Polish Annals of Medicine

Journal homepage: https://www.paom.pl

Research paper

A quantitative assessment of heavy metal contamination in instant coffee beverages: A comparative analysis of toxic element content and public health risk implications

Joanna Domagalska[1], Marta Zadęcka[2], Monika Rusin[1], Michał Górski[3], Marta Buczkowska[3]

[1] Department of Environmental Health, Faculty of Public Health in Bytom, Medical University of Silesia in Katowice, Poland
[2] Graduates of the Faculty of Public Health in Bytom, Medical University of Silesia in Katowice, Poland
[3] Department of Occupational Medicine and Health in Department of Chronic Diseases and Civilization-related Hazards, Faculty of Public Health in Bytom, Medical University of Silesia in Katowice, Poland

Article info

Article history
Received: October 29, 2024
Accepted: November 11, 2024
Available online: July 5, 2025

Keywords
environmental exposure
heavy metals
trace elements
health risk
instant coffee
coffee drinks.

Doi
https://doi.org/10.29089/paom/195838

Abstract

Introduction: The contamination of food products with heavy metals is a significant global health concern due to their high toxicity and ability to bioaccumulate in vital organs, potentially leading to serious physiological disruptions. Instant coffee, as a widely consumed beverage, may serve as an underexplored source of exposure to these toxic elements.

Aim: The objective of study was to quantitatively assess the levels of cadmium, lead, nickel, zinc, arsenic, and chromium in different types of instant coffee beverages, including 3-in-1, 2-in-1, and cappuccino products, and to identify factors differentiating their content across various product categories. Additionally, hazard quotient and hazard index values were calculated for the selected metals to evaluate potential health risks.

Material and methods: 50 samples of instant coffee beverages were analyzed and categorized based on soluble coffee content, manufacturer, and country of origin. Zinc, arsenic, chromium, and nickel concentrations were determined using inductively coupled plasma optical emission spectrometry, while cadmium and lead were quantified using electrothermal atomic absorption spectrometry.

Results and discussion: Lead concentrations were found to be below the limit of quantification in all samples, and cadmium and arsenic were detected in only one sample. The non-cancer health risk assessment associated with heavy metal exposure suggested minimal risk for adult consumers.

Conclusions: Although the immediate health risks are negligible, continuous improvement in monitoring systems and the implementation of advanced technologies are essential to further reduce the presence of heavy metals in food products. Sustained investment in research and technological innovations is critical for ensuring long-term food safety and protecting public health on a global scale.

Corresponding author: Joanna Domagalska; Department of Environmental Health, Faculty of Public Health in Bytom, Medical University of Silesia in Katowice, Piekarska 18, 41-902 Bytom, Poland.
E-mail address: jdomagalska@sum.edu.pl

1. INTRODUCTION

The contamination of food with heavy metals represents a significant global public health concern, particularly in regions where agricultural pollution is prevalent. It is estimated that over 13% of the world's arable land, representing approximately 0.24 billion hectares, and 40% of the world's freshwater bodies are contaminated with heavy metals. The most commonly occurring contaminants are cadmium (Cd), copper (Cu), zinc (Zn), nickel (Ni), cobalt (Co), chromium (Cr), lead (Pb) and arsenic (As). These are often the result of the excessive use of phosphate fertilisers and inadequate irrigation practices.[1] Even at trace levels, heavy metals have the potential to bioaccumulate in human tissues, which can lead to nephrotoxicity, neurotoxicity and an increased risk of carcinogenesis.[1–6] The European Food Safety Authority (EFSA) and the World Health Organisation (WHO) have established stringent limits for heavy metals in food, particularly for lead, cadmium, mercury and arsenic, due to their well-documented toxic effects, including carcinogenic and neurotoxic effects. It is imperative to comply with these limits in order to minimise the health risks associated with heavy metal exposure.[7–9] However, the acceptable levels of heavy metals vary depending on the specific element and food category. Furthermore, it is important to note that not all toxic metals and foods have established regulatory limits. Additionally, our daily diets are diverse, and we are continuously exposed to a wide range of external factors that may contribute to the intake of toxic elements from multiple sources.

