



Health Risk Assessment of Lead, Cadmium, and Arsenic in Leafy Vegetables in Tehran, Iran: the Concentration Data Study

Behrouz Tajdar-oranj¹ · Fardin Javanmardi² · Karim Parastouei¹ · Maryam Taghdir¹ · Morteza Fathi¹ · Sepideh Abbaszadeh¹

Received: 17 April 2023 / Accepted: 13 May 2023 / Published online: 25 May 2023
© The Author(s), under exclusive licence to Springer Science+Business Media, LLC, part of Springer Nature 2023

Abstract

Absorption of heavy and toxic metals causes their accumulation in the edible parts of vegetables. Pollutants such as heavy metals have directly affected the health of society and contributed to emerging diseases in recent years. The current study aimed to detect heavy metals (Pb, Cd, As) in highly consumed leafy vegetables provided from the Tehran market. Four types of vegetables, including dill, parsley, cress, and coriander were selected and 64 samples were randomly collected from fruit and vegetable markets in different regions of Tehran in August and September 2022. Then, samples were analyzed by the ICP-OES system, and health risk assessment was conducted using non-carcinogenic and carcinogenic approach. The range of Pb concentration was 54–314, <LOQ-289, <LOQ-230, and <LOQ-183 µg/kg for dill, cress, parsley, and coriander, respectively. The high mean concentrations of Pb belong to the dill (161.43 ± 77.3 µg/kg) and cress (154.75 ± 72.9 µg/kg). In some samples of dill (37.5% of samples), cress (18.75% of samples), and parsley (12.5% of samples), the Pb content was above the national allowable limit (200 µg/kg). The range of Cd concentration was <LOQ-42, <LOQ-41, <LOQ-30, and <LOQ-38 µg/kg for dill, cress, parsley, and coriander, respectively. In none of the samples, the concentration of Cd was higher than the Iranian national limit (50 µg/kg). The As occurrence was observed in all cress samples with a mean of 165.19 ± 64.83 µg/kg. The range of As concentration was <LOQ-71, <LOQ-256, 58–273, and <LOQ-75 µg/kg for parsley, dill, cress, and coriander, respectively. The THQ and HI values were higher than 1, and either ILCR value was higher than 10^{-4} for all tested heavy metals, it can be concluded that higher levels of heavy metals than the standard limits in some samples may raise the warning alarm and should come to the attention of the authorities.

Keywords Vegetables · Heavy metals · Risk assessment · Iran · Food safety

Introduction

Given the limited natural resources, ensuring food security for a growing population is one of the most critical global issues [1]. Vegetables compared to meat products have a high production rate and are a nutritious and cheap source of carbohydrates, proteins, vitamins, antioxidants, and minerals [2]. According to the Food and agriculture organization

(FAO) report, global vegetable availability is annually around 594 g per capita per day in 2019 [3]. Furthermore, a global systematic review report on vegetable intake remains at 186 g per day [4].

In areas facing a water shortage crisis, vegetable fields are irrigated using treated urban wastewater, which can cause an increase in the levels of heavy metals in the soil [5]. Vegetable contamination with air and soil pollution can lead to decreasing vegetable quality and health problems [6]. Absorption of heavy and toxic metals causes their accumulation in the edible parts of vegetables. Pollutants such as heavy metals have directly affected the health of society and contributed to emerging diseases in recent years [7]. Heavy metals are one of the most substantial nonpoint pollutants occurring in natural resources [8]. Annually, thousands of tons of these metals enter nature worldwide, mainly through water, soil, and air via various natural and synthetic sources

✉ Sepideh Abbaszadeh
Dr_s_abbaszadeh@yahoo.com

¹ Health Research Center, Life Style Institute, Baqiyatallah University of Medical Sciences, Tehran, Iran

² Department of Food Science and Technology, Faculty of Nutrition Sciences and Food Technology, National Nutrition and Food Technology Research Institute, Shahid Beheshti University of Medical Sciences, Tehran, Iran

exerting detrimental short-term and long-term effects [6]. There are two sources of heavy metals comprising, natural or human origin. Rock weathering and soil erosion are the most noteworthy natural cause. In addition, agricultural, industrial, and urban activities are the most significant human causes. Industrial activities, mining, metal smelting, casting, construction activities, by-products of waste incinerators, urban solid waste, urban runoff, sewage, and domestic waste is the most significant human activities increasing the concentration of heavy metals in the environment [9]. Heavy metals enter the cultivation soil in different ways such as through precipitation, chemical and animal fertilizers, compost, sewage, and pesticide usage [10]. The rate of heavy metals reduction through leaching or absorption by plants is often lower than their entry into the soil, which leads to the gradual accumulation of heavy metals [11]. Regardless of the self-purification potential of receiving environments such as surface water, the uncontrolled discharge of industrial effluents leads to reduce the natural resources. Increasing the use of fertilizers and pesticides leads to an increase in the heavy metals content in the soil as well as the content of organic matter, which indicates that it is essential to prioritize sustainable and regenerative agriculture practices that focus on soil health and ensure long-term health and well-being of our food systems [12]. Also, some evidence shows that the type of plants can also be effective in the accumulation of heavy metals. Zhou et al. (2016) reported that there is a significant difference between the concentration of heavy metals in various types of vegetables so that the ability to absorb and accumulate heavy metals is the highest in leafy vegetables and the lowest in melon vegetables [13]. Yang et al. (2009) reported in a study that cadmium increased in a variety of plant species in the following order: leguminous vegetables < melon vegetables < allium vegetables < root vegetables < solanaceous vegetables < leafy vegetables [14]. In addition, Zhong et al. (2017) found that the concentration of heavy metals in fruit vegetables was lower than that of root vegetables, and leafy vegetables had the highest amount of heavy metals [15].

Zhen et al. (2020) reported that continuous use of a high amount of manure significantly increased total concentrations of cadmium (Cd), zinc (Zn), chromium (Cr), and copper (Cu) in soil [16]. These heavy metals enter human and animal bodies from the food chain and threaten their health [17]. The adverse effect of heavy metals depends on the dose and exposure duration. In other words, dietary exposure to more than the threshold level of heavy metals could endanger health [18]. High concentrations of heavy metals such as Cd, arsenic (As), and lead (Pb) in vegetables and fruits increase the risk of stomach, intestinal and skin cancers, kidney damage, high blood pressure, and nervous system disorders [19]. Health risk assessment should be performed, to estimate the dietary exposure and calculate the health risk associated with

heavy metals intake. Various approaches are applicable to assess the related risk. The probabilistic approach (Monte Carlo simulation) has an advantage over other methods, such as deterministic approaches, providing a complete distribution of the risk for established scenarios [20].

Nowadays, the accumulation of heavy metals in vegetables due to irrigation with wastewater or fertilizers and pesticides has become a growing concern over food safety and consumer health. In general, vegetables are among the most consumed foods, and their unsafety impacts may impose high costs on society. Therefore, the aim of this study is to the determination of heavy metals (Pb, Cd, and As) in highly produced and consumed vegetables in Iran using inductively coupled plasma-emission spectroscopy (ICP-OES). In the following, a great deal of research had been done on heavy metals in leafy vegetables from the Iranian market, which was statistically compared with the current study. Furthermore, considering the importance of heavy metals risk in vegetables, a health risk assessment study was conducted.

