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A Survey of Heavy Metal Levels in Some Plant-Based Foods and Their Human Health Risk Assessment: Findings from Ahvaz, Khuzestan Province, Iran

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ABSTRACT

Heavy metals in Khuzestan's wastewater threaten crops and health, especially in Ahvaz, a key agricultural and industrial area. This study aimed to evaluate the levels of trace metals in various plant-based foods from Ahvaz City, Iran. A total of 72 food samples were collected from various markets in Ahvaz to analyze trace metal levels, including lead (Pb), cadmium (Cd), chromium (Cr), arsenic (As), and mercury (Hg). Samples were digested using 10% nitric acid, and heavy metal analysis was performed with inductively coupled plasma atomic emission spectroscopy (ICP-OES). Estimated daily intake (EDI), target hazard quotient (THQ), and hazard index (HI) were used to assess the combined risks from multiple pollutants. The safety assessment was based on the permissible limits established by the World Health Organization (WHO) and Food and Drug Administration (FDA). The trace metal levels in sesame reached up to 0.99 μg g^{-1} for Pb, with low levels of As and Cr. The THQ for Cr indicated potential health risks, but other metals were deemed safe. No heavy metals were found in date palms, and HQ and HI values suggested no risk. Cucumbers and rice also showed low heavy metal levels, with THQs and HIs below one, indicating safety. Wheat had Pb levels of 0.429 μg g^{-1}, raising concerns, while tomatoes had low as levels (0.026 μg g^{-1}), suggesting overall safety in consumption. Most samples exhibited low levels of heavy metals; however, the elevated concentrations of Pb and Cr in wheat highlight the need for continuous monitoring to ensure consumer safety. In conclusion, although most food items contained acceptable levels of heavy metals, the findings in wheat underscore the importance of ongoing surveillance to protect public health.

1. Introduction

The consumption of plant-based foods contaminated with various toxins, including microorganisms, fungal byproducts (metabolites), pesticides, and trace metals, poses significant health concerns worldwide [1]. Exposure to these contaminants can lead to both acute poisoning and long-term health issues. Trace metal contamination, in particular, has garnered increasing public health attention [2]. Toxic metals such as lead (Pb), cadmium (Cd), chromium (Cr), arsenic (As), and mercury (Hg) can enter food sources like grains, fruits, vegetables, and seeds through polluted environments, including water, soil, and air. These non-biodegradable trace metals can also accumulate in livestock and subsequently be transferred to humans through the consumption of food and animal products [3]. Ingesting contaminated food can lead to the accumulation of trace metals in the human body, potentially resulting in neurological problems, liver dysfunction, and other adverse health effects [4]. Given that plant-based foods are a critical component of the human diet, it is essential to assess the levels of trace metals in these food sources and evaluate the associated health risks [5].

Lead (Pb) is a toxic, non-essential trace metal used in various industries. Pb exposure can occur through multiple routes, including respiratory, gastrointestinal, and dermal. It primarily accumulates in the skeleton and can be slowly released, particularly during periods of bone demineralization. Maternal transfer of Pb to children is a concern, as exposure can occur both pre- and post-natally. Pb toxicity primarily affects the nervous system, causing neurotoxicity, psychiatric symptoms, and impaired motor skills. It is also linked to increased blood pressure, kidney disease, and anemia. The International Agency for Research on Cancer (IARC) classifies Pb as a probable carcinogen [6]. According to European Commission guidelines, the maximum permissible levels of Pb in certain foodstuffs range from 0.02 to 0.3 mg/kg fresh weight [7]. Cadmium (Cd) has been classified as a known human carcinogen by the IARC since 1993. Although the absorption rate of Cd through diet is low, it deposits in the kidney and liver, with a half-life of 10–30 years. Chronic dietary exposure to Cd is associated with an increased risk of cancers in the breast, lung, endometrium, and bladder, as well as renal dysfunction and bone demineralization. The World Health Organization (WHO) has set a maximum acceptable level of 0.3 mg/kg for Cd in vegetables [8].

