Journal of Human Environment and Health Promotion
Print ISSN: 2476-5481 Online ISSN: 2476-549X

Assessment of Cadmium and Chromium Contamination in Iranian Commercial Sausages

Ali Mohammadzadeh [a]*, Zohre Farahmandkia [b], Hassan Hassanzadazar [c], Majid Aminzare [d, c], Saeid Vahedi [a], Rana Dizaji [e]

a. Social Determinants of Health Research Center, Health and Metabolic Diseases Research Institute, Zanjan University of Medical Sciences, Zanjan, Iran.
b. Health and Environment Research Center, Zanjan University of Medical Sciences, Zanjan, Iran.
c. Department of Food Safety and Hygiene, School of Public Health, Zanjan University of Medical Sciences, Zanjan, Iran.
d. Nutrition and Food Security Research Center, Health and Metabolic Diseases Research Institute, Zanjan University of Medical Sciences, Zanjan, Iran.
e. Food and Drug Administration, Zanjan University of Medical Sciences, Zanjan, Iran.

***Corresponding author:** Department of Food Safety and Hygiene, School of Public Health, Zanjan University of Medical Sciences, Zanjan, Iran. Postal Code: 4515786349. E-mail: mohamadzadehali800@gmail.com

ARTICLE INFO

Article type:
Original article

Article history:
Received: 26 April 2026
Revised: 6 June 2026
Accepted: 20 June 2026
Available online: 29 June 2026

https://doi.org/10.66224/jhehp.770

Keywords:
Food safety
Heavy metals
Meat products
Inductively Coupled Plasma Mass Spectrometry
Iran

ABSTRACT

Background: Heavy metal contamination in meat products presents a significant public health risk owing to their bioaccumulation potential and subsequent adverse health effects. This study, conducted in Iran in 2025, aimed to quantify cadmium and chromium concentrations in commercially available sausages, assessing potential variations influenced by brand and meat content.
Methods: A total of 99 sausage samples from 11 brands were collected from retail outlets across Iran. Cadmium and chromium concentrations were measured using inductively coupled plasma mass spectrometry after acid digestion. One-way ANOVA assessed differences between brands and meat content categories.
Results: The mean concentrations of cadmium and chromium were determined to be 0.18 ± 0.19 µg/kg and 34.01 ± 41.33 µg/kg, respectively. Cadmium and chromium concentrations ranged from 0.10 to 1.53 µg/kg and 0.10 to 200.50 µg/kg, respectively. While significant inter-brand differences were found for both metals, the percentage of meat content did not exert a statistically significant influence on their concentrations.
Conclusion: According to Codex Alimentarius (CXS 193-1995), all analyzed samples contained cadmium and chromium levels below the maximum permissible limits (50 µg/kg and 1000 µg/kg, respectively). These findings offer valuable insights into the safety and quality of sausage products in the Iranian market, contributing to enhanced food safety surveillance and public health protection.

1. Introduction

Meat products, including sausages, represent a major component of the global food supply and are widely consumed owing to their nutritional value, sensory attributes, and convenience (Oyekunle et al., 2019; Pirsaheb et al., 2024). Worldwide consumption of meat and processed meat products has markedly increased in recent decades, driven by socioeconomic development, urbanization, and evolving dietary preferences (Iammarino et al., 2017; Jayaraj et al., 2025). In Iran, sausages produced by various commercial brands are among the most frequently consumed meat products, contributing substantially to national protein intake and the food industry economy (Bazhan et al., 2025; Pirsaheb et al., 2024).

The formulation of sausages-particularly their meat content-is a key determinant of both nutritional quality and potential contamination. Sausage products with meat

How to cite: Mohammadzadeh, A., Farahmandkia, Z., Hassanzadazar, H., Aminzare, M., Vahedi, S., & Dizaji, R. (XXXX). Assessment of Cadmium and Chromium Contamination in Iranian Commercial Sausages. *J Hum Environ Health Promot*, *XX*(X), XX-XX.

contents ranging from 55% to 80% differ significantly in physicochemical composition and contaminant profiles (Alsadat Mirbod et al., 2022). The nature and proportion of meat, together with additives, spices, and processing conditions, influence the retention and accumulation of chemical contaminants, including heavy metals (Alsadat Mirbod et al., 2022; Dissanayake et al., 2024).

Heavy metal contamination in food constitutes one of the most persistent and serious public health concerns worldwide (Ekhator et al., 2017; Jayaraj et al., 2025). Heavy metals are generally defined as metallic elements with densities exceeding 5 g/cm^3 and represent some of the most significant chemical contaminants in food. Their occurrence in foods of animal origin is of particular concern because it increases the likelihood of human exposure and the associated adverse health effects (Farahmandkia et al., 2023; Farahmandkia et al., 2025). Heavy metals such as cadmium (Cd), chromium (Cr), lead (Pb), mercury (Hg), arsenic (As), copper (Cu), and zinc (Zn) enter the food chain through multiple pathways, including industrial emissions, agricultural runoff, contaminated soil and water, sewage sludge, fertilizers, and pesticides. Both anthropogenic activities, such as electronic waste disposal, metallurgical processes, and personal care products, and natural phenomena like mineral weathering and soil erosion contribute to their bioaccumulation in plants and subsequent transfer into animal tissues (Pop et al., 2024; Tayeb & Movassaghghazani, 2025). Once integrated into the food chain, these heavy metals can accumulate in livestock and processed meat, posing significant health risks through dietary exposure (Han et al., 2022; Jayaraj et al., 2025).

The toxicological importance of heavy metals in foods is well recognized. Pb, Cd, and Hg are among the most hazardous toxicants, capable of inducing profound biochemical, neurological, and physiological impairments (Barone et al., 2021; Jayaraj et al., 2025). Cd is classified as a Group 1 human carcinogen by the International Agency for Research on Cancer (IARC) (Bandara & Indunil, 2022). Cr toxicity varies by oxidation state; at elevated concentrations, it can induce nephritis, anuria, and extensive renal lesions (Barone et al., 2021). The oxidative stress and reactive oxygen species generation elicited by Cd, Cr, Pb, As, and Hg underlie their mechanistic roles in toxicity and carcinogenesis (Oyekunle et al., 2019). Even subacute dietary exposure has been linked to increased risks of cancer, organ dysfunction, and developmental and metabolic disorders (Ekhator et al., 2017; Jayaraj et al., 2025).

