Results And Discussion

#### 3.1. Results

The wavelengths applied for determination of the elements concentration, based on baseline signals and their interferences at selected lines observed experimentally during the measurements, are presented in Table 1.

| Element | Wavelength (nm) | R\(^2\) Value | Calibration range | Recovery (%) | LOD (µg/kg) | LOQ (µg/kg) |
|---------|----------------|--------------|-------------------|--------------|-------------|-------------|
| As      | 189.042        | 0.9922       | 0.3–1200          | 94           | 1           | 3.30        |
| Cd      | 214.438        | 0.9891       | 0.3–1200          | 98           | 0.05        | 0.16        |
| Hg      | 184.950        | 0.9899       | 0.3–1200          | 101          | 0.35        | 1.17        |
| Pb      | 283.305        | 0.9918       | 1.2–1200          | 105          | 2           | 6.60        |

Good linearity was noted according to calibration curves drawn for toxic metals. Correlation factors for all samples ranged from 0.9891 to 0.9922. The limits of detection (LODs) and quantification (LOQs) for Pb, As, Hg and Cd were 2, 1, 0.05 µg kg\(^{-1}\) and 6.6, 3.3, 1.17, 0.16 µg kg\(^{-1}\), respectively. The recoveries all the studied elements were 94% and 105% (Table 1).

Table 2 illustrates toxic metals content in legume, wheat, and potato samples Markazy province as well as permissible levels for toxic metals.
Table 2
Comparison of the heavy metals content in plant-based food samples with Permissible limit of Iran/EC/ FDA (μg/kg)

| Type of food | Area     | Mean±SD | Permissible limit of EC | Permissible limit of Iran | Permissible limit of FDA | p-value |
|--------------|----------|---------|-------------------------|--------------------------|--------------------------|---------|
|              |          | As      | Cd          | Hg          | Pb          | Cd | Hg | Pb | Cd | Hg | Pb | Cd | Hg | Pb | Cd |
| Legume       | (n=60)   | ND      | ND          | 35.45 ± 6.36 | 562.17 ± 34.39 | -  | 20 | 300 | - | - | - | 500 | 6000 | 0.040 | 0.042 |
| Wheat        | (n=30)   | ND      | ND          | 39.54 ± 7.26 | 372.69 ± 26.35 | -  | 30 | 500 | - | - | - | 500 | 6000 | 0.025 | 0.030 |
| Potato       | (n=30)   | ND      | 27.46 ± 2.33| 17.47 ± 1.67 | 470.52 ± 12.61 | 30 | 5  | 100 | - | - | 20 | 100 | 500 | 1000 | 0.04 | 0.043 | 0.043 |

ND: not detect

The concentration of As and Cd in plant-based food was lower than the detection limit (LOD), except for Cd in some samples of potato which they were lower than permissible limit of EC. Therefore, there is no need to estimate their non-carcinogenic risk in the population. Table 3 shows the estimated THQ for toxic metals (Hg, Cd and Pb) exposure through food products (legume, potato, and wheat) consumption by adults and children in Markazi province, respectively.

Table 3
Results of THQ and TTHQact for plant-based food contamination with Hg and Pb in Markazi province

| Type of food | Markazi province |
|--------------|------------------|
|              | Adults | Children    |
| Legume       | Hg     | 0.092 | 0.323 |
|              | Pb     | 0.041 | 0.142 |
| Wheat        | Hg     | 1.733 | 6.066 |
|              | Pb     | 0.454 | 1.588 |
| Potato       | Hg     | 0.139 | 0.486 |
|              | Pb     | 0.104 | 0.363 |
| TTHQact      | 2.563  | 8.968 |

Figure 1 shows the three main contributors in total THQ (TTHQ) for the children and adult’s consumers due to ingestion in plant-based food samples. Uncertainly analysis for percentile 95% CR index and contribution due to content of Pb for children and adult in plant-based food samples is represented in Table 3 and Figure 2. The results of CR indexes for adults and children due to consumption of toxic metals content in plant-based food samples by MCS is depicted in Figure 3. The validity of the data in this study was determined by reference to known, elements concentrations. The samples were experimented through the same sample processes. Percentage of standard elements detected at acceptable level, 95%.