Arsenic (As) is a naturally occurring trace metal that is toxic to humans, with inorganic arsenic (i-As) species being more harmful than organic forms. The oxidation state of As also affects its toxicity, with trivalent arsenicals (+3) being more toxic than pentavalent forms (+5) [9].The U.S. Food and Drug Administration (FDA) permits a concentration of As in food ranging from 0.5 to 2 $\mu g\ g^{-1}$ [10]. Mercury (Hg), another naturally occurring element, is ubiquitous in the environment and can adversely affect various physiological systems, including the nervous, renal, cardiovascular, and gastrointestinal systems. Neurological effects are of particular concern as they manifest at lower doses than other toxic effects [11].The

FAO/WHO permissible Hg limit in food crops is 0.5 µg g^{-1} [12].

Some metals, while essential in small amounts as coenzymes, can exhibit toxic effects when present in excess. Their non-biodegradable nature leads to accumulation in living organisms over time, disrupting metabolic processes and posing significant health risks. This underscores the importance of monitoring and regulating metal exposure in the environment [13]. Chromium (Cr) compounds, for example, can cause severe toxic effects, including carcinogenicity, mutagenicity, and oxidative stress in both humans and animals [14]. The permissible limit for Cr in food, as set by the FAO/WHO, is 2.3 mg kg^{-1} [15].

Ahvaz, located in Khuzestan province, Iran, is a key economic and industrial center in the region [16]. The Karun River irrigates most farms in various regions of Ahvaz. The Karun River, the most important river in Iran, has a close connection with a significant group of industries; including metallurgy, oil, and petrochemicals, while also being in contact with a considerable portion of urban and agricultural wastewater. Therefore, the presence of any metallic element, especially trace metals, in the wastewater entering this river can be considered a potential pollution factor and a significant risk. This is particularly important due to Ahvaz's high potential for producing diverse strategic and industrial agricultural products on one hand, and the impact of industrial activities, inappropriate use of fertilizers, pesticides, and unhealthy irrigation water [17, 18]. Previous studies in Khuzestan Province have reported the presence of heavy metals such as Cd and Pb in agricultural products, including rice and vegetables. For instance, Kolahkaj and Battalebloie, (2018) found that in Meydavood, the Pb level in rice exceeded WHO safety limits (1.07 mg/kg compared to approximately 0.3 mg/kg) [19]. A study by Mansouri Moghadam et al. (2022) found that wheat from two areas, Weiss and Arab Assad, located north of Ahvaz City, contains high levels of heavy metals, especially manganese. These metals pose health risks, particularly for children [20].

This study aims to assess the levels of five metals (Pb, Cd, Cr, As, and Hg) in plant-based foods from Ahvaz City. Additionally, the study emphasizes the estimation of daily intake (EDI), target hazard quotient (THQ), and hazard index (HI) to evaluate the combined risks associated with multiple pollutants. This integrated approach offers a more detailed understanding of potential health threats and provides valuable insights for developing targeted mitigation strategies. This innovative aspect enhances the contribution of our research to the existing body of knowledge and supports more effective policymaking for food safety in Khuzestan

2. Material and methods

2.1. Reagents

A stock standard solution (1000 mg L^{-1}) for each element (Pb, Cd, Cr, As and Hg) was obtained from Chem-Lab (Belgium). Working standard solutions were prepared by appropriate dilution. All reagents used were of analytical grade, and deionized water was exclusively employed for all dilution procedures. Glassware was meticulously cleaned with liquid soap, soaked overnight in 10% (v/v) nitric acid solution to eliminate potential metal contamination, and then thoroughly rinsed with double-distilled water to ensure purity.

2.2. Sample collection

A total of 72 food samples including cucumber (n=12), tomato (n=12), wheat (n=12), rice (n=12), Sesame (n=12), and dates (n=12) were obtained from different markets in different areas of Ahvaz city between January and March 2020–2021 to measure the levels of trace metals including Pb, Cr, Cd, Hg, and As. Polyethylene bags were employed to transport the samples from the markets to the central laboratory of Shahid Chamran University of Ahvaz, and they were then stored in a sterile glass container at 4°C.