Materials and Methods

Materials and Sample Preparation

Chemicals

Nitric acid (65%) and hydrogen peroxide (30%) for acid digestion were purchased from Merck Company (KGaA, Darmstadt, Germany). Ultrapure water was achieved by an integral Milli-Q (MQ) plus water purification system (Millipore, Molsheim, France) and used for the preparation of solutions and dilutions. Heavy metals standard solution was obtained from Fluka (analytical number 51844 multielement standard solution 4) and standard solutions were prepared for calibration curve plotting and validation exams.

Plant Specimens Collected from Tehran Markets

Four commonly consumed vegetables in Iran, including dill (*Anethum graveolens*), parsley (*Petroselinum crispum*), cress (*Lepidium sativum*), and coriander (*Coriandrum sativum*), were selected and sixteen samples of each kind of vegetable were randomly collected ($n = 64$) from fruit and vegetable markets in different regions of Tehran in August and September 2022. To be more precise, sampling design was such that four samples of each kind of vegetable were collected from fruit and vegetable markets located in the north, south, east, and west of Tehran in the first half of the August and September months, as well as in the second half of the August and September months, this sampling plan was repeated.

Extraction and Preparation Procedure

The samples were transferred to the laboratory in polyethylene plastic bags and washed with tap water as it is normally done at home to remove any undesirable pollution. Next, the washed and chopped samples were dried in the oven (Gallenkamp, UK) at 105 °C for 24 h. Then, weighed and powdered for 5 min by the ceramic pestle and mortar and stored in polyethylene bags for further analysis. All samples were weighed before and after oven drying to obtain moisture content. One gram of the powdered vegetables was digested by acid for 1 h in an oven at 130 °C with 2 mL H₂O₂ (30%) and 6 mL HNO₃ (65%) solutions. When acid digestion was completed, samples were filtered using Whatman No.42 filter paper to eliminate turbidity and reached 10 mL by dilution with deionized water. Blank samples included without vegetables were prepared with the exact approach that contained nitric acid, hydrogen peroxide, and deionized water. Prepared samples were maintained in the falcon tube before instrumental analysis with ICP-OES. Treatments to determine the heavy metals contamination were done with three replications [21, 22].

ICP-OES Analysis

Analytical Performance

Samples were analyzed by the ICP-OES system (Spectro, Arcos model SPECTRO, Germany) equipped with torch type of Flared End EOP Torch 2.5 mm, cyclonic Modified Lichte spray chamber, and charge coupled device (CCD) detector. Radio frequency (RF) generator power and frequency were 1400 W and 27.12 MHz, respectively. Plasma, auxiliary, and nebulizer gas was argon with a flow rate of 14.5, 0.9, and 0.85 l/min, respectively. The wavelength for detection of Pb, Cd, and As was set at 220.353, 214.438, and 189.042 nm, respectively.

Validation Method

The detection limits for As, Cd, and Pb were 1.19, 0.04, and 2.18 µg/kg, respectively. The limit of quantitation for Pb, Cd, and As was 6.54, 0.12, and 3.57 µg/kg respectively. Different standard solutions were prepared of multielement standards for ICP and were applied to calibration curve plotting. The calibration curve showed high linearity with the correlation coefficient (R^2) of 0.9996, 0.9994, and 0.9998 for Pb, Cd, and As, respectively. In order to ensure the accuracy of the data, three standards were analyzed after every 10 samples. The difference between the level of heavy metals in the standard solution and the determined content by ICP-OES was less than 5%. In leafy vegetable samples, heavy metals concentration was obtained based on dry weight; then, the

values were converted to fresh weight using the calculated moisture content.

Literature Review and Search Strategy

In order to compare the current investigation with previously published studies in Iran that have assessed heavy metals in leafy vegetables, a systematic search was conducted in the Scopus and PubMed databases leading to finding relevant research. The term ((TITLE-ABS("heavy metal*") OR TITLE-ABS("trace metal*") OR TITLE-ABS("potentially toxic element*") OR TITLE-ABS(lead) OR TITLE-ABS(cadmium) OR TITLE-ABS(arsenic) AND (TITLE-ABS(leafy vegetable) AND (TITLE-ABS(vegetable) AND (AFFIL(Iran) OR TITLE-ABS(Iran)))) was used through Scopus search. In PubMed database, the term (("heavy metal*" [tiab] OR "trace metal*" [tiab] OR "potentially toxic element*" [tiab] OR lead [tiab] OR cadmium [tiab] OR arsenic [tiab]) AND (leafy vegetable [tiab]) AND (vegetable [tiab]) AND (Iran [pl] OR Iran [tiab] OR Iran [ad])) was searched. Eventually, a total of 241 studies were found in the database search strategy. The inclusion criteria enclosed the evaluation of heavy metals Pb, Cd, and As concentration in dill, parsley, cress, and coriander vegetables, in which the mean concentration and standard deviation were mentioned or could be calculated. Exclusion criteria included studies that measured other than Pb, Cd, and As. Furthermore, if the mean concentration and standard deviation were not mentioned, the study was excluded. After checking the titles, 146 articles were excluded and 21 articles were excluded after checking the abstracts. After that, 58 full-text articles were evaluated, of which 15 articles were included in the data extraction stage and 43 articles were excluded. It is noteworthy that the full text of 6 articles was not found and 10 studies were review articles (Fig. 1).