Among these heavy metals, Cd and Cr have drawn particular scientific and regulatory attention in processed meat products. Cd, a non-essential toxic metal, accumulates in biological tissues with an estimated biological half-life of about ten years, rendering chronic exposure especially concerning (Ekhator et al., 2017). It can enter animal feed and meat via industrial pollution or phosphate fertilizers used in agriculture (Han et al., 2022; Pop et al., 2024). Cr, although an essential trace element at low levels, becomes toxic when elevated, causing severe renal dysfunction (Barone et al., 2021). Contamination of meat with Cr may arise from environmental sources, Cr-containing additives or processing equipment, and migration from packaging materials (Bandara & Indunil, 2022; Dissanayake et al., 2024).

While the European Union has established maximum permitted levels (MPLs) for Cd and Pb in many food categories, comprehensive regulatory limits for Cr in meat products remain lacking (Barone et al., 2021; Pop et al., 2024). Considering the widespread consumption of commercial sausages in Iran, the documented occurrence of Cd and Cr in processed meat products worldwide (Barone et al., 2021; Fedoseeva et al., 2023; Han et al., 2022), and the well-established toxicological risks associated with these metals (Bandara & Indunil, 2022; Jayaraj et al., 2025; Oyekunle et al., 2019), there is a clear need for a systematic assessment of their presence in commercially available sausages in Iran. Moreover, although formulation characteristics, particularly meat content, have been shown to influence contaminant concentrations in processed meat products (Alsadat Mirbod et al., 2022; Dissanayake et al., 2024), the relationship between meat content and heavy metal contamination has not yet been comprehensively investigated in the Iranian context. Therefore, this study aimed to: (1) determine the concentrations of Cd and Cr in commercial sausages with varying meat content available in the Iranian market; (2) compare contamination levels among different meat-content categories; and (3) evaluate compliance of measured concentrations with relevant national and international standards. The results are expected to strengthen the scientific basis for food safety regulation, enhance public awareness, and support targeted monitoring programs addressing heavy metal contamination in processed meat products.

2. Materials and Methods

2.1 Reagents and Instrumentation

Nitric acid (HNO_3, 68%; Ariyachem Co., Iran) and a Borna plate heater (Teb Azma Co., Iran) were used for sample digestion. Heavy metal quantification was performed using an inductively coupled plasma mass spectrometer (ICP-MS, Agilent 7900; Agilent Technologies, USA). Operating parameters were as follows: RF power = 1200 W; auxiliary gas flow = 1-2 l/min; solution uptake rate = 1 mL/min; mass range = 7-238 amu; and unit mass resolution ≈ 1 amu. The detector was an electron multiplier (EM). The dynamic range extended from 0.001 µg/kg to 1000 mg/kg, with an argon plasma flow of 17 l/min, abundance sensitivity 10^6-10^8, and scanning rate 3000 amu/s.

2.2 Sampling Procedure

A total of 99 sausage samples from 11 major domestic brands with varying declared meat contents were randomly procured from different retail outlets across Iran. Each sausage was sampled at the initial, middle, and terminal portions, homogenized, and weighed precisely. The homogenized subsamples were packaged, labeled, and stored at -18 °C until further analysis. Sample size calculation followed Daniel's equation:

$$N = \frac{Z^2 S^2}{D^2}$$

where N is the required sample size, Z represents the critical value from the standard normal distribution, S is the estimated standard deviation, and D is the margin of error.

2.3 Sample Digestion

Digestion was carried out according to *U.S. EPA Method 3050B* (EPA, 1996), with minor modifications for processed meat matrices. Approximately 2.0 g of homogenized sample was placed into acid-washed polypropylene tubes, followed by the addition of 5 mL of concentrated nitric acid. Samples were pre-digested for 24 h at room temperature to facilitate acid penetration and partial oxidation of the organic matrix (Mehrasebi et al., 2023).

Subsequently, the tubes were heated in a controlled water bath at 95 °C for 30 min to ensure complete matrix breakdown and release of heavy metals. The digested solutions were filtered through Whatman No. 42 filter paper and diluted to 15 mL with deionized water. The filtrates were transferred to acid-washed polyethylene vials and stored at 4 °C until instrumental analysis. Quantitative analysis was performed on the Agilent 7900 ICP-MS system using high-purity argon (99.9 %) as the carrier gas. The dilution factor (*DF*) was calculated as:

$$DF = \frac{V(ml)}{m(gr)}$$

where *V* is the final digestion volume and *m* is the sample mass.

2.4 Method Validation and Quality Control

ICP-MS calibration employed multi-element standards (Merck, Darmstadt, Germany) prepared in an identical acid matrix. Calibration curves exhibited excellent linearity ($R^2 > 0.999$) for all analytes, with $R^2 = 0.999$ for Cd and Cr. Continuing Calibration Verification (CCV) standards were analyzed after every ten samples to verify instrument stability.

Accuracy and precision were evaluated using matrix-spike recoveries and relative standard deviation (RSD%). Limits of detection (LOD) and quantification (LOQ) were determined as:

LOD = 3.3 SD, LOQ = 10 SD

where *SD* is the standard deviation of the blank response and *S* is the slope of the calibration curve. The calibration curves for Cd and Cr are presented in Figures 1 and 2, respectively.