Coffee, one of the most widely consumed beverages globally, exhibits notable geographical variations in consumption patterns. In Poland, 95.2% of adults report regular coffee consumption, a figure that is significantly higher than in Italy (61%) and Spain (78%).[10] This places Poland among the foremost coffee-consuming countries in Europe. Instant coffee is the preferred choice among Polish consumers, largely due to its convenience and rapid preparation. Although ground coffee is often perceived as more natural, instant coffee remains popular due to its higher average caffeine content (approximately 60 mg per teaspoon) and polyphenol concentration (approximately 61 mg/g) compared to ground coffee, which contains approximately 40 mg per teaspoon of caffeine and 19 mg/g of polyphenols.[11,12] It is important to note, however, that these levels can vary depending on factors such as the coffee bean variety, processing methods and brewing techniques. The current research indicates that the caffeine content of coffee varies depending on the brewing method. Espresso is found to have a higher concentration of caffeine (approximately 75 mg per serving), while Americano and cappuccino, prepared with espresso, have a higher caffeine content (94–166 mg). Instant coffee contains approximately 64 mg of caffeine per 160 mL. Ground coffee brewed at home has the lowest caffeine content, averaging 23 mg per 160 mL.[13] Additionally, instant coffee typically contains higher concentrations of minerals such as calcium, magnesium, zinc, iron, manganese, aluminium, chromium and nickel, largely due to the methods used to produce it.[11] Variability in mineral content can occur between brands and regions, making regular monitoring and analysis essential to ensure product safety.

Coffee plants are capable of absorbing heavy metals from contaminated soil, which can then accumulate in the beans. Although metal concentrations in coffee beans are typically lower than in other plant parts, they may still pose a potential risk to consumers. Chronic exposure to heavy metals through coffee consumption has been linked to neurological damage, liver dysfunction, and an increased risk of mutagenesis and carcinogenesis.[14–16] The bioavailability and accumulation of these metals in plants are influenced by various factors, including soil pH, organic matter content, and soil texture.[16]

Plants have evolved a variety of defence mechanisms to mitigate the toxicity of heavy metals, including the production of thiol-containing compounds such as glutathione (GSH) and cysteine (Cys). These compounds function as chelators for toxic metals, thereby facilitating the detoxification process. GSH functions as a precursor for the synthesis of phytochelatins, which play a crucial role in detoxification, particularly in response to metals such as cadmium and nickel.[17–19] However, prolonged exposure to even low concentrations of heavy metals can exceed a plant's ability to detoxify these elements. Furthermore, natural antioxidants, including polyphenols, melatonin, carotenoids, quercetin, resveratrol, vitamins E and C, and L-carnitine, have been demonstrated to alleviate some of the detrimental effects of heavy metals through their antioxidant and metal-chelating characteristics.[20–24]

The persistence of heavy metals in the environment and their capacity to bioaccumulate in the food chain give rise to significant concerns regarding the presence of these contaminants in coffee products. The quality of soil in coffee plantations, along with environmental factors and the use of pesticides, plays a crucial role in determining the metal content of coffee. Furthermore, improper storage or packaging may result in additional contamination, which can promote mould growth.[25]

Regular monitoring of the chemical composition of coffee is essential to ensure consumer safety. From a public health perspective, it is crucial to educate the population regarding the benefits and risks associated with coffee consumption. Further investigation into the effects of coffee on the health of the Polish population may enhance our understanding of its role in dietary practices. Comprehensive analysis of the chemical constituents of coffee available in the Polish market, coupled with an assessment of consumption patterns, is necessary to ensure the protection of public health and to optimise the potential health benefits of coffee.

2. AIM

The objective of this study is to evaluate the concentrations of heavy metals, including cadmium, lead, nickel, zinc, arsenic, and chromium, in coffee beverages formulated as 3-in-1, 2-in-1, and cappuccino. Furthermore, the study aims to identify the factors that contribute to variations in metal concentrations. Additionally, an attempt will be made to estimate the non-cancer risk associated with the consumption of the analysed products containing zinc, nickel, and chromium.

3. MATERIAL AND METHODS

3.1. Research material

The study analyzed 50 instant coffee beverages, including 3-in-1, 2-in-1, and cappuccino varieties, sourced from local retailers in Poland during the first half of 2024. The products were categorized based on three criteria:

(1) The soluble coffee content (to assess the non-cancer risk, the following parameters were assumed): less than 8% (Group 1), 8%–10% (Group 2), 12%–100% (Group 3).
(2) Country of origin: Poland or the Netherlands.
(3) Producer: Producer 1, Producer 2, and Producer 3.