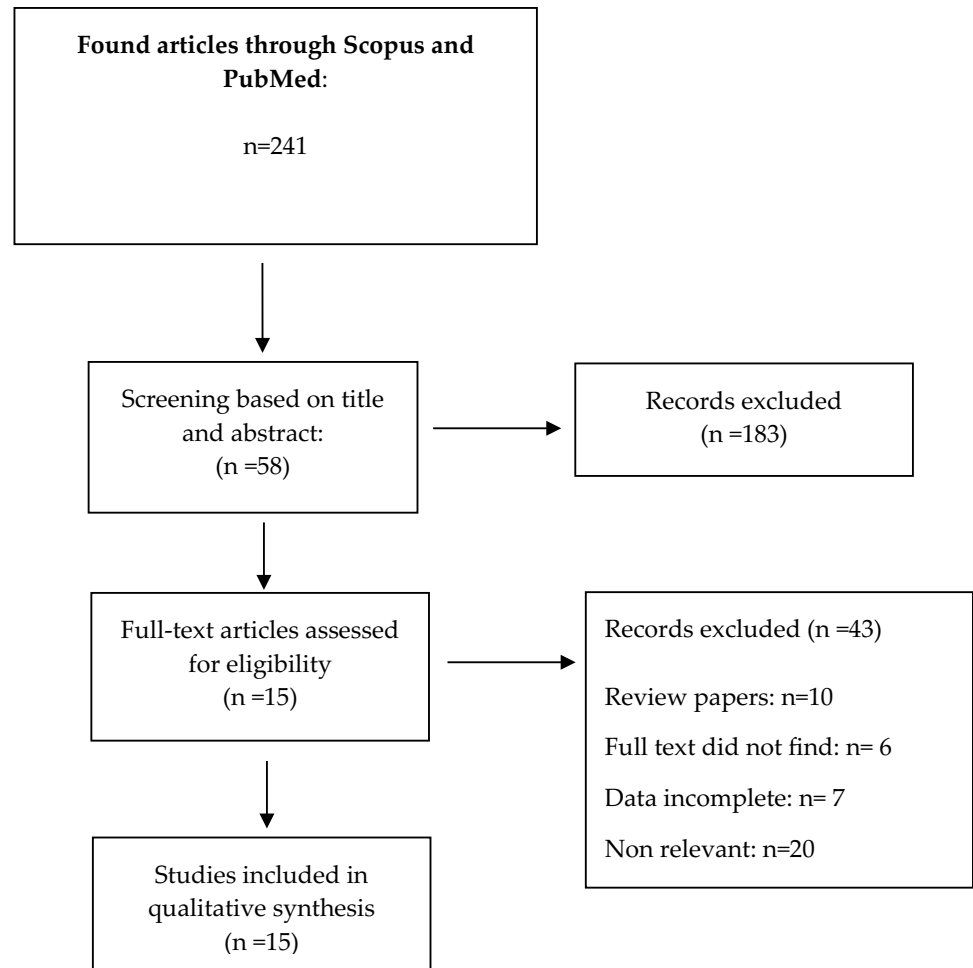
Health Risk Assessment Study

Health risk assessment was conducted using non-carcinogenic target hazard quotient (THQ), based on the leafy vegetables consumption contaminated with heavy metals. If $THQ < 1$, then there is no obvious hazard for consumers. In the first step estimated daily intake (EDI) of heavy metals via leafy vegetables consumption was calculated with Eq. (1) [8];

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

where C (mg/kg) presents heavy metal concentration; IR (kg/person/day), means ingestion rate of leafy vegetables; ED, 70 years' exposure duration for adults; EF, 350 days per year exposure frequency; BW, adults body weight (70 kg); AT, 25,550 days' adults average life time [23].

Fig. 1 Scheme of screening process of articles based on PRISMA



$$THQ = \frac{EDI}{Rfd \text{ or } TDI} \quad (2)$$

The non-carcinogenic risk was calculated by using the target hazard quotient (Eq. (2)), where *Rfd* is the oral reference dose and 0.0018 and 0.0003 mg/kg body weight/day for Cd and As, respectively [24]. TDI means tolerable daily intake which would be 0.0036 mg/kg body weight/day for Pb, established by World Health Organization (WHO) [8]. According to the Iran statistical center, per capita consumption of studied leafy vegetables in Iran was estimated at 15.72 ± 0.5 g/n-day [25].

The following equation was used for the hazard index (HI) calculation of Pb, Cd, and As [26].

$$HI = \sum THQPb + THQcd + THQAs \quad (3)$$

The cancer risk assessment of Pb, Cd, and As was conducted using the Incremental Lifetime Cancer Risk (ILCR) equation (Eq. (4)):

$$ILCR : EDI \times CSF \quad (4)$$

In Eq. (4), CSF is the oral slope factor of Pb, Cd, and As which equals 0.0085, 6.3, and 1.5 mg/kg per day, respectively [24, 27]. If ILCR is lower than 10^{-6} , cancer risk would be negligible. When ILCR is greater than 10^{-4} , cancer risk is intolerable and needs immediate risk management action, and finally, cancer risk is endurable for consumers when ILCR is between 10^{-6} and 10^{-4} [28].

Statistical Analysis

For data gathering and descriptive statistical analysis, minimum, maximum, mean, and standard deviation were calculated by Microsoft Excel (Excel 2016). A health risk assessment study was conducted with Monte Carlo simulation (Oracle crystal ball software). The reputation number in the simulation was 100,000. A cumulative view was used for health risk assessment plotting, and 5 and 95%ile were used to show low- and high-risk consumers, respectively. Heavy metals concentration in evaluated leafy vegetables was plotted with GraphPad Prism 9 software. Accordingly, forest plots of Pb, Cd, and As were obtained with STATA 14.0 (STATA 14.0 Statistical

Software, College Station, TX, USA) to compare previously published studies. P -value < 0.05 was considered statistically significant an I^2 statistic was used for investigating heterogeneity among studies in different subgroups.

Results and Discussion

Heavy Metal Concentration

Lead Concentration in Leafy Vegetables

The results of the concentration analysis of the Pb, Cd, and As heavy metals in leafy vegetable samples are presented in Fig. 2. As shown in Fig. 2, the mean \pm SD concentrations of Pb in parsley, dill, cress, and coriander samples were 87.56 ± 81.84 , 161.43 ± 77.27 , 154.75 ± 72.90 , and 84.5 ± 64.09 $\mu\text{g}/\text{kg}$, respectively. Thus, the rank order of concentration of Pb in leafy vegetables was as follows: dill $>$ cress $>$ parsley $>$ coriander. However, the concentration of Pb was not observed in five samples of parsley and coriander vegetables

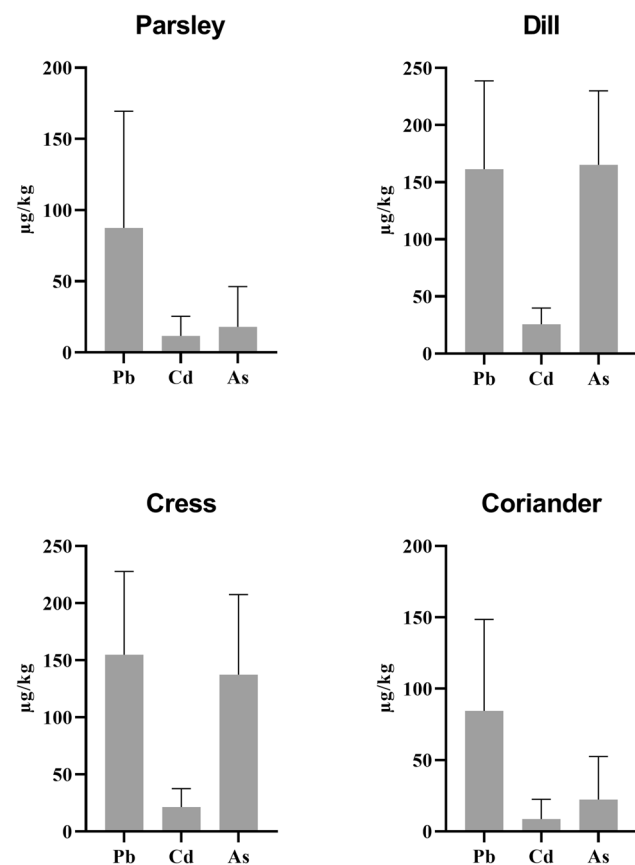


Fig. 2 The concentration of the Pb, Cd, and As heavy metals in leafy vegetable samples

and either in one sample of cress. Pb was detected in all dill samples. The range of Pb concentration was 54–314, $<$ LOQ-289, $<$ LOQ-230, and $<$ LOQ-183 $\mu\text{g}/\text{kg}$ for dill, cress, parsley, and coriander, respectively. According to the Iranian national standard, 0.2 mg/kg was considered the maximum permitted level of Pb in leafy vegetables [29, 30]. In some samples of dill (37.5% of samples), cress (18.75% of samples), and parsley (12.5% of samples), the concentration of Pb was above the national permissible limit. The highest concentration of Pb is related to a dill sample, which has a concentration of 314 $\mu\text{g}/\text{kg}$.