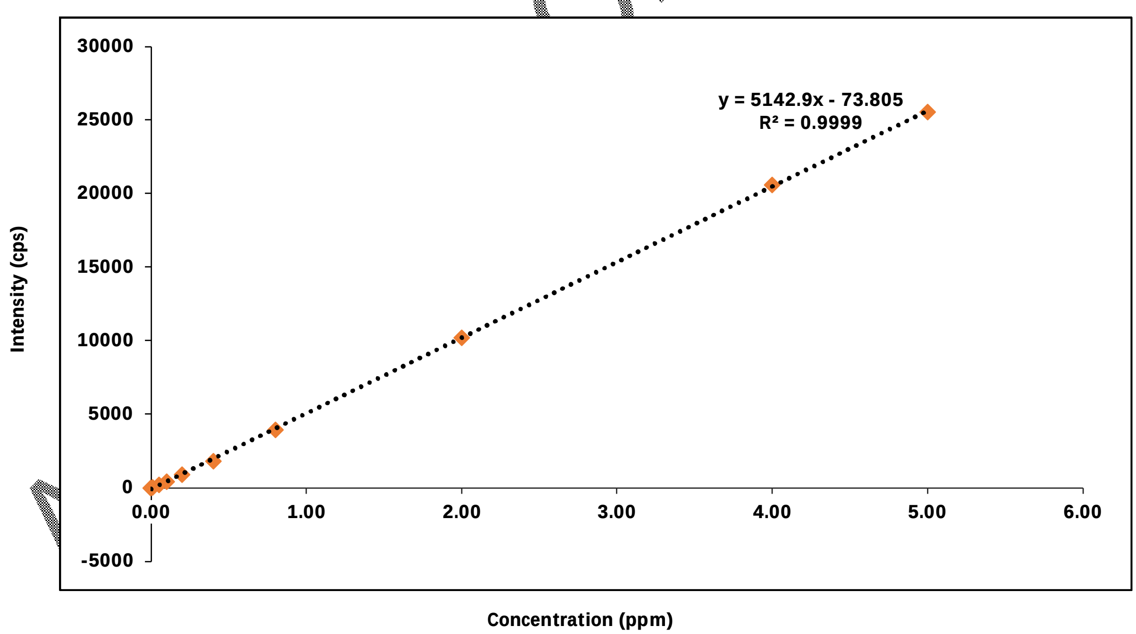

Figure 1. Calibration curve of Cd

Validated analytical performance parameters were as follows:

Cd - LOD = 0.45 µg/kg, LOQ = 1.500 µg/kg

Cr - LOD = 1.500 µg/kg, LOQ = 4.900 µg/kg

The RSD was measured using repeated measurements of known concentrations, and for both of the heavy metals was < 5 %. Recovery rates ranged from 83-91 % for Cd and 106-108.8 % for Cr, within the acceptable limits (85-115 %) defined in *EPA Method 3050B* (Belouafa et al., 2017; EPA, 1996). To avoid contamination, all glassware and plasticware were pre-soaked in 10 % HNO_3 for 24 h and rinsed thoroughly with deionized water before use.

2.5 Statistical Analysis

Statistical analyses were conducted using IBM SPSS Statistics® version 25 (IBM Corp, Armonk, NY, USA). Descriptive statistics-including mean, median, standard deviation (SD), and interquartile range (IQR)-were computed to characterize the data distribution. The Kolmogorov-Smirnov test was employed to assess the normality of the data sets. To compare metal concentrations among distinct sample groups, a One-Way Analysis of Variance (ANOVA) was performed. Statistical significance was defined at a level of $P < 0.05$. In instances where ANOVA revealed significant differences, Tukey's Honestly Significant Difference (HSD) post hoc test was utilized to identify specific pairwise mean differences within the sausage sample groups.

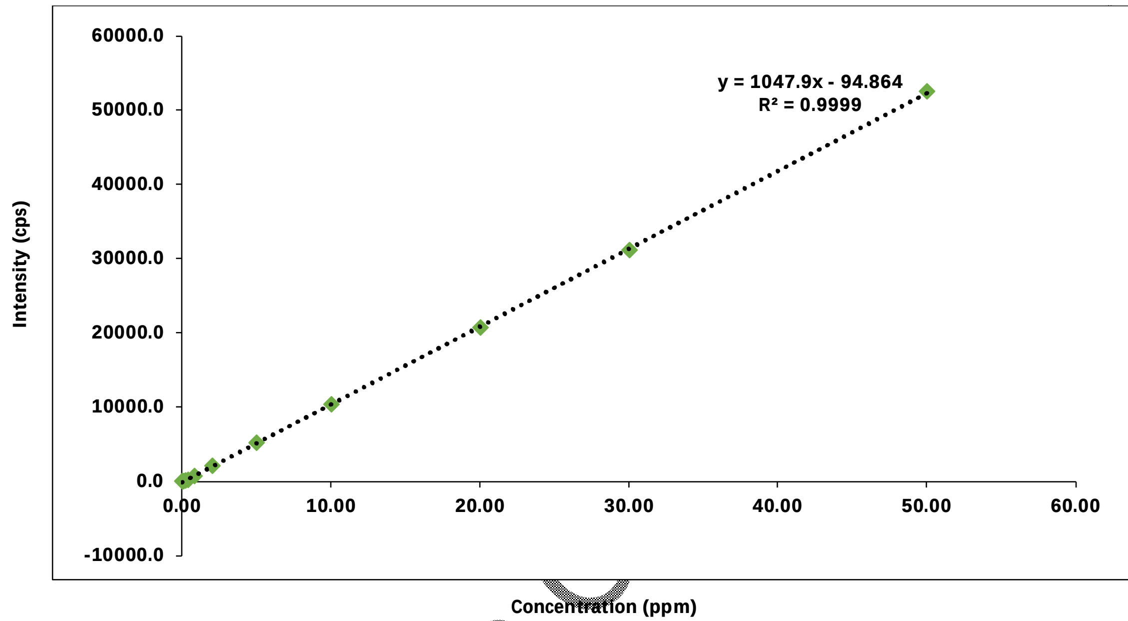

Figure 2. Calibration curve of Cr

3. Results and Discussion

The mean concentrations of Cd and Cr in all samples were 0.18 ± 0.19 µg/kg and 34.01 ± 41.33 µg/kg, respectively. The mean concentrations of Cd in almost all samples were lower than LOD. It is recommended that the 1/2LOD should be considered instead of the data with values lower than LOD. However, in the present case, almost all concentrations are lower than LOD, and the results will not change. The highest observed concentrations for Cd and Cr were 1.53 µg/kg and 200.50 µg/kg, respectively. According to the Codex Alimentarius General Standard for Contaminants and Toxins in Food and Feed (CXS 193-1995) and the Iranian National Standard No. 12968 (First Revision), the maximum permissible levels (MPL) for Cd and Cr are 50 µg/kg and 1000 µg/kg, respectively (Codex Alimentarius Commission, 1995; Iran National Standards Organization, 2021).

A comparison with these established standards reveals that the concentrations of both heavy metals in all analyzed samples remain below the maximum permissible limits. In this study, the Kolmogorov-Smirnov test indicated that the data followed a normal distribution, justifying the use of parametric statistical analyses. The mean concentrations of Cd and Cr across different brands and meat percentages are presented in Tables 1 and 2 and illustrated in Figures 3-6.

Among the brands, Brand A and Brand E exhibited the highest and lowest Cd concentrations, with means of 0.59 ± 0.48 µg/kg and 0.12 ± 0.04 µg/kg, respectively. Again, in all brands except Brand A, the mean concentrations of Cd were lower than LOD. Regarding Cr, samples from Brand A and Brand K registered the highest and lowest mean concentrations, at 137.76 ± 47.25 µg/kg and 9.86 ± 4.99 µg/kg, respectively.