3.2. Toxic metals concentration

The concentration of As and Cd in all samples (except for potato samples in the case of Cd) was lower than the LOD (1 and 0.05 μg kg⁻¹, respectively). For instance, the mean content reported for Cd in wheat and legume samples were lower than LOD, while in potato samples of Markazi province was obtained 27.46 μg kg⁻¹, which were lower than the permissible limit proposed by EC (30 μg kg⁻¹). In some of the previous studies also As, Cd concentrations were lower other elements (Hg and Pb) which probably due to the low absorption of As and Cd through the plant root compared to Hg and Pb (Cheng et al. 2017). In this study, among all food samples, the highest average concentration of Pb was observed in legume samples (562.17 μg kg⁻¹). The highest mean concentration of Hg was observed in wheat samples (39.54 μg kg⁻¹). The similar studies have shown that Pb concentration in vegetables and crops is higher than other toxic metals, due to their high ability to absorb even small amounts of Pb from polluted air, soil and water (Liu et al. 2013; Sharafi et al. 2019). However, air pollution is the main source of Hg in plants through plant uptake, while uptake through soil is partial (Ghasemidehkordi et al. 2018b).
Pruvot et al. (2006) showed that the soil near the smelter is more contaminated than the reference soil (Pruvot et al. 2006). Also, higher levels of toxic metals in industrial and mining areas are due to lack of environmental protection and pollution (Pang et al. 2016; Fang et al. 2014). Agrawal et al. (2003) noted that agricultural lands near industrial centers and highways should also be polluted due to air pollution around them (Agrawal et al. 2003). Therefore, atmospheric sedimentation in agricultural lands located in industrial areas might play a critical role in the uptake of higher levels of toxic metals by plants (Rahman et al. 2013). Moreover, industrialization influences the toxic metals concentration in soil, water, and air leads to an increase in the concentration of these elements in plant-based food. Lei et al. (2015) mentioned that human activities, like mineral exploration, refining, and manipulation, as well as sewage sludge, are the most important sources of toxic metals pollution (Lei et al. 2015).

The rank of Hg concentration of plant-base products can be summarized as wheat ≥ legume ≥ potato. The rank of Pb concentration of plant base products was legume ≥ potato ≥ wheat. Although plant-based products have the ability to absorb a variety of toxic metals, there is no uniform relationship between toxic metal concentrations and food types (Fang et al. 2014). Moreover, the toxic metals level in legume samples was higher than potato samples due to the different susceptibility of vegetables to pollution. Pruvot et al. (2006) reported that the leafy vegetables had higher levels of Pb and Cd than potatoes (roots or tuberous vegetables) (Pruvot et al. 2006). Liu et al. (2013), also reported the differences in toxic metals concentration between different plants owing to their diverse accumulation capacities and different soil characteristics (Liu et al. 2013). Momen et al. (2006) reported that the concentrations of Pb and Cd were lower than LOQ in all legume samples (except for Cd concentration in white bean, faba bean, and lentil samples were 900, 800 and 500 µg kg⁻¹, respectively) (Momen et al. 2006).

According to Tadesse et al. (2015), Pb concentration in potatoes of Ethiopia was in the range of 2000–17400 µg kg⁻¹ (higher than permissible EC level), while in the present study, the Pb concentration was below the LOD (< 100 µg kg⁻¹). Similar study showed that the Cd and Pb concentration in some of vegetables were 200 and 3950 µg kg⁻¹, respectively (Bahemuka and Mubofu 1999). Ghasemidehkordi et al. (2018) determined the concentrations of Pb and Hg in 10 kinds of the agriculture products from agricultural lands near to industrial areas of Iran. The highest amount of Pb and Hg reported 56.147 µg kg⁻¹ and 1733.62 µg kg⁻¹, respectively, which were higher than authenticated regulations (WHO/FAO) (Ghasemidehkordi et al. 2018a).

Wheat considers as an important cereal in the diet and provides a 50–90% protein requirement and total caloric content in many countries especially in Iran (Khaniki et al. 2005). The mean Pb concentration of Pb in different traditional flat breads in Iran by Jahed Khaniki et al. (2005), was determined between 270–520 µg kg⁻¹, while the mean Cd concentration was found as 120–650 µg kg⁻¹ (Khaniki et al. 2005). As the contamination of metals on the grain bran is more endosperm. Therefore the amount of toxic metals in cereal-based products like bread is associated with the extraction rate of flour. Furthermore, the supply of wheat from industrial areas can cause further pollution (Khaniki et al. 2005; Tajdar-oranj et al. 2018).

### 3.3. Risk assessment of toxic metals by intake of plant-based food

#### 3.3.1. Non-carcinogenic risk

The results demonstrated that the rank order of food products based on THQ was wheat > potato > legume among adults and children population (Table 3).

Non-carcinogenic risk of wheat was found to higher than potatoes and legumes due to high consumption rate of wheat (320 g/day). As illustrated in Table 2, Markazi province had a hazard index for non-carcinogenic health risks, which can be correlated with the higher concentration of toxic metals in all tested samples. Children because of lower body weight and more intakes of toxic metals in each kilogram of the body weight while compared with adults are exposed to higher risk. The calculated THQ of children was approximately 3 times higher than adults in Markazi province as expected (Figure 1).