Duplicate samples were included only if they originated from different production batches.

3.2. Laboratory analysis of heavy metal content in test samples

Samples were transported to the Analytical Laboratory of the Department of Environmental Health at the Medical University of Silesia in Katowice, maintaining their original packaging to prevent contamination. Each sample was systematically coded and weighed to an accuracy of 0.5 g (with a permissible deviation of ±2%) using a PS 750/X (RADWAG, Radom, Poland) precision balance. The weighed samples were then transferred to Teflon digestion vessels.

For the subsequent digestion process, 9 mL of ultra-pure nitric acid (HNO_3; 65% ultra-pure, MERCK) and 1 mL of 30% hydrogen peroxide (H_2O_2; 30% by Stanlab) were added to each Teflon vessel. The vessels were then sealed and placed into a Milestone ETHOUS UP multi-station microwave mineralizer, wherein the samples underwent a multi-stage mineralization protocol as follows:

(1) Stage I: Duration: 20 minutes. Temperature: 210°C. Generator power: 1800 W.
(2) Stage II Duration: 15 minutes Temperature: 210°C. Generator power: 1800 W.
(3) Stage III: Cooling process: 30 minutes.

At the end of the digestion process, the samples were transferred to 15 mL volumetric flasks and diluted to the required volume with ultrapure water. Cadmium and lead were quantified by electrothermal atomic absorption spectrometry (ET-AAS) using a Savanta Sigma atomic absorption spectrometer from GBC, while the other elements (Zn, Ni, Cr, As) were analysed by inductively coupled plasma optical emission spectrometry (ICP-OES) using an Ultima Expert LT spectrometer from HORIBA Scientific.

3.3 Statistical analysis

The elemental concentrations in the samples were statistically analysed using Statistica v.13.3 (StatSoft). A comprehensive descriptive statistical analysis was performed, including the calculation of the arithmetic mean, median and standard deviation, both for the total sample set and for each subgroup defined by the specific differentiating factors. In addition, skewness and kurtosis were calculated to assess the distribution characteristics of the data, while the minimum and maximum values were also checked. Prior to the distribution test, the normality of the data was assessed using the Shapiro-Wilk test. Non-parametric statistical tests were then applied, including the Mann-Whitney U test, the Kruskal-Wallis H test and Spearman's rank correlation analysis. The significance level was set at $\alpha = 0.05$.

It is important to note that in cases where the elemental concentration was below the limit of quantification, a common practice was to include half of the limit of quantification in the data set for analysis.

3.4. Assessment of non-cancer health risks associated with exposure to zinc, nickel, and chromium in product samples

Non-cancer risks associated with heavy metal exposure (oral exposure) were estimated using the Average Daily Dose (ADD) formula recommended by the US Environmental Protection Agency (US EPA)[26]:

$$\mathrm{ADD} = \frac{\mathrm{C} \times \mathrm{IngR} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}} \ [\mathrm{mg/kg/day}]$$

where:

ADD – average daily potential dose of Zn/Ni/Cr ingested via the dietary route, mg/kg/day;
C – concentration of Zn/Ni/Cr in the food product, mg/g;
IngR – ingestion rate, g/day;
EF – exposure frequency (365 days);
ED – exposure duration (70 years);
BW – body weight (70 kg);
AT – averaging time (25,550 days).

According to recent data from the Central Statistical Office, the average daily coffee consumption per capita in Polish households is approximately 6 g per day.[27] However, this study focuses specifically on instant coffee, for which the IngR is defined by the average weight of a single sachet, typically 15 g. The average Polish consumer is reported to consume one to three sachets of this product per day. For the purpose of this analysis, it is assumed that the average consumer consumes one sachet per day.

The health risk assessment for adults was performed for each element by estimating the hazard quotient (HQ) using the following formula[28]:

$$\mathrm{HQ} = \mathrm{ADD}/\mathrm{RfD}$$

The US EPA has established reference doses (RfD) for oral exposure, specifically: 0.3 mg/kg a day for zinc, 0.02 mg/kg a day for nickel, and 0.0009 mg/kg a day for chromium.[29–31]

To estimate the total potential non-cancer health effects due to exposure to a mixture of heavy metals from the consumption of instant coffee, a cumulative hazard index (HI) was calculated in accordance with the EPA Health Risk Assessment Guidelines.[32] The cumulative risk from concurrent exposure to multiple non-carcinogenic substances is determined by summing the individual HQ values to obtain the HI, which is interpreted in a manner analogous to the HQ index.