The results of Pb concentration in previous studies in coriander, cress, dill, and parsley vegetables show in Fig. 3. The concentration of Pb in coriander was investigated previously in four researches in Iran from 2018 to 2022 [22, 29, 31, 32]. As shown in Fig. 3, the lowest concentration of Pb observed in coriander was related to the current study (0.08 mg/kg (95% CI: -0.04 to 0.21)). The highest concentration of Pb for coriander vegetable is related to the study of Jalali et al., with a mean of 14 mg/kg (95% CI: 7.67 to 20.33) [31]. In the literature, the oldest study related to the analysis of Pb in cress in Iran is related to the study of Shariatpanahi et al., which reported a mean concentration of 0.8 mg/kg (95% CI: 0.02 to 1.58) for Pb [33]. The present study obtained 0.15 mg/kg (95% CI: 0.01 to 0.3) for the Pb concentration in cress, which is in line with the study of Bahrami et al. (0.17 mg/kg) [34]. In cress, the highest Pb concentration is related to the study of Jalali et al. (17.00 mg/kg (95% CI: 6.40 to 27.60)) [31] and subsequently to the study of Maleki et al. (13.11 mg/kg (95% CI: 12.44 to 13.78)) [35]. According to the eight included studies in Fig. 3, the average concentration of Pb in cress is 0.55 mg/kg (95% CI: 0.48 to 0.62) [22, 29, 31–35]. The average concentration of Pb in included studies in dill is 1.78 mg/kg (95% CI: 1.76 to 1.80) [31, 32, 34, 36, 37]. The mean concentration of 0.16 mg/kg (95% CI: 0.01 to 0.31) reported in dill samples in this study, which is consistent with the study of Bahrami et al. (0.12 mg/kg (95% CI: 0.08 to 0.18)) [34]. For parsley, a mean concentration of 0.2 mg/kg (95% CI: 0.13 to 0.26) was found for the combination of 10 studies were included from 2007 to 2022 [18, 22, 31, 34, 35, 37–40]. The mean concentration of the present study (0.09 mg/kg (95% CI: -0.07 –0.25)) was lower than the average concentration. I^2 values for all vegetable types are higher than 97%, which indicates high heterogeneity in the results, which can be the origin of the difference in extraction methods and analysis methods. In addition, different geographical areas can have different pollution concentrations. Based on previously published studies, the average concentration of Pb was found as follows: dill $>$ cress $>$ coriander $>$ parsley.

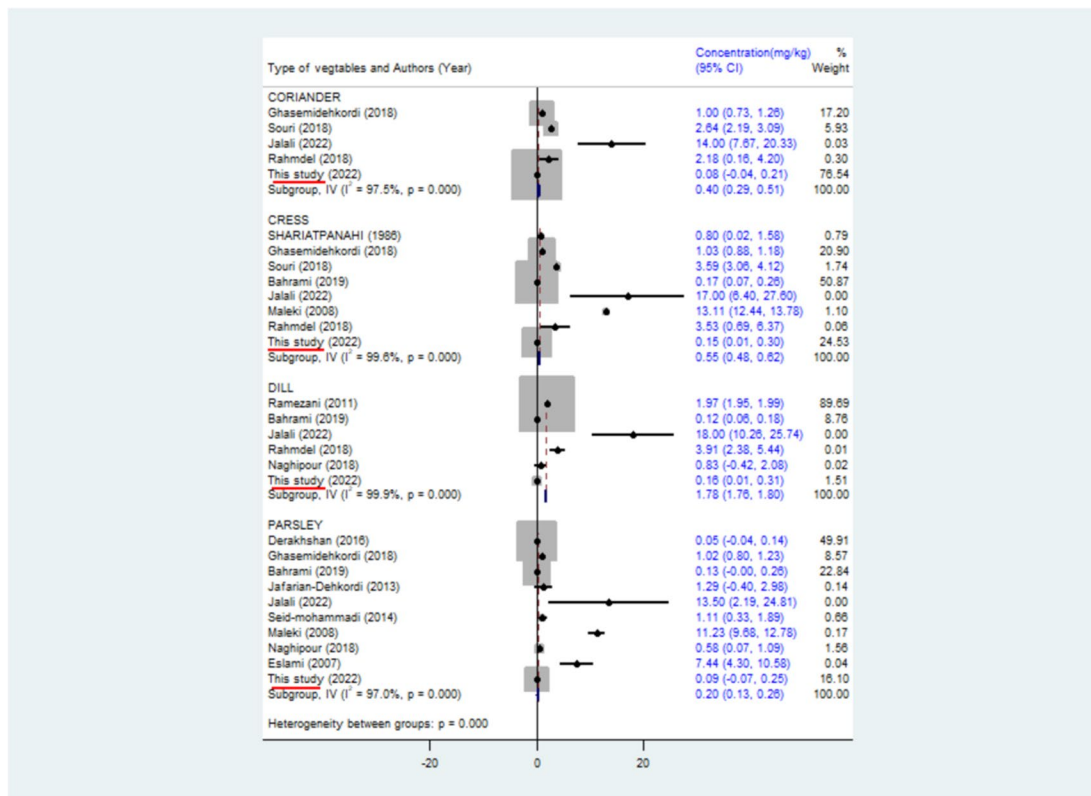


Fig. 3 Results of Pb concentration in previous studies in coriander, cress, dill, and parsley vegetables

Cadmium Concentration in Leafy Vegetables

The mean concentrations of Cd in parsley, dill, cress, and coriander samples were 11.62 ± 13.77 , 25.68 ± 14.15 , 21.43 ± 16.11 , and 8.68 ± 13.76 $\mu\text{g}/\text{kg}$, respectively (Fig. 2). The rank order of mean concentration of Cd was dill > cress > parsley > coriander samples. Coriander had the highest number of non-detected samples (11 samples), and the lowest non-detected samples were reported for dill (3 samples). The range of Cd concentration was <LOQ-42, <LOQ-41, <LOQ-30, and <LOQ-38 $\mu\text{g}/\text{kg}$ for dill, cress, parsley, and coriander, respectively. According to the Iranian national standard, 0.05 mg/kg was considered for Cd as the maximum permitted level in leafy vegetables [30]. In none of the samples, the concentration of Cd was higher than the Iranian national limit.