2.3. Sample preparation

The samples were first washed with tap water and then rinsed twice with deionized water to remove any surface contamination. After being air-dried at room temperature for one week, they were further dried in an oven at 105°C for four hours. The dried samples were ground using a porcelain mortar to avoid metal contamination and then transferred to deionized water-washed containers. Prepared samples were stored at 4°C for no longer than one week in clean, hermetically sealed polyethylene containers. Subsequently, 10 g of each powdered sample was weighed and placed in sterilized crucibles. The samples were heated on a hot plate to remove moisture, resulting in pre-ashed material, which was further ashed in a muffle furnace at 480°C for about 2 -8 hours for different samples. The resultant ash was digested in a 10% nitric acid (HNO_3) solution, and the digested samples were filtered through a 0.45 µm filter into 50 mL polyethylene volumetric flasks. Finally, the filtered solutions were diluted with 1% (v/v) HNO_3 for analysis using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) on a PerkinElmer Optima 8300 device [21-23].

2.4. Inductively coupled plasma –optical emission spectrometer (ICP-OES) analysis

All analyses were conducted using a PerkinElmer Optima 8300 ICP-OES Spectrometer (USA), equipped with two SCD detectors covering a spectral range of 163–782 nm. High-purity argon gas (>99.995%) was used to sustain the plasma and as a carrier gas. The operational parameters were as follows:

Power (watts): 1500
Plasma gas flow rate (L min^{-1}): 10
Auxiliary gas flow rate (L min^{-1}): 0.2
Nebulizer gas flow rate (L min^{-1}): 0.70
Replicate read time (s): 3
Sample uptake delay time (s): 25
Sample flow rate (mL min^{-1}): 1.00
Flush time (s): 5
Replicates: 5

The operating emission lines for Pb, Cd, Cr, As, and Hg were 220.353, 214.440, 267.716, 193.696, and 253.652 nm, respectively.

2.5. Method validation, LODs, and LOQs

The ICP-OES measurements were validated by evaluating linearity, precision, and limits of detection (LODs) and quantification (LOQs). Linearity was assessed using calibration curves in the concentration range of 0–100 µg L^{-1}, yielding correlation coefficients (r) between 0.997 and 0.999. The precision of the method was expressed as the relative standard deviation (RSD), which was less than 8% for three replicate measurements (the repetitions are related to the sample injection stage into the device). The LOD and LOQ values, presented in Table 1, were determined using the 3σ and 10σ criteria, respectively [22].

Table 1. The LOD and LOQ value of heavy metal detected by ICP-OES.

Trace metals	LOD (μg g^{-1})	LOQ (μg g^{-1})
Cd	0.105	0.35
Pb	0014	0.093
As	0.105	0.35
Hg	0.09	0.3
Cr	0.09	0.3

2.6. Human health risk assessment

2.6.1 Estimated daily intake

The estimated daily intake (EDI) of metals is influenced by their concentration in food and the amount of food consumed daily. Additionally, body weight can affect tolerance to pollutants. EDI is calculated using the following equation [23]:

$$\mathrm{EDI} = \frac{\mathrm{EF} \times \mathrm{ED} \times \mathrm{FIR} \times \mathrm{C}}{\mathrm{WAB} \times \mathrm{TA}}$$

Where:

- **C** is the metal concentration (μg g^{-1}),
- **FIR** is the food ingestion rate (3, 100, 35, 100, 334, and 52 g day^{-1} for sesame, date palm, cucumber, rice, wheat, and tomato, respectively),
- **EF** is the exposure frequency (365 day year^{-1}),
- **ED** is the exposure duration (70 years, corresponding to the average lifespan),
- **WAB** is the average body weight (70 kg), The risk assessment focused on the adult population (average body weight 70 kg) due to the availability of exposure data.
- **TA** is the averaging exposure time for non-carcinogens, calculated as 365 days year^{-1} × ED [24-27]

The risk assessment focused on the adult population (average body weight 70 kg) due to the availability of exposure data.