An HQ or HI value up to 1 indicates negligible risk, while values over 1 suggest potential health risks.[28,32]

4. RESULTS

4.1. Analysis of selected heavy metal concentrations in coffee beverages

The concentrations of cadmium, lead, and arsenic were below the limit of quantification (LOQ = 0.10 mg/kg for Pb, 0.01 mg/kg for Cd, and 0.48 mg/kg for As) in most samples. Only one sample demonstrated detectable levels of Cd (0.02 mg/kg) and As (0.58 mg/kg), thus these metals were excluded from further statistical analyses.

The concentration of zinc varied significantly across samples, with values ranging from 0.70 mg/kg (for values above the LOQ of 0.69 mg/kg) to 10.86 mg/kg. Nickel concentrations ranged from 0.50 mg/kg to 2.85 mg/kg. Chromium levels varied from 0.22 mg/kg to 0.52 mg/kg. The detailed results are presented in Table S1 (Supplementary material).

4.2. Comprehensive statistical analysis of heavy metal concentrations in selected coffee beverages

To examine the distributions of the quantitative variables, basic descriptive statistics were calculated and the Shapiro-Wilk test was used to assess the normality of the distributions. The results of the analysis are presented in Table 1.

Statistically significant variations in zinc levels were identified across different producers. The Bonferroni post-hoc test indicated a significant discrepancy in zinc concentration between Producer 2 and Producer 1, with a moderate effect size, as shown in Table 2.

A positive correlation was found between soluble coffee content and nickel concentration, indicating that an increase in coffee content is associated with higher nickel levels. This correlation was statistically significant and of moderate strength (Table 3).

Statistically significant differences in zinc concentrations were observed, with products originating from the Netherlands displaying higher zinc levels than those from Poland. The effect size for this comparison was moderate, as shown in Table 4.

Table 1. Descriptive statistics of the analyzed variables.

Dependent variable	M	Me	SD	Sk.	Kurt.	Min.	Max	W	*P*
Soluble coffee content in the product	13.47	8.95	18.30	4.47	19.91	3.40	100.00	0.39	<.001
Cr concentration (mg/kg)	0.29	0.27	0.07	2.66	6.82	0.22	0.52	0.64	<.001
Zn concentration (mg/kg)	3.24	1.74	3.49	1.09	–0.24	0.35	10.86	0.79	<.001
Ni concentration (mg/kg)	0.37	0.21	0.46	4.08	18.66	0.21	2.85	0.40	<.001

Comments: M – mean; Me – median; SD – standard deviation; Sk. – skewness; Kurt. – kurtosis; Min – minimum value; Max. – maximum value; W – Shapiro-Wilk test statistic; *P* – *P*-value for Shapiro-Wilk test

Table 2. Comparative analysis of soluble coffee content and heavy metal concentrations across various coffee producers.

Dependent variable	Producer 1 (*n* = 12)			Producer 2 (*n* = 18)			Producer 3 (*n* = 20)			*H(2)**	*P*	η^2
	average rank	M	Me	average rank	M	Me	average rank	M	Me			
Soluble coffee content in the product	27.75	10.80	9.50	26.69	20.32	10.00	23.08	8.90	8.88	0.96	0.618	<0.01
Zn concentration (mg/kg)	33.00	0.29	0.28	18.69	0.28	0.26	27.13	0.29	0.27	7.55	**0.023**	0.12
Ni concentration (mg/kg)	23.25	5.70	5.82	27.89	1.71	0.83	24.70	3.41	3.46	1.85	0.397	<0.01
Cr concentration (mg/kg)	28.58	0.46	0.42	22.61	0.67	0.42	26.25	0.48	0.42	1.30	0.523	<0.01

Comments: *n* – number of observations; M – mean; Me – median; H* - Kruskal–Wallis non-parametric H test statistic; *P* – statistical significance; η^2 – effect strength index.

Table 3. Correlation between soluble coffee content and levels of zinc, nickel, and chromium.