The results of similar studies for Cd concentration in leafy vegetables in Iran are shown in Fig. 4. Four studies have evaluated the concentration of Cd in coriander [29, 31, 32, 38], which is the highest recorded concentration related to the study of Jalali et al., which reported an average of 1.46 mg/kg (95% CI: 0.21 to 2.71) [31]. The overall mean of Cd concentration in coriander was 0.09 mg/kg (95% CI: 0.07 to 0.11). Similar studies for Cd concentration in cress were found from 1986 to 2022 [29, 31–35,

41], and the results of the present study were more similar to the results of the study by Khajeh et al. [41]. In cress, the mean concentration of 0.06 mg/kg for Cd was found resulting in eight studies conducted in Iran. The highest mean concentration of Cd in Iran for dill vegetables is 2.5 mg/kg (95% CI: 0.13 to 4.87) in Jalali et al.'s study [31] and 2.26 mg/kg (95% CI: -0.05 to 4.57) in Jafarian-Dehkordi's study [38]. The present study with an average of 0.03 mg/kg (95% CI: 0.00 to 0.05) is in line with the findings of Bahrami et al. with a mean concentration of 0.07 mg/kg (95% CI: 0.03 to 0.11) [34]. The Cd data collected from seven included studies showed a total average concentration of 0.1 mg/kg (95% CI: 0.08 to 0.12) in dill vegetables [31, 32, 34, 36–38]. The findings of the present study on the mean concentration of Cd in parsley (0.01 mg/kg (95% CI: -0.01 to 0.04)) were in line with the findings of Seid Mohammadi et al. (0.01 mg/kg (95% CI: 0.00 to 0.02)) [39], Bahrami et al. (0.02 mg/kg (95% CI: -0.01 to 0.06)) [34], and Derakhshan et al. (0.05 mg/kg (95% CI: 0.02 to 0.08)) [18]. In total, the mean concentration of 0.05 mg/kg (95% CI: 0.04 to 0.05) obtained from all studies in parsley [18, 31, 34, 35, 37–40]. The value of I^2 for coriander, cress, parsley, and dill was 96.3%, 99.3%, 97%, and 99%, respectively. The high I^2 indicates the high heterogeneity of the studies, which was higher in cress and

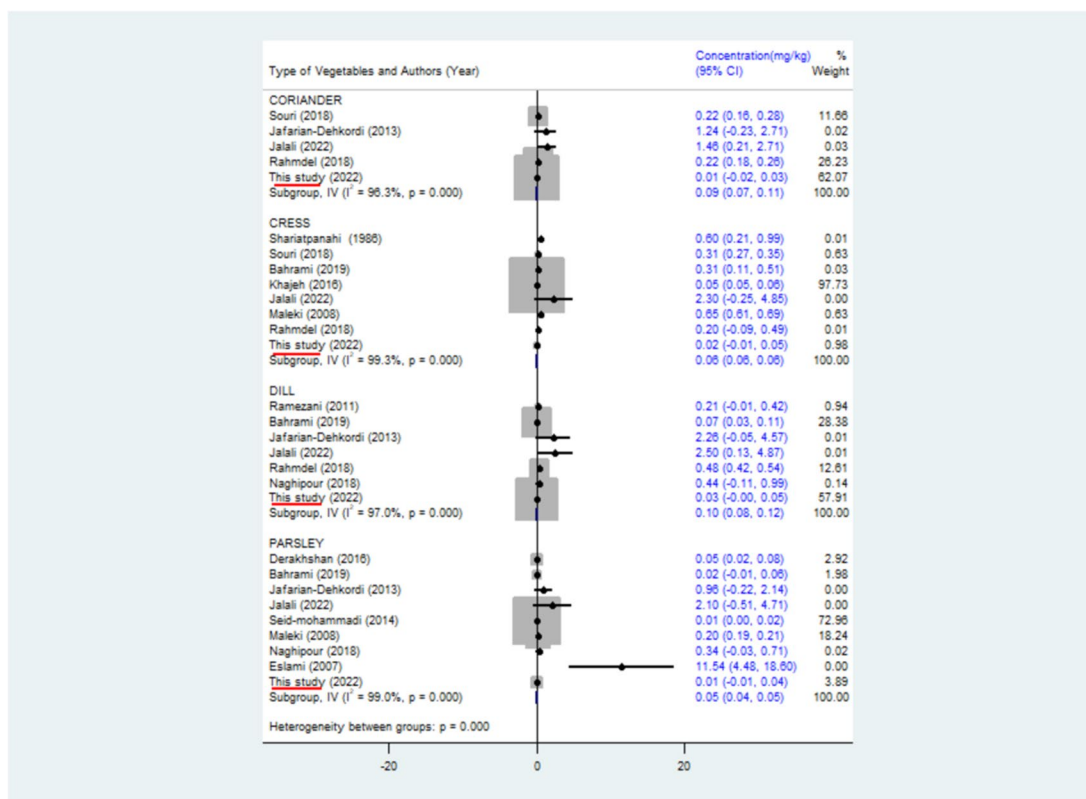


Fig. 4 Results of Cd concentration in previous studies in coriander, cress, dill, and parsley vegetables

parsley. Various parameters can play a role in the heterogeneity of the results, such as the geographical area that was sampled or the number of samples and the analysis method can be the main reasons for this heterogeneity.

Arsenic Concentration in Leafy Vegetables

The mean concentrations of As in parsley, dill, cress, and coriander samples were 18.03 ± 28.19 , 165.19 ± 64.83 , 137.38 ± 70.10 , and 22.28 ± 30.25 $\mu\text{g}/\text{kg}$, respectively (Fig. 2). The rank order of mean As concentration was dill > cress > coriander > parsley samples. The As occurrence was observed in all cress samples, but As in some samples of parsley, dill, and coriander were not detected. The range of As concentration was < LOQ-71, < LOQ-256, 58–273, and < LOQ-75 $\mu\text{g}/\text{kg}$ for parsley, dill, cress, and coriander, respectively.

Previous studies in Iran for As concentration in leafy vegetables was smaller than Cd and Pb (Fig. 5), so no study for As in dill was found. Therefore, it is suggested to pay more attention to As in leafy vegetables in future studies. In the study of Souri et al., the mean concentration of As reported for coriander was 0.05 mg/kg (95% CI: 0.03–0.06), which is in line with the results of the present study [29]. Also, according to

two studies conducted on As concentration in cress, the study by Souri et al. (2018) showed more affinity with the findings of this study [22, 29]. In parsley, the findings of the present study were the most similar to the results of Sanaei et al. with As concentration (0.06 mg/kg (95% CI: -0.01–0.13) [42]. The value of I^2 for coriander, cress, and parsley was 0.0%. The $I^2 = 0$ shows the absence of heterogeneity in theory, but the reason is due to the small number of studies in each subgroup. More studies are needed to determine the prevalence of As in vegetables.