The initial Analysis of Variance (ANOVA) revealed statistically significant differences in Cd and Cr concentrations among sausage brands ($p < 0.05$). Post-hoc comparisons indicated that Brand A exhibited significantly higher mean concentrations of both metals than all other brands ($p < 0.001$).

For Cd no significant differences were observed among the remaining brands. For Cr, although Brand A remained a clear outlier ($p < 0.001$), the mean concentration in Brand B did not differ significantly from those of Brands G, E, H, and J ($p < 0.001$).

In contrast, Brand K exhibited the lowest mean Cr concentration; however, this difference was significant only when compared with Brands A and B ($p < 0.05$). Overall, these findings indicate a substantial elevation of Cr levels in Brand A, whereas most other brands showed comparable concentrations.

Table 1. Descriptive statistics of Cd and Cr based on sausage brands (µg/kg)

Heavy Metal	C				Cr			
Brand	**Mean ± SD**	**Median (IQR)**	**Min**	**Max**	**Mean ± SD**	**Median (IQR)**	**Min**	**Max**
A	0.59 ± 0.48 [b]	0.38 (0.81)	0.15	1.53	137.76 ± 47.25 [c]	161.70 (80.51)	64.87	200.50
B	0.18 ± 0.05 [a]	**0.18 (0.09)**	0.10	0.27	56.82 ± 30.46 [b]	47.51 (36.93)	17.32	117.90
C	0.16 ± 0.05 [a]	**0.18 (0.08)**	0.10	0.24	12.30 ± 20.26 [a]	5.04 (8.40)	0.30	65.35
D	0.14 ± 0.04 [a]	0.12 (0.08)	0.10	0.21	11.93 ± 11.98 [a]	7.24 (16.74)	2.73	34.78
E	0.12 ± 0.04 [a]	0.10 (0.05)	0.10	0.21	26.65 ± 12.73 [ab]	19.58 (21.56)	13.47	49.50
F	0.14 ± 0.04 [a]	0.15 (0.08)	0.10	0.21	17.46 ± 3.16 [a]	16.96 (4.89)	13.69	23.70
G	0.15 ± 0.04 [a]	0.15 (0.05)	0.10	0.24	35.04 ± 33.66 [ab]	19.15 (42.13)	4.47	106.50
H	0.16 ± 0.05 [a]	0.18 (0.09)	0.10	0.24	22.66 ± 20.23 [ab]	15.09 (18.02)	7.69	72.64
I	0.16 ± 0.06 [a]	0.15 (0.11)	0.10	0.27	19.09 ± 6.23 [a]	17.89 (7.81)	8.27	30.18
J	0.13 ± 0.04 [a]	0.12 (0.06)	0.10	0.21	24.60 ± 12.09 [ab]	20.79 (10.69)	5.96	50.10
K	0.13 ± 0.06 [a]	0.10 (0.05)	0.10	0.26	9.86 ± 4.99 [a]	11.08 (5.85)	0.10	16.77

* Means sharing the same letters in each column are not significantly different according to Tukey's test ($p > 0.05$).

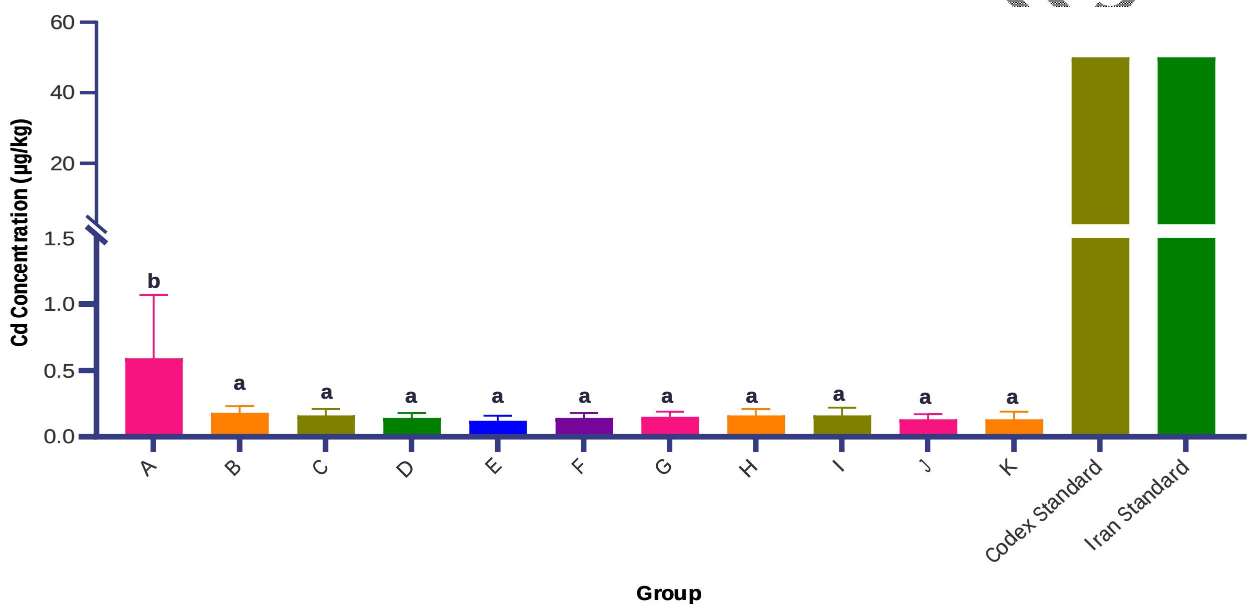

Figure 3. Comparison of the mean concentrations of Cd across brands with the Codex Alimentarius standard and the maximum tolerance of the Iranian National Standard
* Columns sharing the same letters are not significantly different from each other according to Tukey's test ($p > 0.05$).