Variable		*Soluble coffee content in the product*
Zn concentration, mg/kg	Spearman's rho	–0.05
	significance	0.713
Ni concentration, mg/kg	Spearman's rho	**0.40**
	significance	**0.004**
Cr concentration, mg/kg	Spearman's rho	0.10
	significance	0.497

Table 4. Comparative analysis of soluble coffee content and heavy metal concentrations in coffees from Poland and the Netherlands.

Dependent variable	Poland (n = 38)			Netherlands (n = 12)			Z*	P	η^2
	average rank	M	Me	average rank	M	Me			
Soluble coffee content in the product	24.79	14.31	8.88	27.75	10.80	9.50	-0.62	0.539	<0.01
Zn concentration (mg/kg)	23.13	0.28	0.27	33.00	0.29	0.28	-2.07	**0.038**	0.09
Ni concentration (mg/kg)	26.21	2.61	1.49	23.25	5.70	5.82	-0.92	0.360	0.02
Cr concentration (mg/kg)	24.53	0.57	0.42	28.58	0.46	0.42	-0.84	0.401	0.01

Comments: n - number of observations; M - mean; Me - median; Z - Mann-Whitney U test statistic; p - statistical significance; η^2 - effect strength index

Table 5. Comprehensive analysis of average daily dose and hazard quotient for oral exposure.

Trace element	Concentration [mg/kg]	RfD [mg/kg/day]	ADD[mg/kg/day]	HQ	HI
Average concentration of toxic elements					
Zn	3.24	0.3	0.00069	0.0023	
Ni	0.37	0.02	0.00008	0.0040	0.0753
Cr	0.29	**0.0009**	0.00006	0.0690	
Maximum concentration of toxic elements					
Zn	10.86	0.3	0.00233	0.0078	
Ni	2.85	0.02	0.00061	0.0305	0.1621
Cr	0.52	0.0009	0.00011	0.1238	

Comments: RfD - reference dose, ADD - average daily intake, HQ - hazard quotient, HI - cumulative hazard index

4.3 Quantitative assessment of non-cancer health risks from adult exposure to zinc, nickel, and chromium in instant coffee

The non-cancer health risks associated with the consumption of instant coffee by adults were assessed quantitatively. The assessment showed that the risks posed by exposure to selected heavy metals through coffee consumption are negligible for both average and maximum concentrations (Table 5).

The analysis also took into account the coffee content of the products evaluated. The results indicate that the likelihood of non-carcinogenic effects manifesting in individuals consuming instant coffee is extremely low. However, it is important to note that both the HQ and HI values increased with an increased coffee content in the product (Supplementary materials Table 1b). This suggests that both coffee content and other factors, such as coffee type and country of origin, contribute significantly to the exposure levels of heavy metals. In the risk estimation procedure including the country of production as a differentiating factor, the HI was found to be slightly higher for products originating from the Netherlands. However, coffee from Poland had a higher HQ for chromium. Despite these differences, the values of the calculated indices remain well below the critical threshold of 1 for both countries (Supplementary materials Table 1c). Furthermore, when considering the producer as a variable, the highest HI values were observed for products from Producer 2 (HI = 0.1780), while the lowest values were found for Producer 3 (HI = 0.1510) (Supplementary materials Table 1d). This finding shows that the level of heavy metal exposure from instant coffee consumption can be influenced by the manufacturer, although the overall risk remains minimal.

5. DISCUSSION

The continuous monitoring of heavy metal content in food, together with the introduction of preventive measures, is of paramount importance to ensure food safety and maintain product quality. Metals such as chromium, zinc and nickel, when accumulated in food, pose a significant health risk due to their potential to cause toxicity and contribute to the development of chronic diseases.[33–35] Systematic research in this area is crucial as it allows early identification of potential risks and facilitates the prompt implementation of corrective measures. Furthermore, by modifying production processes and monitoring raw material sources, consumer exposure to heavy metals can be reduced, thereby increasing confidence in food products.

A review of the literature reveals a significant gap in research on the assessment of heavy metal content in instant coffee. Most studies focus on coffee beans, with limited attention to instant coffee products or differentiation between country of origin and producer. Therefore, the results of this study are compared with the available data on heavy metal concentrations in coffee beans, despite the inherent differences between these product forms.