Leafy Vegetable Risk Assessment

Non-carcinogenic Risk Scenario

According to the United States Environmental Protection Agency (USEPA), if the THQ and HI values are higher than 1, it indicates that consumers are at risk [43]. The results of the leafy vegetable non-carcinogenic risk assessment by exposure to Pb, Cd, and As are shown in Table 1. As seen in the table, the THQ level is higher than 1, which indicates that consumers are at risk. Accordingly, the HI value > 1 was obtained for the studied heavy metals. In the study conducted

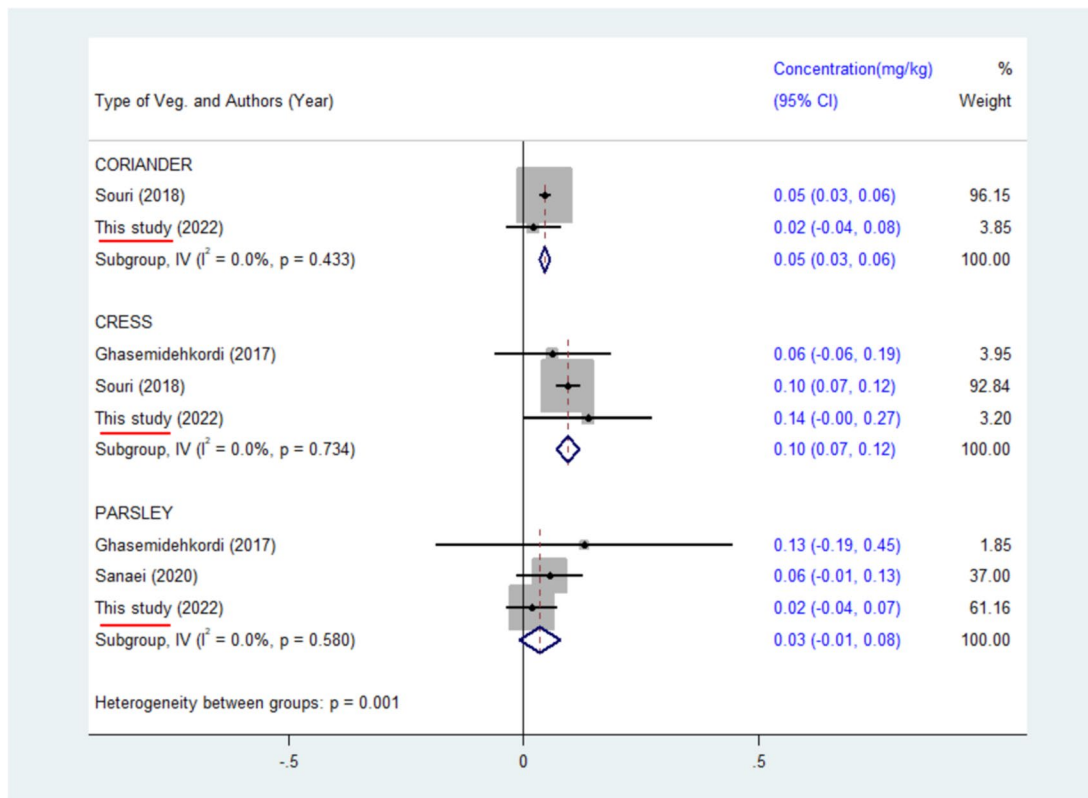


Fig. 5 Results of As concentration in previous studies in coriander, cress, dill, and parsley vegetables

in the Markazi province of Iran by Ghasemidehkordi et al. on the Pb risk assessment in leafy vegetables, the level of Pb risk is higher than 1, which is in line with the present study [22]. A study conducted in the Hamedan province of Iran by Jalali et al. also shows that the risk of Pb intake by consuming basil and peppermint vegetables is higher than one [31]. Furthermore, in a study conducted in Sanandaj, Iran, the EDI level obtained for Pb and Cd was higher than the Provisional Tolerable Daily Intake (PTDI) recommended by Codex Alimentarius (Pb: 214 µg/day, Cd: 60 µg/day) which indicates the high risk of consuming these vegetables [35]. A risk assessment study conducted by Sharifi et al. about exposure to As by consuming

tubular vegetables in Iran, also shows a risk rate higher than 1 (to 75), which indicates the fact that exposure to heavy metals through the consumption of vegetables is serious and it deserves more attention [27]. The study by Bahrami et al. in Ahvaz City (2019) also shows that the total risk of analyzed heavy metals is higher than 1, which is in line with the HI value obtained in this study [34]. Human activities that increase the concentration of heavy metals in the soil can be referred to as the use of phosphate and potash fertilizers, manure, and pesticides [34, 44]. In addition, the use of treated wastewater for irrigation is another source for increasing the entry of heavy metals into the soil, which subsequently affects the safety of the products [24].

Table 1 Estimated THQ, HI, and ILCR from leafy vegetable consumption

Heavy metal	THQ			ILCR		
	P5th	Mean	P95th	P5th	Mean	P95th
Pb	1.90	37.05	110.65	5.83E-5	1.13E-3	3.39E-3
Cd	0.53	10.15	30.22	6.01E-3	1.15E-1	3.43E-1
As	39.84	235.75	549.79	1.79E-2	1.06E-1	2.47E-1
SUM (HI)	42.27	282.95	690.66	-	-	-
SUM (ILCR)	-	-	-	2.40E-2	2.22E-1	5.93E-1

Carcinogenic Risk Scenario

Human consumption of contaminated leafy vegetables can cause serious diseases such as cancer during a lifetime. According to the literature in health risk assessment studies, when ILCR is greater than 10^{-4} , cancer risk is intolerable and needs immediate risk management action [45]. The results of the leafy vegetable carcinogenic risk assessment by exposure to Pb, Cd, and As are shown in Table 1. As seen in the table, the ILCR level is higher than 10^{-4} , which indicates that consumers are at risk. In a study conducted by Alimohammadi et al. in some cucurbits, leafy, and root vegetables, ILCR levels were indicated $3.04E-5$, $6.13E-6$, and $1.86E-4$ for As, Pb, and Cd, respectively [24]. This reveals that the products that were assessed for carcinogenesis risk had a lower risk than the products studied in the current research. In the field investigation conducted in Tehran and Kermanshah city on leafy vegetables, the study of the risk of carcinogenesis shows a maximum value of 10^{-4} , which findings of the current research demonstrates carcinogenesis risk to be more in leafy vegetables [46]. The results of the ILCR stimulated attributed to heavy metal show that the carcinogenic risk via leafy vegetable consumption stands higher than the permissible level. The primary approaches to diminishing the intake of heavy metal risk in vegetables are to control heavy metal concentrations in the cultivation field, such as irrigation source monitoring and control of fertilizers and pesticides used.

Conclusion

In this study, the most consumed leafy vegetables were investigated in Tehran to examine the heavy metals. The results showing the concentration of Pb, Cd, and As above the permissible limit in some samples is about to raise concern. The risk assessment study determined that the THQ and HI values are higher than 1, and either ILCR value is higher than 10^{-4} , which indicates the risk for consumers of leafy vegetables in Iran and requires urgent action to identify the polluted cultivation regions. Also, the previous studies conducted in Iran were gathered with a search strategy design and analyzed from the viewpoint of the significance of heterogeneity. It can be concluded that the issue of heavy metals occurrence in leafy vegetables is of great importance in Iran. Therefore, it is suggested to investigate the geographical topography of soils' heavy metals contamination in future studies. The finding of the suggested study can help authorities to control and monitor the use of fertilizers and pesticides with priority in highly polluted areas and implement phytoremediation projects to reduce heavy metals, as well.