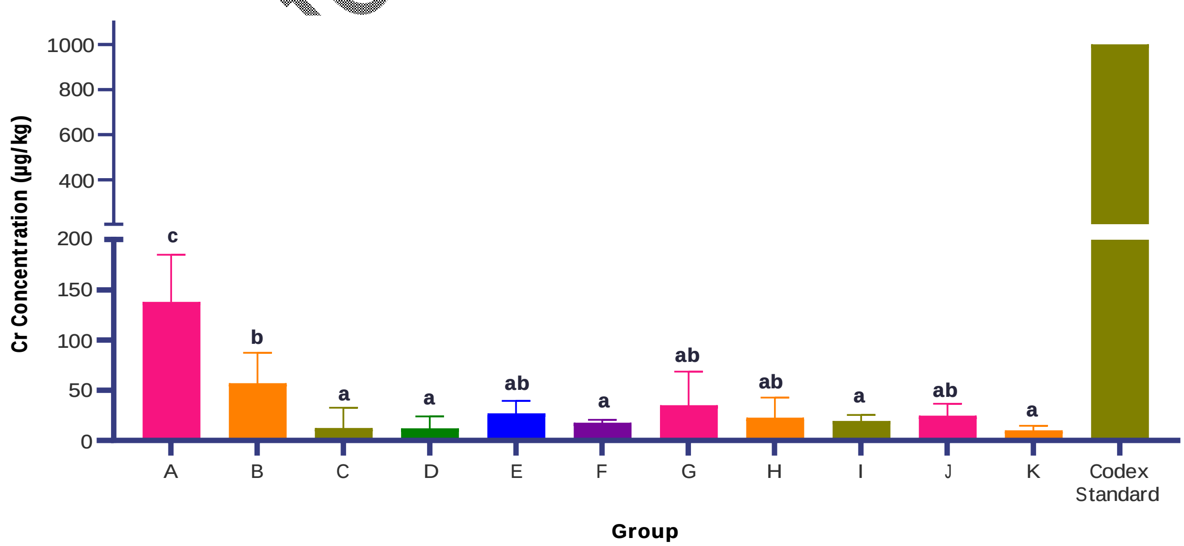

Figure 4. Comparison of the mean concentrations of Cr across brands with the Codex Alimentarius standard
* Columns sharing the same letters are not significantly different from each other according to Tukey's test ($p > 0.05$).

To assess the influence of meat content on metal accumulation, samples were stratified into three categories based on their specified meat percentage: low (40% to 55%), medium (60% to 75%), and high (80% to 90%). The mean heavy metal concentrations ($\bar{x}$ ± SD) observed across these categories are presented in Table 2. For Cd, the respective mean concentrations were 0.15 ± 0.05, 0.16 ± 0.08, and 0.24 ± 0.31 µg/kg for the low, medium, and high meat groups. Similarly, for Cr, the concentrations were 25.97 ± 23.87, 33.20 ± 44.21, and 42.07 ± 50.16 µg/kg, respectively. A subsequent ANOVA confirmed that increasing meat percentage did not result in a statistically significant elevation of either Cd or Cr concentration across these defined groups ($p > 0.05$) for both heavy metals.

Table 2. Descriptive statistics of Cd and Cr based on meat percentage in sausages (µg/kg)

Heavy Metal	Cd				Cr			
Meat Percentages	Mean ± SD	Median (IQR)	Min	Max	Mean ± SD	Median (IQR)	Min	Max
Low (40-55%)	0.15 ± 0.05 [a]	0.15(0.08)	0.10	0.29	25.97 ± 23.87 [a]	18.90 (22.42)	0.10	107.5
Medium (60-70%)	0.16 ± 0.08 [a]	0.15(0.08)	0.10	0.47	33.20 ± 44.21 [a]	16.98 (30.96)	0.30	161.7
High (80-90%)	0.24 ± 0.31 [a]	0.15(0.11)	0.10	1.53	42.07 ± 50.16 [a]	19.52 (34.76)	0.05	200.5

* Means sharing the same letters in each column are not significantly different according to Tukey's test ($p > 0.05$).

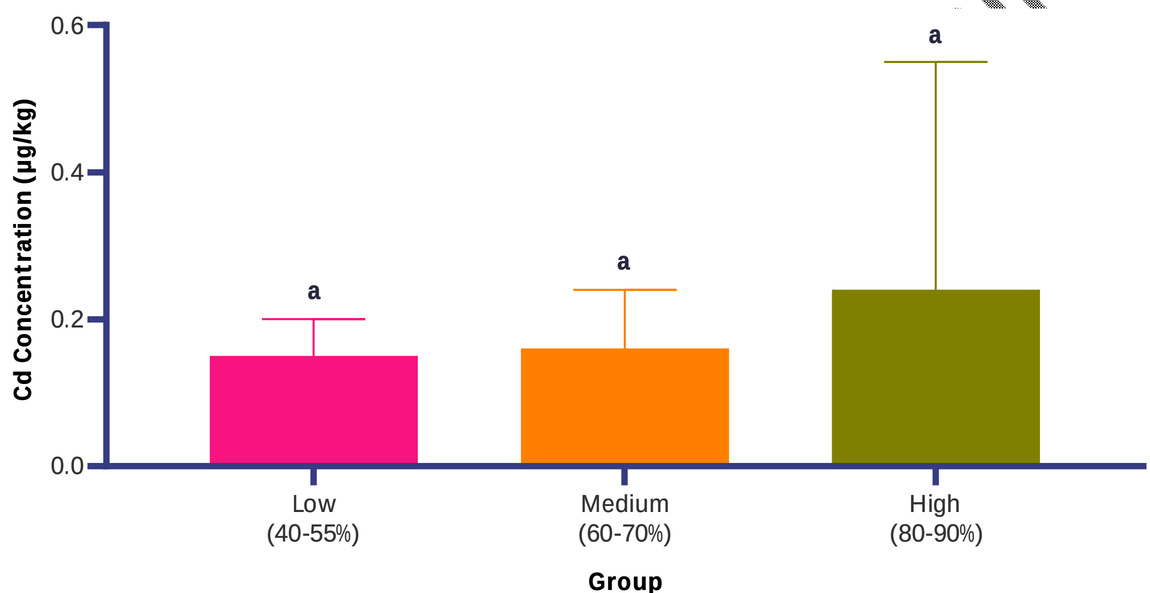

Figure 5. Comparison of Cd mean concentrations by meat percentages
* Columns sharing the same letters are not significantly different from each other according to Tukey's test ($p > 0.05$).