The 95% THQ index of Hg and Pb for adults in wheat were 2.59E+00 and 7.19E-01; in potato 2.07E-01 and 1.64E-01; in legume 1.41E-01 and 2.20E-01; whiles the other toxic metals estimated to have less than 20 percent contribution. Moreover, the THQ index of Hg and Pb in wheat for adults were 2.59E+00 and 7.19E-01; in potato 2.07E-01 and 1.64E-01; in legume 1.41E-01 and 2.20E-01 (Table 3). In Markazi province is a considerable non-carcinogenic risk (THQ > 1) for the children due to ingestion wheat and potatoes. When TTHQ ≤ 1, risk is improbable, but when TTHQ > 1 shows the probability of adverse effects, when TTHQ > 10, the adverse health effects in exposed population is high for chronic or even acute adverse effects. As Fig. 1 represents, Hg is main contributors in total THQ, whiles the other toxic metals estimated to have less than 20 percent contribution.

Total non-carcinogenic risk from the plant-based food exceeded the safety limit in Markazi Province (TTHQ > 1); for the exposed population, Hg and Pb were indicated as the most evident pollutant leading to non-carcinogenic risk regarding the wheat and potatoes. Because the high daily consumption of wheat and persistent nature of toxic metals during food processing and bioaccumulation of them in the body of human (Stefanović et al. 2008), the associated safety considering the toxic metals concentration is highly concern.

#### 3.3.2. Carcinogenic risk
Based on MCS, the percentile 95% of CR indexes in the legume, wheat and potatoes for adults and children due to Pb were 1.96E-6, 2.18E-5 and 5.08E-6 and 2.72E-5, 2.98E-4 and 6.90E-5, respectively (Fig. 2, 3). The characteristic of the cancer risk (CR) can be qualitatively described as follows; safe limit CR < 10 \(-\) 6; threshold risk limit CR > 10 \(-\) 4; considerable risk limit CR > 10 \(-\) 3. Comparison between percentile 95% carcinogenic risk assessment of Pb wheat for children illustrated that CR index violated the threshold risk limit (> 10 \(-\) 4).

In various study, agricultural soil is generally considered to be one of the main sources and receptors for toxic metals. However, in Markazi Province, the presence of toxic metals in the soil may be from various sources such as industrial activities, Pb and Zn mines and fuel combustion, greenhouse gas emissions and municipal waste disposal.

Excessive entry of heavy metals and synthetic chemicals into the studied soils may lead to deterioration of the soil biology, thereby altering the physicochemical properties of the soil and causing other environmental problems. Increasing air, water and soil pollution caused by traffic jams, mines, various manufacturing industries and industrial waste is a serious problem that negatively affects the public health (Hani and Karimineja 2010; Proshad et al. 2018; Islam et al. 2020; Ghiyasi et al. 2010; Ariananjad et al. 2015)

Although the urban structure of this province seems to be advanced, but despite the advanced urban facilities, the main problems caused by air, water and soil pollution of the area may cause pollution in crop base products of the Markazi Province. Plant base products are the main foodstuffs used in many countries around the world, and pollution in most parts of the world has been reported due to soil, groundwater and air. With regard to the increase the level of heavy metals in agricultural soils and their uptake in plant base products, may be a serious health problem has arisen in some parts of the this Province.

4. Conclusion

The results showed that the concentration of As and Cd in all samples (legumes, wheat, potatoes) were lower than LOD, and also the concentration of Cd in potato samples was less than permitted limit of EC. Pb had the highest mean of toxic metals in all plant food samples. The concentrations of Hg and Pb in all samples (legume, wheat, potatoes) of Markazi Province were lower than LOD, and also the concentration of Pb in wheat samples was lower than permitted limit of EC. Wheat was identified as the most important source of toxic metal exposure among children and adults due to its high consumption compared to potatoes and legumes. The results of MCS showed exposed population including adults and children from Markazi Province are at the considerable health risk (HQ > 1 and CR > 1E-4), by ingestion of wheat and potato samples. Therefore, further research to identify the potential sources of contamination with toxic metals and possible control or corrective strategies and continuous monitoring of plant-based food are recommended. Also farmers, craftsman and others people in the community should be aware of the dangers of food exposed to heavy metals in the province, which can reduce the level of toxic metals in these foods by providing guidelines and action.

Abbreviations

LOD: Limit of Detection
LOQ:Limit of Quantification
CR: Cancer Risk
EC: European Commission
CDI: Chronic Daily Intake
MCS: Monte Carlo Simulation
ICP-OES : Inductively coupled plasma - optical emission spectrometry)
WHO/FAO: World Health Organization & Food and Agriculture Organization
THQ: Target hazard quotient
TTHQ: Total THQ

Declarations

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Authorship contributions
Nabi Shariatifar: Conceptualization, Supervision, Design of study Writing- Reviewing and Editing. Fereshteh Karimi.: Data curation, Writing- Original draft preparation. Mohammad Rezaei: Visualization, Investigation. Mahsa Alikord: Writing- Reviewing and Editing, Software Majid Arabameri: Saftware, Methodology, Validation:

Availability of data and materials
The datasets applied and analysed during this research are available from the corresponding author on request.

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