2.6.2 Target hazard quotient

Non-cancer risk assessments estimate potential health risks of pollutants using the target hazard quotient (THQ). A THQ less than 1 indicates that the exposure level is below the provisional tolerable weekly intake (PTWI), suggesting that daily exposure at this level is unlikely to cause adverse effects over a lifetime [23]:

$$THQ = \frac{7 \times EDI}{PTWI}$$

The PTWI values for Cd, Pb, As, Hg, and Cr are recommended by the Joint FAO/WHO Expert Committee on Food Additives: 7 µg Cd kg^{-1} bw $week^{-1}$; 25 µg Pb kg^{-1} bw $week^{-1}$; 3 µg As kg^{-1} bw $week^{-1}$; 1.6 µg methylmercur kg^{-1} bw $week^{-1}$; and 0.7 µg Cr kg^{-1} bw $week^{-1}$ [15, 25, 28, 29].

2.6.3. Hazard index

The Hazard Index (HI) assesses the potential non-carcinogenic risk from multiple pollutants. It quantifies the risk of adverse health effects from chemical mixtures, depending on target tissues and mechanisms of action. HI values for daily food consumption in humans were calculated using the following equation [23]:

$$HI = \sum_{n=0}^{i} THQn$$

2.7. Statistical analysis

All measurements were performed in triplicate to ensure reproducibility. Mean values were reported, and standard deviations were calculated to reflect variability. Data were expressed as mean ± standard deviation.

3. Results and discussion

3.1. Sesame

Sesame (*Sesamum indicum*), a member of the *Pedaliaceae* family, is one of the most significant oil seeds in developed countries. In Iran, sesame cultivation is common in arid and semi-arid regions, especially in tropical areas such as Khuzestan, Fars, and Sistan and Baluchistan provinces. Sesame seeds are considered an essential source of oil due to their high oil content and exceptional quality. Additionally, their aromatic properties make them widely used as a flavoring agent in the bread and pastry industries. Sesame seeds are a rich nutritional source but may also contain anti-nutritional substances [25, 30]. This study analyzed the levels of Pb, Cd, As, Hg, and Cr in sesame samples using ICP-OES. The analyzed metal levels (µg g^{-1}) are shown in Table 2.

Table 2. Average concentration, estimated daily intake (ED), target hazard quotient (THQ) and hazard index (HI) of trace metals in sesame samples

Trace metal	Pb	Cd	As	Hg	Cr
Average (µg g^{-1})	0.560± 0.193	ND	0.114± 0.074	ND	0.1± 0.063
Minimum (µg g^{-1})	0.315	ND	ND	ND	ND
Maximum (µg g^{-1})	0.990	ND	0.21	ND	0.185
Permissible limit (µg g^{-1})	0.02 -0.3 [7]	0.3 [8]	0.5-2 [10]	0.5 [12]	2.3 [15]
EDI (µg kg^{-1} bw day^{-1})	0.235± 0.080	-	0.048± 0.049	-	0.042± 0.022

THQ	0.066± 0.023	-	0. 111± 0.066	-	0.421± 0.232
HI			0.599		

ND: Not detectable

The concentrations of metals recorded in sesame samples were as follows: Pb (0.315–0.990 µg g^{-1}), As (no detectable–0.21 µg g^{-1}), and Cr (no detectable–0.185 µg g^{-1}). Cd and Hg levels in all samples were below the detection limits of the device. Consequently, all sesame samples contained trace metal levels below established standards, except for Pb, which was above the permissible limit.

Previous studies, such as those by Bolaños et al. (2015) and Almaaly (2019), have reported varying levels of trace metals like Ag, Al, Cu, Fe, Cd, Pb, and As in sesame seeds [31, 32]. Eghbaljoo-Gharehgheshlaghi et al. (2022) noted that the sesame variety influences trace metal concentrations [25]. Other studies, including Gebrekidan et al. (2019) and Muazu et al. (2010), confirmed trace metal presence in sesame seeds, with concentrations influenced by climatic conditions, agricultural practices, soil and water pollution, and processing methods [33, 34].