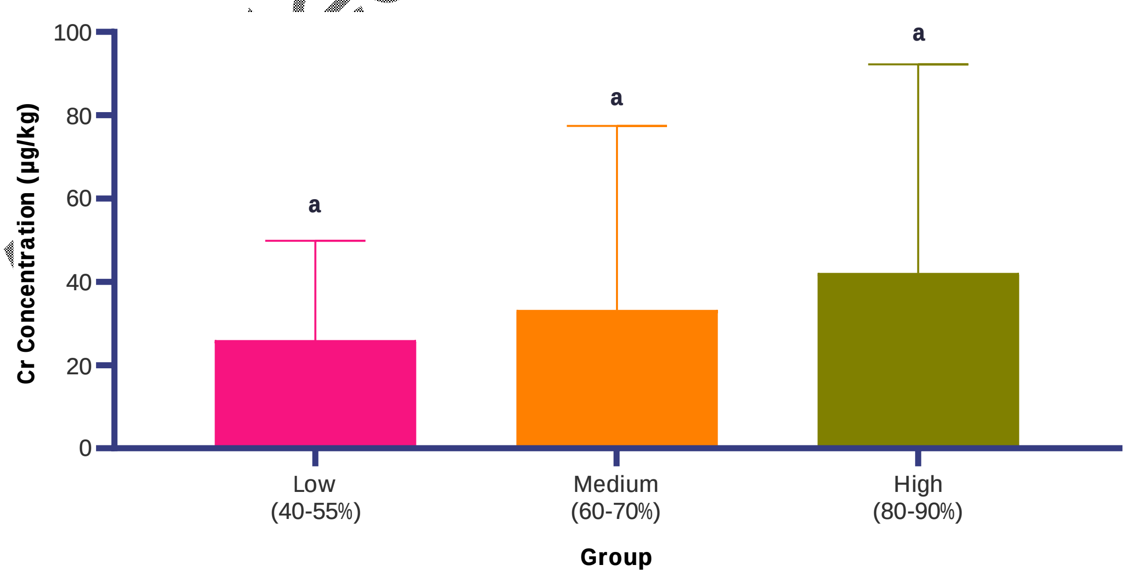

Figure 6. Comparison of Cr mean concentrations by meat percentages
* Columns sharing the same letters are not significantly different from each other according to Tukey's test ($p > 0.05$).

The presence of Cd and Cr in commercial sausages is attributable to multifactorial sources, encompassing both pre-harvest and post-harvest contamination pathways. A primary route of metal bioaccumulation in animal tissues originates from environmental contamination of animal feed and pasture. This contamination arises from anthropogenic sources, including industrial emissions, mining operations, and the application of phosphate fertilizers, which can introduce Cd and Cr into the agricultural ecosystem (Pop et al., 2024). Post-harvest, the processing of meat into sausages introduces further contamination vectors. These include the potential incorporation of heavy metals through contaminated spices, additives, and colorants, as well as the migration of heavy metals from food packaging materials (Bandara & Indunil, 2022; Dissanayake et al., 2024). A recent study documented the presence of Cd, Cr, Pb, and other heavy metals in packaging materials derived from recycled paper, with migration assessments confirming their potential to contaminate food products (Bandara & Indunil, 2022). Cd, a naturally occurring heavy metal, poses a significant public health challenge due to its lack of beneficial biological function and its propensity for extensive bioaccumulation within the human body, primarily in the renal cortex and liver, over decades-long biological half-lives (Faroon et al., 2012). Chronic Cd intoxication is pathologically characterized by a spectrum of adverse health outcomes. Early indicators often manifest as renal dysfunction, specifically proximal tubular damage evidenced by glucosuria and proteinuria, which can inexorably progress to chronic kidney disease (CKD) and irreversible renal failure (Faroon et al., 2012; Järup & Åkesson, 2009). Historically, severe Cd exposure has been linked to Itai-Itai disease, a debilitating osteomalacia characterized by extreme skeletal pain, deformities, and increased fracture susceptibility (Friberg et al., 1974; World Health Organization (WHO), 1992). Cr, widely utilized in industrial applications such as stainless-steel manufacturing, electroplating, and pigment production, presents health risks primarily through its hexavalent form (Cr VI). Chronic exposure to Cr VI, predominantly via inhalation in occupational settings or through environmental contamination of water and soil, is associated with serious chronic diseases (Wilbur et al., 2012). Robust epidemiological evidence implicates Cr VI exposure in an elevated risk of lung carcinoma, particularly among workers in chromate production and electroplating industries (Gibb et al., 2000; Armstrong et al., 2012). Furthermore, chronic inhalation of Cr VI can induce chronic bronchitis, diminished pulmonary function, asthma-like symptoms, and nasal septum perforation, resulting from sustained respiratory tract irritation and inflammation (Wilbur et al., 2012). Extrapulmonary effects of prolonged Cr VI exposure may include nephrotoxicity, hepatic dysfunction, and the development of dermatitis, especially with repeated dermal contact (Costa & Klein, 2006; World Health Organization (WHO), 1988).

The findings concerning Cd and Cr contamination in commercial sausages carry substantial implications for food safety management in Iran. Qualitative research among Iranian consumers underscores health and safety as paramount concerns, highlighting demand for enhanced production standards, superior raw material quality, and stringent regulatory oversight (Bazhan et al., 2025). The present study's empirical data on heavy metal contamination in sausages provides a crucial basis for addressing these consumer apprehensions and for informing the development of targeted surveillance programs and regulatory interventions. Consistent with existing literature, the continuous monitoring of heavy metal concentrations in meat and meat products is a critical strategy for safeguarding food safety and protecting public health (Fedoseeva et al., 2023; Han et al., 2022; Naseri et al., 2021).

Comparison of the present findings with previous studies reveals considerable geographical variation in Cd and Cr concentrations in meat products. In Nigeria (Lafia), Cd and Cr levels in sausages and salami ranged from 48-161 and 146-1893 µg/kg, respectively (Iorvue et al., 2025), while in Pakistan (Lahore), similar products contained 47.3-153.4 µg/kg Cd and 136-1783.7 µg/kg Cr (Shahzad et al., 2023), indicating substantially higher concentrations than those observed in the current study (0.10-1.53 µg/kg Cd and 0.10-200.50 µg/kg Cr). Similarly, Manea et al. (2017) reported markedly elevated Cr levels in Romania (Brasov), ranging from 1119-3295 µg/kg, with corresponding Cd levels between 91-95 µg/kg. In South Italy, sausages contained 10-30 µg/kg Cd and 150-230 µg/kg Cr (Barone et al., 2021), whereas in Nigeria (Lagos State), meats and meat products showed Cd and Cr ranges of 2-80 and 40-220 µg/kg, respectively (Bolawa & Amusan, 2018). Lower concentrations were documented in the United States, where processed meat products contained 2.10-5.34 µg/kg Cd and 8.26-36.18 µg/kg Cr (Olmedo et al., 2024). In Iran (Tehran), previous investigations reported Cd levels of 2.23-13.50 µg/kg in meat products (Sobhanardakani, 2018) and 2.20-13.50 µg/kg in sausages (Abedi et al., 2011), while Cr was not reported in those studies. Overall, the Cd concentrations detected in the present study were markedly lower than those reported in most previous studies, and although the upper range of Cr (200.50 µg/kg) was comparable to some reports (Barone et al., 2021; Bolawa & Amusan, 2018), it remained considerably lower than the extreme values documented in Romania, Nigeria (Lafia), and Pakistan. These differences may reflect variations in environmental contamination, raw material sources, industrial processing practices, and regulatory control across regions.