Author Contribution All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Behrouz Tajdar-oranj, Fardin Javanmardi, Sepideh Abbaszadeh, and Karim Parastouei. The first draft of the manuscript was written by Behrouz Tajdar-oranj and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Data Availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Competing Interests The authors declare no competing interests.

References

1. Akbari M, Foroudi P, Shahmoradi M, Padash H, Parizi ZS, Khosravani A, Ataei P, Cuomo MT (2022) The evolution of food security: where are we now, where should we go next? *Sustainability* 14:3634. <https://doi.org/10.3390/su14063634>
2. Sarkar T, Salauddin M, Roy S, Chakraborty R, Rebezov M, Shariati M A, Thiruvengadam M, and Rengasamy K R R (2022), Underutilized green leafy vegetables: frontier in fortified food development and nutrition. *Crit Rev Food Sci Nutr*: 1–55 <https://doi.org/10.1080/10408398.2022.2095555>.
3. FAO (2022) Food balances 2010–2019: global, regional and country trends. FAOSTAT Analytical Brief Series No. 40. Rome, FAO. Available at <https://www.fao.org/food-agriculture-statistics/data-release/data-release-detail/en/c/1505836/>
4. Kalmpourtzidou A, Eilander A, Talsma EF (2020) Global vegetable intake and supply compared to recommendations: a systematic review. *Nutr* 12:1558. <https://doi.org/10.3390/nu12061558>
5. Alnaimy MA, Shahin SA, Vranayova Z, Zelenakova M, Abdel-Hamed EMW (2021) Long-term impact of wastewater irrigation on soil pollution and degradation: a case study from Egypt. *Water* 13:2245. <https://doi.org/10.3390/w13162245>
6. Bharti R, Sharma R (2022) Effect of heavy metals: an overview. *Mater Today: Proc* 51:880–885. <https://doi.org/10.1016/j.matpr.2021.06.278>
7. Witkowska D, Słowik J, Chilicka K (2021) Heavy metals and human health: Possible exposure pathways and the competition for protein binding sites. *Mol* 26:6060. <https://doi.org/10.3390/molecules26196060>
8. Sadighara P, Mofid V, Mahmudiono T, Rahmani A, Tajdar-Oranj B, Peivasteh-Roudsari L, Farhangfar A, Moradi M, and Fakhri Y (2022), Concentration of heavy metals in canned tuna fish and probabilistic health risk assessment in Iran. *Int J Environ Anal Chem*: 1–11 <https://doi.org/10.1080/03067319.2022.2045589>.
9. Liu H, Zhang Y, Yang J, Wang H, Li Y, Shi Y, Li D, Holm PE, Ou Q, Hu W (2021) Quantitative source apportionment, risk assessment and distribution of heavy metals in agricultural