Differences between this study and previous findings may result from variations in sample size, soil type, genetic diversity, and environmental conditions. Post-harvest processing, especially peeling, significantly reduces toxic metal content, as pollutants tend to accumulate in the outer layers [35]. Monitoring trace metal levels in sesame seeds is essential for public health safety. The Estimated Daily Intake (EDI) and Target Hazard Quotient (THQ) values for Pb, Cd, As, Hg, and Cr are provided in Table 2. Notably, the highest THQ values were observed for Cr, approaching unity, suggesting potential health concerns. Conversely, the THQ values for Pb, Cd, As, and Hg were significantly below unity (<1), indicating no immediate health risks. The Hazard Index (HI), derived from the sum of all THQ values, was below one (<1), implying no significant synergistic non-carcinogenic health risk.

3.2. Date Palm

The date palm (*Phoenix dactylifera*), part of the Arecaceae family, is a vital symbol of life in desert regions, thriving under high temperatures, water scarcity, and salinity. It is among the oldest cultivated trees in arid climates and serves as a unique dietary staple due to its rich content of essential minerals, carbohydrates, vitamins, and proteins. However, date palm fruits can be susceptible to metal contamination from fertilizers, pesticides, and industrial pollution. The plant's leaves can act as indicators of metal pollution in the environment. Factors such as plant size and growth rate also influence metal accumulation [23]. In Iran, dates are a strategic agricultural product, with over 20% of the country's production occurring in Khuzestan province [35].

Table 3. Average concentration, estimated daily intake (ED), target hazard quotient (THQ) and hazard index (HI) of trace metals in date palm samples.

Trace metal	Pb	Cd	As	Hg	Cr

Average ($\mu g\ g^{-1}$)	0.192± 0.162	ND	0.092± 0.042	ND	ND
Minimum ($\mu g\ g^{-1}$)	ND	ND	ND	ND	ND
Maximum ($\mu g\ g^{-1}$)	0.53	ND	0.18	ND	ND
Permissible limit ($\mu g\ g^{-1}$)	0.02 -0.3 [7]	0.3 [8]	0.5-2 [10]	0.5 [12]	2.3 [15]
EDI ($\mu g\ kg^{-1}$ bw day^{-1})	0.274± 0.241	-	0.131± 0.062	-	-
THQ	0.077± 0.067	-	0.305± 0.145	-	-
HI			0.381		

ND: Not detectable

The concentrations of metals in date palm samples are presented in Table 3. The detected levels ranged from nondetectable–0.53 $\mu g\ g^{-1}$ (Pb) and nondetectable–0.18 $\mu g\ g^{-1}$ (As). Some date palm samples show that Pb levels exceed permissible limits. Toxic trace metals Cd, Cr, and Hg were undetectable in all samples. A similar study in Ahvaz reported that Cd and Pb concentrations in dates were below permissible limits, indicating the safety of these fruits for consumption [36]. The absence of toxic metals enhances the safety profile of date palm fruits compared to samples from other regions [23]. The health risk assessment, including EDI, HQ, and HI values, revealed that both HQ and HI were below 1.0 (<1), indicating no significant public health risks. The absence of Cd, Cr, and Hg further reinforces the safety of these fruits for consumption, with no carcinogenic threats identified.

3.3. Cucumbers

Cucumbers (*Cucumis sativus L.*) are widely consumed fruits, valued for their nutritional benefits, refreshing taste, and high water content. They are a key ingredient in Iranian salads, which are particularly popular in the region. However, cucumbers can accumulate pollutants, including microplastics, polycyclic aromatic hydrocarbons, trace metals, and antibiotics, raising concerns about food safety [25]. For instance, Zafarzadeh and Rahimzadeh (2015) found trace metals like Cd and Pb in cucumbers from Gorgan and Gonbad cities exceeding WHO limits [37]. Similarly, Jafarian and Alhashem (2013) reported high levels of Cr, Cd, and Pb in cucumbers, attributed to the excessive use of pesticides, chemical fertilizers, and contaminated surface water [38].