4. Conclusion

Overall, the concentrations of Cd and Cr in all tested sausage samples were below the recommended standards. Significant differences in Cr concentration were observed among different brands, while for Cd, only one brand showed a significant difference compared to the others. No significant difference was observed in the comparison of the effect of increasing meat percentage on metal concentrations.

Heavy metal contamination in food products represents a significant public health concern due to the potential for serious adverse health effects in consumers. Continuous monitoring and stringent control of heavy metal concentrations in food matrices are therefore essential to ensure consumer safety. Manufacturers are strongly advised to prioritize the use of high-quality, contaminant-free raw materials and to procure ingredients exclusively from reputable and certified suppliers. In addition, comprehensive training programs on food hygiene and safety for production personnel can play a critical role in mitigating the risk of metal contamination during processing. The adoption of more rigorous regulatory standards, accompanied by routine analytical surveillance, is imperative to reduce potential health hazards and to reinforce consumer confidence in processed food products. Such monitoring should include periodic assessments of both raw materials and finished products to verify compliance with established safety and quality thresholds. It must also be acknowledged that contamination with heavy metals not only poses direct health risks but can also undermine public trust in food brands and manufacturers. In an era of increasing consumer demand for safe and wholesome food products, failure to meet quality standards may result in diminished market share, reputational damage, and loss of customer loyalty.

Authors' Contributions

Ali Mohammadzadeh: Conceptualization; Methodology; Investigation; Resources; Data curation; Writing-original draft preparation; Writing-review and editing; Supervision; Project administration; Funding acquisition. **Zohre Farahmandkia:** Conceptualization; Software; Validation; Writing-original draft preparation; Writing-review and editing. **Hassan Hassanzadazar:** Conceptualization; Writing-review and editing. **Majid Aminzare:** Conceptualization; Writing-review and editing; Visualization. **Saeid Vahedi:** Conceptualization; Software; Formal analysis; Writing-review and editing; Visualization. **Rana Dizaji:** Conceptualization.

Funding

This work was supported by Zanjan University of Medical Sciences. (Project code: A-12-1400-5).

Conflicts of Interest

The authors declare no conflict of interest.

Acknowledgments

This article is based on a master's thesis titled " Assessment of cadmium and chromium contamination in Iranian commercial sausages: influence of meat content" The authors would like to express their gratitude to Zanjan University of Medical Sciences for supporting this project.

Ethical Considerations

The authors have observed all ethical considerations in this article, including avoiding plagiarism, republishing, data distortion, and data fabrication. (Ethics Number: IR.ZUMS.BLC.1402.067).

Using Artificial Intelligence

Artificial intelligence tools were used solely to improve the grammar, language clarity, and readability of the manuscript. Specifically, a large language model (ChatGPT, OpenAI) was utilized during the manuscript revision stage for linguistic editing purposes only. The AI tool did not contribute to the study design, data collection, data analysis, interpretation of results, or the formulation of conclusions. The authors reviewed and verified all content and take full responsibility for the accuracy, originality, and integrity of the manuscript.

References

Abedi, A., Ferdousi, R., Eskandari, S., Seyyedahmadian, F., & Khaksar, R. (2011). Determination of lead and cadmium content in sausages from Iran. *Food Additives and Contaminants: Part B, 4*(4), 254-258.

Alsadat Mirbod, M., Hadidi, M., Huseyn, E., & Mousavi Khaneghah, A. (2022). Polycyclic aromatic hydrocarbon in smoked meat sausages: effect of smoke generation source, smoking duration, and meat content. *Food Science and Technology, 42*, e60921.

Armstrong, B., Baverstock, K., Brenner, D. J., Cardis, E., Green, A., Guilmette, R., . . . & Ullrich, R. (2012). *IARC monographs on the evaluation of carcinogenic risks to humans. Volume 100. A review of human carcinogens. Part D: Radiation (pp. 385).* International Agency for Research on Cancer (IARC).

Bandara, R., & Indunil, G. M. (2022). Food packaging from recycled papers: Chemical, physical, optical properties and heavy metal migration. *Heliyon, 8*(10), e10959.

Barone, G., Storelli, A., Quaglia, N. C., Garofalo, R., Meleleo, D., Busco, A., & Storelli, M. M. (2021). Trace metals in pork meat products marketed in Italy: Occurrence and health risk characterization. *Biological Trace Element Research, 199*(8), 2826-2836.

Bazhan, M., Shahamati, D., Shafiei Sabet, F., & Aminzare, M. (2025). A qualitative analysis of Iranian consumers′ perspectives on improving sausage quality. *Scientific Reports, 15*(1), 18516.

Belouafa, S., Habti, F., Benhar, S., Belafkih, B., Tayane, S., Hamdouch, S., . . . & Abourriche, A. (2017). Statistical tools and approaches to validate analytical methods: Methodology and practical examples. *International Journal of Metrology and Quality Engineering, 8*, 9.

Bolawa, O. E., & Amusan, O. (2018). The determination of heavy metals and trace elements in meats and meat prodcts found in Lagos State. *Journal of Pollution and Public Health, 1*(10008), 1-4.

Codex Alimentarius Commission. (1995). *Codex general standard for contaminants and toxins in food and feed (CODEX STAN 193-1995).* https://www.fao.org/fileadmin/user_upload/livestockgov/documents/1_CXS_193e.pdf

Costa, M., & Klein, C. B. (2006). Toxicity and carcinogenicity of chromium compounds in humans. *Critical Reviews in Toxicology, 36*(2), 155-163.

Dissanayake, K., Rifky, M., Hunupolagama, D., Harris, J. M., Zokirov, K., Azizova, K., . . . & Samadiy, M. (2024). Inorganic additives in meat production and processing. *E3S Web of Conferences, 510*, 01028.

Ekhator, O., Udowelle, N., Igbiri, S., Asomugha, R., Igweze, Z., & Orisakwe, O. (2017). Safety evaluation of potential toxic metals exposure from street foods consumed in mid-West Nigeria. *Journal of Environmental and Public Health, 2017*(1), 8458057.