This study investigated the concentrations of several heavy metals in instant coffee drinks, including zinc, nickel, chromium, lead, cadmium and arsenic. In particular, lead concentrations remained below the limit of quantification in all samples, while cadmium and arsenic were detected in only one sample. These results corroborate those of Winiarska-Mleczan et al. who also reported undetectable levels of lead in ground coffee using a similarly sensitive analytical method (LOQ = 0.00003 mg/kg).[10] This consistency suggests effective regulatory oversight, particularly by bodies such as the State

Sanitary Inspection in Poland, which monitors the quality of coffee beans. A subsequent study by the same author reported that the highest concentrations of cadmium were found in chicory and cereal coffee, with levels reaching 0.004 mg/kg. In contrast, a blend of chicory and naturally roasted coffee had a slightly lower cadmium concentration of 0.003 mg/kg. Notably, the lowest cadmium levels were observed in cappuccino drinks and natural instant coffee, both with concentrations below 0.0001 mg/kg, as well as in 2-in-1 and 3-in-1 coffee products. For lead, the highest concentration was found in natural instant coffee, with 82.6 mg/kg, while the lowest was found in chicory and natural coffee blend, as well as in 2-in-1 and 3-in-1 products, with lead concentrations of 0.011 ± 0.0019 mg/kg.[11] These findings highlight the considerable variability in heavy metal content between different types of coffee and underline the need for further research to thoroughly assess the safety of these products.

In terms of zinc concentration, this study found considerable variability between coffee samples, ranging from 0.70 mg/kg to 10.86 mg/kg. The highest concentration was found in a product containing 9.50% instant coffee, while the lowest concentration was found in a product containing 7.60% coffee. These results are in line with the work of Gure et al. who reported zinc levels ranging from 6 to 30 mg/kg in Ethiopian coffee,[36] and Alves da Silva et al. who found zinc concentrations ranging from 5.53 to 55.83 mg/kg in Brazilian coffee.[15] The variability of zinc content in these studies highlights the influence of geographical factors, production methods and packaging materials. Interestingly, one Brazilian study exceeded the legal limit of 50 mg/kg, highlighting the need for regulatory vigilance in different regions.[15] Consistent findings by Morgano et al. (8.33 mg/kg)[37] and Grembecka et al. (9.5 mg/kg) (9.5 mg/kg)[38] in Arabica coffee further support the notion that zinc content is influenced by both intrinsic and extrinsic factors in coffee production. The observed differences in zinc concentrations may indeed be influenced by the packaging materials used, as zinc-based compounds, including nanoparticles, are commonly used as stabilisers in food packaging due to their resistance to heat and light. These stabilisers have the potential to migrate into food products, especially under conditions of heat exposure, and may therefore affect zinc levels. Further investigation into the composition of the packaging and the conditions under which it is stored could clarify this effect.[39]

Nickel concentrations also varied considerably. The highest concentration (2.85 mg/kg) was found in a product containing 100% instant coffee, while the lowest (0.50 mg/kg) was found in a product containing 19% coffee. These results are consistent with the wide range of nickel levels reported by Alves da Silva et al. (0.03 to 1.95 mg/kg)[15] and Teixeira Pigozzi et al. (0.3 to 1.95 mg/kg).[40] The substantial variation in nickel content between studies may reflect differences in environmental exposure, particularly soil contamination in coffee-growing regions. Lower nickel concentrations observed by Berego et al., Massoud et al. and Nędzarek et al. (0.003 to 0.9326 mg/kg)[14,41,42] further emphasise regional differences and highlight the need for localised monitoring.

In the case of chromium, the highest concentration (0.52 mg/kg) was found in chocolate-flavoured coffee drinks, while the lowest (0.22 mg/kg) was found in sugar and milk-based products. These results differ from previous studies, such as those by Guadalupe et al. who reported chromium concentrations of 0.01 ± 0.006 mg/kg,[43] and Alkherraz et al. who observed higher levels (up to 7.5 mg/kg) in coffee from different geographical regions.[44] Teixeira Pigozzi et al. also reported a significantly higher chromium concentration (3.27 mg/kg) in one sample, exceeding the Brazilian regulatory limits (0.1 mg/kg).[40] The wide range of reported values indicates the complexity of chromium contamination and the influence of both intrinsic (e.g. uptake by coffee plants) and extrinsic factors (e.g. manufacturing processes, added ingredients).