In this study, the mean levels ($\mu g\ g^{-1} \pm$ SD) of trace metals in cucumbers from Ahvaz City were as follows: Pb (0.019 ± 0.02), As (0.084 ± 0.02), and nondetectable levels of Cd, Hg, and Cr (Table 4). These concentrations were below the permissible limits set by international standards. The THQ for each metal was below unity (<1), suggesting no significant health risks. The HI value, encompassing all metals, was also below unity (<1), indicating that cucumbers from the region are safe for consumption.

Table 4. Average concentration, estimated daily intake (ED), target hazard quotient (THQ) and hazard index (HI) of trace metals in Cucumbers samples.

Trace metal	Pb	Cd	As	Hg	Cr
Average (µg g^{-1})	0.019± 0.020	ND	0.084± 0.02	ND	ND
Minimum (µg g^{-1})	ND	ND	ND	ND	ND
Maximum (µg g^{-1})	0.125	ND	0.08	ND	ND
Permissible limit (µg g^{-1})	0.02 -0.3 [7]	0.3 [8]	0.5-2 [10]	0.5 [12]	2.3 [15]
EDI (µg kg^{-1} bw day^{-1})	0.009± 0.019	-	0.042± 0.092	-	-
THQ	0.002± 0.005	-	0.097± 0.228	-	-
HI			0.100		

ND: Not detectable

3.4. Rice

Rice, particularly white rice, is a staple food in Iran and across Asia. While the quality of cooked rice is a primary consumer concern, trace metal contamination has raised safety issues [22]. Studies have shown that Cd, As, and Pb levels in some Iranian rice varieties exceed national standards. However, the overall average weekly intake of these metals, along with Co, Ni, and Cr, is below WHO/FAO-recommended limits, except for Hg, which exceeds these recommendations [39].

In this study, the average concentrations (µg g^{-1}) of Pb and As in rice samples were 0.117 ± 0.177 and 0.058 ± 0.042, respectively, with some samples showing levels of Pb exceeding the permissible limits (Table 5). Cd, Cr, and Hg were undetectable in the samples. The EDI values for Pb and As were 0.167 ± 0.025 and 0.083 ± 0.060 µg kg^{-1} bw day^{-1}, respectively the THQs for these metals were below unity (<1). The calculated HI was 0.239, indicating no significant health risks to consumers.

Table 5. Average concentration, estimated daily intake (ED), target hazard quotient (THQ) and hazard index (HI) of trace metals in rice samples.

Trace metal	Pb	Cd	As	Hg	Cr
Average (µg g^{-1})	0.117± 0.177	ND	0.058± 0.042	ND	ND
Minimum (µg g^{-1})	ND	ND	ND	ND	ND
Maximum (µg g^{-1})	0.515	ND	0.1	ND	ND
Permissible limit (µg g^{-1})	0.02 -0.3 [7]	0.3 [8]	0.5-2 [10]	0.5 [12]	2.3 [15]
EDI (µg kg^{-1} bw^{-1})	0.167± 0.025	-	0.083± 0.060	-	-

THQ	0.046± 0.070	-	0.193± 0.140	-	-
HI			0.239		

ND: Not detectable

3.5. Wheat

Wheat is a strategic agricultural product that provides essential calories and protein to both urban and rural populations in Iran. Various studies have been conducted to assess trace metal contamination in wheat grown across the country. For instance, Kianpour et al. identified cadmium contamination in wheat from Hamedan, while Ismaili et al. reported no cadmium in wheat from Bushehr province [40, 41]. Soil contamination with trace metals in Khuzestan province has raised concerns about food safety and environmental health, particularly in wheat cultivation areas.