EPA, U. S. (1996). Method 3050B: Acid digestion of sediments, sludges, and soils. *U.S. Environmental Protection Agency, 2*, 3-5.

Farahmandkia, Z., Tajdar-Oranj, B., Zare, L., Peyda, M., Feizolahi, R., & Alizadeh, A. M. (2025). Health risk assessment of lead and cadmium in milk-based products of Iran. *Journal of Agriculture and Food Research, 19*, 101558.

Farahmandkia, Z., Feizolahi, R., Mehrasbi, M. R., & Peyda, M. (2023). Lead and cadmium concentrations in raw milk and dairy products in Zanjan, Iran: A study on Winter and Summer variations. *Journal of Human Environment and Health Promotion*, *9*(4), 210-215.

Faroon, O., Ashizawa, A., Wright, S., Tucker, P., Jenkins, K., Ingerman, L., & Rudisill, S. (2012). *Toxicological profile for cadmium.* Agency for Toxic Substances and Disease Registry (ATSDR).

Fedoseeva, N., Tetdoev, V., Sarsembenova, O., Sepiashvili, E., & Gribkova, V. (2023). Excessive copper levels in cooked sausages: A case study of local market products. *BIO Web of Conferences, 69*, 03021.

Friberg, L., Piscator, M., Nordberg, G. F., & Kjellström, T. (1974). *Cadmium in the environment*. 2nd Edition, CRC Press, Boca Raton.

Gibb, H. J., Lees, P. S., Pinsky, P. F., & Rooney, B. C. (2000). Lung cancer among workers in chromium chemical production. *American Journal of Industrial Medicine, 38*(2), 115-126.

Han, J. L., Pan, X. D., & Chen, Q. (2022). Distribution and safety assessment of heavy metals in fresh meat from Zhejiang, China. *Scientific Reports, 12*(1), 3241.

Iammarino, M., Marino, R., & Albenzio, M. (2017). How meaty? Detection and quantification of adulterants, foreign proteins and food additives in meat products. *International Journal of Food Science and Technology, 52*(4), 851-863.

Iran National Standards Organization. (2021). *Food and feed-maximum limit of heavy metals and test methods (No. 12968).* https://standard.inso.gov.ir/

Ioryue, I. S., Effiom, E. O., Uzah, T. T., & Akor, R. O. (2025). Potential human health risk assessment of heavy metals in various brands of sausages and salami sold in different eateries in Lafia Township-Nigeria. *Biological Sciences, 5*(1), 822-830.

Järup, L., & Åkesson, A. (2009). Current status of cadmium as an environmental health problem. *Toxicology and Applied Pharmacology, 238*(3), 201-208.

Jayaraj, S., Kothandan, L., Murugan, V. B., Prakash, S. K., Vijayakumar, V., & Rani, E. (2025). Food toxicology and safety: Evaluating dietary risks and functional ingredients. *Food Bioengineering, 4*(2), 182-198.

Manea, I., Manea, L., Radulescu, C., Dulama, I. D., Teodorescu, S., Stirbescu, R. M., . . . & Bucurica, I. A. (2017). Assessment of metals level in several meat products obtained through conventional and traditional methods. *Romanian Reports in Physics, 69*(4), 711.

Mehrasebi, M. R., Peyda, M., Feizolahi, R., Taromi, A., Homayuni, P., Fathi, S., & Farahmandkia, Z. (2023). Comparison of three digestion methods for determination of lead and cadmium in milk and dairy products. *Environmental Health Engineering and Management Journal, 10*(2), 191-196.

Naseri, K., Salmani, F., Zeinali, M., & Zeinali, T. (2021). Health risk assessment of Cd, Cr, Cu, Ni and Pb in the muscle, liver and gizzard of hen′s marketed in East of Iran. *Toxicology Reports, 8*, 53-59.

Olmedo, P., Chen, R., Grau-Perez, M., Nachman, K. E., Gil, F., Rule, A. M., & Navas-Acien, A. (2024). Manufacturing practices as potential sources of cadmium and other relevant metals in processed meat products. Risk and nutritional assessment. *Food Control, 158*, 110225.

Oyekunle, J. A., Yussuf, N. A., Durodola, S. S., Adekunle, A. S., Adenuga, A. A., Ayinuola, O., & Ogunfowokan, A. O. (2019). Determination of polycyclic aromatic hydrocarbons and potentially toxic metals in commonly consumed beef sausage roll products in Nigeria. *Heliyon, 5*(8), e02345.

Pirsaheb, M., Nouri, M., Massahi, T., Makhdoumi, P., Azadi Baban, N., & Hossini, H. (2024). Microplastics contamination in the most popular brands of Iranian sausages and evaluation of its human exposure. *Heliyon, 10*(14), e34363.

Pop, O. L., Ciont, C., Gabbianelli, R., Coldea, T. E., Pop, C. R., Mudura, E., . . . & Suharoschi, R. (2024). Deciphering contaminants and toxins in fermented food for enhanced human health safeguarding. *Comprehensive Reviews in Food Science and Food Safety, 23*(5), e13428.

Shahzad, L., Hayyat, M. U., Sharif, F., Ameer, R., Amir, M., Khalil, M., & Saleem, M. (2023). Health risk assessment of heavy metals in various brands of sausages and salami in local markets of Lahore, Pakistan. *Environmental Engineering and Management Journal, 22*(1), 167-176.

Sobhanardakani, S. (2018). Analysis of contamination levels of Cu, Pb, and Zn and population health risk via consumption of processed meat products. *Jundishapur Journal of Health Sciences, 10*(1), e14059.

Tayeb, J., & Movassaghghazani, M. (2025). Assessment of lead and cadmium exposure through olive and corn oil consumption in Gonbad-Kavus, North of Iran: A public health risk analysis. *Toxicology Reports, 14*, 101922.

Wilbur, Sh., Abadin, H., Fay, M., Yu, D., Tencza, B., Ingerman, L., . . . & James, Sh. (2012). *Toxicological profile for chromium.* Agency for Toxic Substances and Disease Registry (ATSDR).

World Health Organization (WHO). (1988). *Chromium.* https://iris.who.int/server/api/core/bitstreams/026af2e6-1989-4b90-8a5b-40d3789ee584/content

World Health Organization (WHO). (1992). *Cadmium: Environmental aspects.* https://iris.who.int/server/api/core/bitstreams/4a24e649-2250-4d93-aacc-460e3d2b5a3a/content