- soils from southern Shandong Peninsula of China. *Sci Total Environ* 767:144879. <https://doi.org/10.1016/j.scitotenv.2020.144879>
10. Kumari S, Mishra A (2021) Heavy metal contamination. In *Soil Contamination-Threats and Sustainable Solutions*. IntechOpen. <https://doi.org/10.5772/intechopen.93412>
 11. Lin H, Wang Z, Liu C, and Dong Y (2022), Technologies for removing heavy metal from contaminated soils on farmland: a review. *Chemosphere*: 135457 <https://doi.org/10.1016/j.chemosphere.2022.135457>
 12. Mukhles MB, Rahman MM, Rana MR, Huda N, Ferdous J, Rahman F, Rafi MH, Biswas SK (2022) Effect of pesticides on nitrification activity and its interaction with chemical fertilizer and manure in long-term paddy soils. *Chemosphere* 304:135379. <https://doi.org/10.1016/j.chemosphere.2022.135379>
 13. Zhou H, Yang W-T, Zhou X, Liu L, Gu J-F, Wang W-L, Zou J-L, Tian T, Peng P-Q, Liao B-H (2016) Accumulation of heavy metals in vegetable species planted in contaminated soils and the health risk assessment. *Int J Environ Res Public Health* 13:289
 14. Yang Y, Zhang F-S, Li H-F, Jiang R-F (2009) Accumulation of cadmium in the edible parts of six vegetable species grown in Cd-contaminated soils. *J Environ Manage* 90:1117–1122
 15. Zhong T, Xue D, Zhao L, Zhang X (2018) Concentration of heavy metals in vegetables and potential health risk assessment in China. *Environ Geochem Health* 40:313–322
 16. Zhen H, Jia L, Huang C, Qiao Y, Li J, Li H, Chen Q, Wan Y (2020) Long-term effects of intensive application of manure on heavy metal pollution risk in protected-field vegetable production. *Environ Pollut* 263:114552. <https://doi.org/10.1016/j.envpol.2020.114552>
 17. Alizadeh AM, Hosseini H, Meybodi NM, Hashempour-Baltork F, Alizadeh-Sani M, Tajdar-Oranj B, Pirhadi M, Khaneghah AM (2022) Mitigation of potentially toxic elements in food products by probiotic bacteria: a comprehensive review. *Food Res Int* 152:110324
 18. Derakhshan Z, Faramarzian M, Mahvi A, Hosseini M, Miri M (2016) Assessment of heavy metals residue in edible vegetables distributed in Shiraz. *Iran J Food Qual Hazards Control* 3:25–29
 19. Manwani S, Vanisree C, Jaiman V, Awasthi KK, Yadav CS, Sankhla MS, Pandit PP, Awasthi G (2022) Heavy metal contamination in vegetables and their toxic effects on human health. *Sustainable Crop Prod* 181. <https://doi.org/10.5772/intechopen.102651>
 20. Taghizadeh SF, Rezaee R, Boskabady M, Mashayekhi Sardoo H, Karimi G (2022) Exploring the carcinogenic and non-carcinogenic risk of chemicals present in vegetable oils. *Int J Environ Anal Chem* 102:5756–5784
 21. Tajdar-Oranj B, Shariatifar N, Alimohammadi M, Peivasteh-Roudsari L, Khaniki GJ, Fakhri Y, Mousavi Khaneghah A (2018) The concentration of heavy metals in noodle samples from Iran's market: probabilistic health risk assessment. *Environ Sci Pollut Res* 25:30928–30937. <https://doi.org/10.1007/s11356-018-3030-y>
 22. Ghasemidehkordi B, Malekirad AA, Nazem H, Fazilati M, Salavati H, Shariatifar N, Rezaei M, Fakhri Y, Khaneghah AM (2018) Concentration of lead and mercury in collected vegetables and herbs from Markazi province, Iran: a non-carcinogenic risk assessment. *Food Chem Toxicol* 113:204–210. <https://doi.org/10.1016/j.fct.2018.01.048>
 23. Taghizadeh SF, Karimi G, Tzatzarakis M, Tsakiris I, Ahmadpourmir H, Azizi M, Afshari A, Ghorani V, Yarmohammadi F, Tsatsakis A (2022) Probabilistic risk assessment of exposure to multiple metals and pesticides through consumption of fruit juice samples collected from Iranian market. *Food Chem Toxicol* 170:113493
 24. Alimohammadi M, Younesian M, Madihi-Bidgoli S, NabizadehNoddehi R, JahedKhaniki GR, Hadi M, Ghanbari F (2020) Heavy metal (oid) s concentration in Tehran supermarket vegetables: carcinogenic and non-carcinogenic health risk assessment. *Toxin Rev* 39:303–310. <https://doi.org/10.1080/15569543.2018.1522644>
 25. Hashempour-baltork F, Jannat B, Tajdar-oranj B, Aminzare M, Sahebi H, Alizadeh AM, Hosseini H (2023) A comprehensive systematic review and health risk assessment of potentially toxic element intakes via fish consumption in Iran. *Ecotoxicol Environ Saf* 249:114349. <https://doi.org/10.1016/j.ecoenv.2022.114349>
 26. Taghizadeh SF, Azizi M, Hassanpourfard G, Rezaee R, Karimi G (2023) Assessment of carcinogenic and non-carcinogenic risk of exposure to metals via consumption of coffee, tea, and herbal tea in Iranians. *Biol Trace Elem Res* 201:1520–1537
 27. Sharifi R, Moore F, Keshavarzi B, Badieli S (2018) Assessment of health risks of arsenic exposure via consumption of crops. *Exposure Health* 10:129–143. <https://doi.org/10.1007/s12403-017-0250-1>
 28. Taghizadeh SF, Rezaee R, Badibostan H, Karimi G (2020) Probabilistic carcinogenic and non-carcinogenic risk assessment of heavy metal ingestion through consumption of different walnut cultivars: an Iranian study. *Environ Monit Assess* 192:1–15
 29. Souri MK, Alipanahi N, Hatamian M, Ahmadi M, Tesfamariam T (2018) Elemental profile of heavy metals in garden cress, coriander, lettuce and spinach, commonly cultivated in Kahrizak, South of Tehran-Iran. *Open Agric* 3:32–37. <https://doi.org/10.1515/opag-2018-0004>
 30. Institute of Standards and Industrial Research of Iran ISIRI (2021) Food and feed maximum limit of heavy metals and test methods. ISO 12968. ISIRI Press, Tehran, Iran. Available at <http://standard.isiri.gov.ir/StandardView.aspx?Id=56594>
 31. Jalali M, Meyari A (2022) Heavy metal contents, soil-to-plant transfer factors, and associated health risks in vegetables grown in western Iran. *J Food Compos Anal* 106:104316. <https://doi.org/10.1016/j.jfca.2021.104316>
 32. Rahmdel S, Rezaei M, Ekhlasi J, Zarei SH, Akhlaghi M, Abdollahzadeh SM, Sefidkar R, Mazloomi SM (2018) Heavy metals (Pb, Cd, Cu, Zn, Ni, Co) in leafy vegetables collected from production sites: their potential health risk to the general population in Shiraz. *Iran Environ Monit Assess* 190:1–10. <https://doi.org/10.1007/s10661-018-7042-3>
 33. Shariatpanahi M, Anderson AC (1986) Accumulation of cadmium, mercury and lead by vegetables following long-term land application of wastewater. *Sci Total Environ* 52:41–47. [https://doi.org/10.1016/0048-9697\(86\)90103-8](https://doi.org/10.1016/0048-9697(86)90103-8)
 34. Bahrami S, Moore F, Keshavarzi B (2021) Evaluation, source apportionment and health risk assessment of heavy metal and polycyclic aromatic hydrocarbons in soil and vegetable of Ahvaz metropolis. *Hum Ecol Risk Assess* 27:71–100. <https://doi.org/10.1080/10807039.2019.1692300>
 35. Maleki A, Zarasvand MA (2008) Heavy metals in selected edible vegetables and estimation of their daily intake in Sanandaj Iran. *Southeast Asian J Trop Med Public Health* 39:335
 36. Ramezani Z, Aghel N, Shiralipour R, Zahed DR (2011) Determination of lead and cadmium content of dill (*Anethum graveolens*) and onion (*Allium Cepa L.*) cultivated in Khozestan/Iran. *Iran J Pharm Sci* 7:197–203
 37. Naghipour D, Chenari MA, Taheri N, Naghipour F, Mehrabian F, Attarchi MS, Jaafari J, Roubakhsh E (2018) The concentration data of heavy metals in vegetables of Guilan province. *Iran Data Brief* 21:1704–1708. <https://doi.org/10.1016/j.dib.2018.10.114>
 38. Jafarian-Dehkordi A, Alehashem M (2013) Heavy metal contamination of vegetables in Isfahan. *Iran Res Pharm Sci* 8:51
 39. Seid-Mohammadi A, Roshanaei G, Asgari G (2013) Heavy metals concentration in vegetables irrigated with contaminated and fresh water and estimation of their daily intakes in suburb areas of Hamadan. *Iran J Res Health Sci* 14:70–75

40. Eslami A, Khaniki GR, Nurani M, Mehrasbi M, Peyda M, Azimi R (2007) Heavy metals in edible green vegetables grown along the sites of the Zanzanrood river in Zanjan. *Iran J Biol Sci* 7:943–948. <https://doi.org/10.3923/jbs.2007.943.948>
41. Khajeh M, Saravani F, Ghaffari-Moghaddam M, Bohlooli M (2016) Flotation-Assisted homogenous liquid–liquid microextraction for determination of cadmium in vegetables. *J Veg Sci* 22:266–273. <https://doi.org/10.1080/19315260.2015.1039744>
42. Sanaei F, Amin MM, Alavijeh ZP, Esfahani RA, Sadeghi M, Bandarrig NS, Fatehizadeh A, Taheri E, Rezakazemi M (2021) Health risk assessment of potentially toxic elements intake via food crops consumption: Monte Carlo simulation-based probabilistic and heavy metal pollution index. *Environ Sci Pollut Res* 28:1479–1490. <https://doi.org/10.1007/s11356-020-10450-7>
43. USEPA (2005) Guidelines for carcinogen risk assessment. In Risk Assessment Forum US Environmental Protection Agency, Washington, DC EPA/630/P-03/001F (vol 1)
44. Yadav H, Kumar R, Sankhla MS (2020) Residues of pesticides and heavy metals in crops resulting in toxic effects on living organism. *J Seybold Rep* 1533:9211
45. Mohammadi A, Tajdar-oranj B, Hosseini H, Kamankesh M, Shariyatifa N, Jazaeri S, Hosseini-Esfahani F (2023) Probabilistic dietary exposure and carcinogenic risk of heterocyclic aromatic amines formed in the main groups of fast foods: investigation of different ages and genders. *J Food Compos Anal* 105344. <https://doi.org/10.1016/j.jfca.2023.105344>
46. Ahmadi-Jouibari T, Ahmadi Jouybari H, Sharafi K, Heydari M, Fattahi N (2021) Assessment of potentially toxic elements in vegetables and soil samples irrigated with treated sewage and human health risk assessment. *Int J Environ Anal Chem* 1–17. <https://doi.org/10.1080/03067319.2021.1893704>

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.