Table 6 presents the concentrations, EDI, and THQ of trace metals in wheat samples from Ahvaz. The average concentration of Pb was 0.429 ± 0.670 μg g-1, with an EDI of 2.045 ± 3.02 μg kg^{-1} bw^{-1} and a THQ of 0.572 ± 0.895, indicating potential health risks. Cd was not detected, which is favorable given its high toxicity. As was detected at 0.058 ± 0.042 μg g^{-1}, with an EDI of 0.083 ± 0.060 µg/kg bw/day and a THQ of 0.193 ± 0.140, suggesting the need for ongoing monitoring. Hg showed a concentration of 0.042 ± 0.145 µg g^{-1}, with an EDI of 0.2 ± 0.695 µg kg^{-1} bw day^{-1} and a THQ of 0.878 ± 3.04, indicating some caution is warranted. Cr was present at 0.06 ± 0.087 µg g^{-1}, with an EDI of 0.286 ± 0.418 µg kg^{-1} bw day^{-1} and a concerning THQ of 2.862 ± 4.181, highlighting potential health risks.

In summary, while Cd was absent, the elevated levels of Pb and Cr, some of which exceeded the permissible limits, indicate the need for continued monitoring of trace metal contamination in wheat to ensure consumer safety.

Table 6. Average concentration, estimated daily intake (ED), target hazard quotient (THQ) and hazard index (HI) of trace metals in wheat samples.

Trace metal	Pb	Cd	As	Hg	Cr
Average (µg g^{-1})	0.429± 0.670	ND	0.058± 0.042	0.042± 0.145	0.060± 0.087
Minimum (µg g^{-1})	ND	ND	ND	ND	ND
Maximum (µg g^{-1})	0.51	ND	0.14	0.505	0.245
Permissible limit (µg g^{-1})	0.02 -0.3 [7]	0.3 [8]	0.5-2 [10]	0.5 [12]	2.3 [15]
EDI	2.045± 3.020	-	0.083± 0.060	0.200± 0.695	0.286± 0.418

(µg kg^{-1} bw day^{-1})					
THQ	0.572± 0.895	-	0.193± 0.140	0.878± 3.040	2.862± 4.181
HI			4.892		

ND: Not detectable

3.6. Tomato

Tomatoes are versatile fruit vegetables rich in potassium, phosphorus, magnesium, and iron—nutrients essential for nerve and muscle function. The tomato (*Solanum lycopersicum*), a perennial herbaceous plant commonly grown as an annual in temperate climates, is a key source of vitamin C, potassium, and antioxidants, including lycopene. According to the FAO, Iran is the seventh-largest tomato producer globally, with a production of over 4.8 million tons [42].

Studies have reported trace metal contamination in tomatoes from various regions of Iran, often attributed to soil and water pollution, as well as the use of chemical fertilizers [38, 42, 43].

Table 7. Average concentration, estimated daily intake (ED), target hazard quotient (THQ) and hazard index (HI) of trace metals in tomato samples.

Trace metal	**Pb**	**Cd**	**As**	**Hg**	**Cr**
Average (µg g^{-1})	ND	ND	0.026± 0.045	ND	ND
Minimum (µg g^{-1})	ND	ND	ND	ND	ND
Maximum (µg g^{-1})	ND	ND	0.145	ND	ND
Permissible limit (µg g^{-1})	0.02 -0.3 [7]	0.3 [8]	0.5-2 [10]	0.5 [12]	2.3 [15]
EDI (µg kg^{-1} bw day^{-1})	-	-	0.019± 0.033		-
THQ	-	-	0.044± 0.770		-
HI			0.044		

ND: Not detectable

Table 7 provides the concentrations of trace metals in tomatoes from Ahvaz City and their associated health risks. The concentration of As was 0.026 ± 0.045 µg g^{-1}, while Pb, Cd, Hg, and Cr were not detected (ND). The EDI for As was 0.019 ± 0.03 µg kg^{-1} bw day^{-1}, indicating low exposure. The THQ for As was 0.044, suggesting minimal risk.

Overall, the findings indicate that trace metal levels in tomatoes from the region are within safe limits for consumption, with no significant public health risks identified.

4. Conclusions

This study provides a comprehensive assessment of trace metal contamination in food samples, including sesame, date palm, cucumbers, rice, wheat, and tomatoes from Ahvaz City. The findings show that trace metal levels for Pb, As, Cd, Hg, and Cr in these food items are generally below permissible limits set by national and international standards.