The presence of additional ingredients such as sugar, skimmed milk and vegetable oils in instant coffee products significantly affects the final concentration of heavy metals. Trace amounts of metals in these ingredients can contribute to the overall metal burden of the product. For example, sugar may contain metals depending on the refining process.[45,46] Similarly, vegetable oils may contain metals, especially if the oil is derived from contaminated raw materials. Skimmed milk, as a product of animal origin, can also accumulate heavy metals if the animals have been exposed to contaminated feed or environmental pollutants.[47–49]

Although the current concentrations of heavy metals in instant coffee do not pose an immediate health risk, the potential for long-term accumulation of trace metals in the body warrants attention. Chronic exposure to metals such as cadmium and lead, which have long biological half-lives, poses risks to the nervous, cardiovascular and endocrine systems.[48] The results of this study underscore the importance of continued monitoring and regulation to minimise exposure to heavy metals, especially given the potential for bioaccumulation over time.

6. CONCLUSIONS

(1) Concentrations of heavy metals in instant coffee drinks vary considerably depending on the soluble coffee content, the origin of the product and the producer.
(2) Non-cancer health risks from exposure to zinc, nickel and chromium in instant coffee are minimal. The hazard quotients and cumulative hazard indices calculated for these metals were well below the thresholds of concern, indicating negligible health risks for adult consumers.
(3) Continued monitoring and the use of innovative processing technologies are essential to further reduce heavy metal levels in food products and ensure long-term consumer safety.

Conflict of interest
None declared.

Funding

None declared.

References

1 Kayiranga A, Zhu Li, Isabwe A, et al. The effects of heavy metal pollution on collembola in urban soils and associated recovery using biochar remediation: a review. *Int J Environ Res Public Health*. 2023;20(4):3077. https://doi.org/10.3390/ijerph20043077.

2 Speurdoli I. Heavy metal toxicity effects on plants. Institute of plant breeding and genetic resources. *Toxics*. 2022;10(12):715. https://doi.org/10.3390/toxics10120715.

3 Kumar V, Sight J, Kumar P. Heavy metals accumulation in crop plants: Sources, response mechanisms, stress tolerance and their effects. In: Contaminants in Agriculture and Environment: Health Risks and Remediation. *Agro Environ Media*. 2019;39–57. http://dx.doi.org/10.26832/AESA-2019-CAE-0161-04.

4 Mitra S, Chakraborty JA, Tareq MA, et al. Impact of heavy metals on the environment and human health: Novel therapeutic insights to counter the toxicity. *J King Saud Univ Sci*. 2022;34:101865. https://doi.org/10.1016/j.jksus.2022.101865.

5 Gebeyehu HR, Bayissa LD. Levels of heavy metals in soil and vegetables and associated health risks in Mojo area, Ethiopia. *PLoS One*. 2020;15(1):0227883. https://doi.org/10.1371/journal.pone.0227883.

6 Ostadrahimi H, Payahoo L, Somi MH, et al. The association between blood cadmium levels and the risk of gastrointestinal cancer in Tabriz, northwest of Iran. *Pol Ann Med*. 2017;24(2):133–137. https://doi.org/10.1016/j.poamed.2016.05.004.

7 Evaluation of certain food additives and contaminants: ninety-first report of the Joint FAO/WHO Expert Committee on Food Additives. World Health Organization. https://iris.who.int/handle/10665/364702. Accessed: October 28, 2024.

8 Commission Regulation (EU) 2023/915 of 25 April 2023 on maximum levels for certain contaminants in food and repealing Regulation (EC) No 1881/2006. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02023R0915-20240722. Accessed: October 28, 2024.

9 Metals as contaminants in food. European Safety Food Authority. 2024. https://www.efsa.europa.eu/en/topics/topic/metals-contaminants-food. Accessed: October 28, 2024.

10 Winiarska-Mieczan A, Kwiatkowska K, Kwiecień M, Zariska E. Assessment of the risk of exposure to cadmium and lead as a result of the consumption of coffee infusions. *Biol Trace Elem Res*. 2021;199(6):2420–2428. https://doi.org/10.1007/s12011-020-02332-3.

11 Winiarska-Mieczan A, Jachimowicz K, Kislova S, Kwiecień M, Zasadna Z, Yanovych D. Cadmium and lead concentration in drinking instant cofee, instant cofee drinks and cofee substitutes: safety and health risk assessment. *Biol Trace Elem Res*. 2022;201(1). https://doi.org/10.1007/s12011-022-03129-2.