Sesame: Pb levels ranged from 0.315 to 0.99 µg g^{-1}, while As and Cr were detected at nondetectable to 0.21 µg/g and nondetectable to 0.185 µg/g, respectively. Cd and Hg were below detection limits, ensuring compliance with safety standards.

Date Palm: Toxic trace metals (Cd, Cr, Hg) were not detected, reinforcing the safety profile of date palm fruits for consumption.

Cucumbers: Trace metal concentrations, including Pb and As, were below permissible limits, with THQ and HI values indicating no significant health risks.

Rice: Pb and As levels were low, while Cd, Cr, and Hg were undetectable. The EDI and THQ values for Pb and As suggest minimal health risks.

Wheat: Although Cd was not detected, elevated levels of Pb and Cr necessitate ongoing monitoring to ensure safety.

Tomatoes: Trace metal levels, including As, were within safe limits, with no significant risks posed by their consumption.

The overall Hazard Index (HI) values for all food samples were below unity (<1), indicating no significant health risks from trace metal exposure. However, continuous monitoring of trace metal contamination in food products remains critical to safeguard public health, particularly in regions where environmental factors may influence metal accumulation in agricultural produce.

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بررسی سطوح فلزات کمیاب در برخی از غذاهای گیاهی و ارزیابی خطر سلامت انسانی آنها: یافته های استان خوزستان، ایران

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چکیده

وجود فلزات سنگین در فاضلاب استان خوزستان به‌ویژه در اهواز که یک منطقه کلیدی کشاورزی و صنعتی است، محصولات کشاورزی و سلامتی مردم را تهدید می‌کند. این مطالعه با هدف ارزیابی میزان فلزات کمیاب در مواد غذایی گیاهی مختلف در شهر اهواز، ایران، انجام شد. در مجموع، ۷۲ نمونه غذایی از بازارهای مختلف اهواز جمع‌آوری شد تا میزان فلزات کمیاب مانند سرب(Pb) ، کادمیوم(Cd) ، کروم(Cr) ، آرسنیک (As) و جیوه (Hg)مورد بررسی قرار گیرد. نمونه‌ها با استفاده از اسید نیتریک ۱۰ درصد هضم شده و تحلیل طیف‌سنجی نشر نوری با پلاسمای القایی (ICP-OES) انجام گردید. برای ارزیابی خطرات ترکیبی ناشی از چندین آلاینده، شاخص‌هایی همچون میزان دریافت روزانه تخمین زده شده(EDI) ، ضریب خطر هدفمند(THQ) ، و شاخص خطر (HI) استفاده شدند. .ارزیابی ایمنی بر اساس محدودیت های مجاز تعیین شده توسط سازمان بهداشت جهانی (WHO) و سازمان غذا و دارو (FDA) بود. میزان فلزات کمیاب در کنجد تا ۰.۹۹ میکروگرم بر گرم برای Pb رسید، در حالی که مقادیر As و Cr پایین بود. THQ مربوط به Cr نشان‌دهنده خطرات احتمالی برای سلامتی است اما سایر فلزات ایمن به نظر می رسند. در خرما هیچ فلز سمی یافت نشد و مقادیر HQ و HI نشان داد که خطری وجود ندارد. خیار و برنج نیز میزان فلزات کمیاب پایینی نشان دادند و مقادیر THQ و HI کمتر از یک بودند که ایمنی آن‌ها را نشان می‌داد. گندم دارای مقادیرPb برابر با ۰.٤۲۹ میکروگرم بر گرم بود که جای نگرانی دارد، در حالی که گوجه‌فرنگی دارای سطوح پایین As (به میزان ۰.۰۲۶ میکروگرم بر گرم) بود که نشان‌دهنده ایمنی کلی در مصرف آن بود. بیشتر نمونه‌ها مقادیر پایینی از فلزات کمیاب را نشان دادند، اما غلظت‌های بالاتر Pb و Cr در گندم نیاز به پایش مستمر را برای اطمینان از ایمنی مصرف‌کنندگان را گوشزد می‌کند.