12 Wierzejska R. Coffee – does it harm or help? *Przem Spoż*. 2010;12:18–22.

13 Wierzejska RE, Gielecińska I. Evaluation of the Caffeine Content in Servings of Popular Coffees in Terms of Its Safe Intake – Can We Drink 3–5 Cups of Coffee per Day, as Experts Advise? *Nutrients*. 2024;16(15):2385. https://doi.org/10.3390/nu16152385.

14 Massoud R, Mir Mohammed Mikki FS, Mir Mohammed Mikki NS, Massoud N. Evaluation of heavy metals in Roasted Coffee powder in Iran and Turkey. *Coffee Science*. 2022;e172013. https://doi.org/10.25186/.v17i.2013.

15 Alves da Silva S, Mendes F, Reis M, et al. Determination of heavy metals in the roasted and ground coffee beans and brew. *Afr J Agric Res*. 2017;12(4):221–228. https://doi.org/10.5897/AJAR2016.11832.

16 Várady M, Ślusarczyk S, Boržíkova J, et al. Heavy-metal contents and the impact of roasting on polyphenols, caffeine, and acrylamide in specialty coffee beans. *Foods*. 2021;10(6):1310. https://doi.org/10.3390/foods10061310.

17 Yadav SK. Heavy metals toxicity in plants: An overview on the role of glutathione and phytochelatins in heavy metal stress tolerance of plants. *S Afr J Bot*. 2010;76:167–179. https://doi.org/10.1016/j.sajb.2009.10.007.

18 Basharat A, Rafaqat AG. Heavy metal toxicity in plants: Recent insights on physiological and molecular aspects. *Front Plant Sci*. 2022;21(13):1016257. https://doi.org/10.3389/fpls.2022.1016257.

19 Yavas I, Ali S, Abbas Z, Hussain S. Heavy metal toxicity in plants: an overview on tolerance mechanisms and management strategies. *Turkish JAF Sci Tech*. 2022;8(10): 1468–1481. https://doi.org/10.24925/turjaf.v10i8.1468-1481.5220.

20 Wang Y, Wu Y, Luo K, et al. The protective effects of selenium on cadmium-induced oxidative stress and apoptosis via mitochondria pathway in mice kidney. Food Chem. *Toxicol*. 2013;58:61–67. https://doi.org/10.1016/j.fct.2013.04.013.

21 Ibrahim TA, Tarboush HA, Alada A, Mohanna MA. The effect of selenium and lycopene on oxidative stress in bone tissue in rats exposed to cadmium. *Food Nutr Sci*. 2014;5:1420–1429. http://dx.doi.org/10.4236/fns.2014.514155.

22 El-Boshy ME, Risha EF, Abdelhamid FM, Mubarak MS, Hadda TB. Protective effects of selenium against cadmium induced hematological disturbances, immunosuppressive, oxidative stress and hepatorenal damage in rats. *Trace Elem Med Biol*. 2015;29:104–110. https://doi.org/10.1016/j.jtemb.2014.05.009.

23 El-Sayed YS, El-Gazzar AM, El-Nahas AF, Ashry KM. Vitamin C modulates cadmium-induced hepatic antioxidants gene transcripts and toxicopathic changes in Nile tilapia, Oreochromis niloticus. *Environ Sci Pollut Res*. 2016;23:1664–1670. doi: 10.1007/s11356-015-5412-8.

24 Genchi G, Sinicropi MS, Lauria G, Carocci A, Catalano A. The Effects of Cadmium Toxicity. *Int J Environ Res Public Health*. 2020;17(11):3782. https://doi.org/10.3390/ijerph17113782.

25 Adler G, Nędzarek A, Tórz A. Concentrations of selected metals (Na, K, Ca, Mg, Fe, Cu, Zn, Al, Ni, Pb, Cd) in coffee. *Zdr Varst*. 2019; 58(4):187–193. https://doi.org/10.2478/sjph-2019-0024.

26 *Exposure assessment tools by routes–ingestion*. US EPA United States Environmental Protection Agency. 2024. https://www.epa.gov/expobox/exposure-assessment-tools-routes-ingestion. Accessed: October 28, 2024.

27 Statistics Poland. *Household survey in 2022*. 2023. https://stat.gov.pl/en/topics/living-conditions/living-conditions/household-budget-survey-in-2022,2,18.html. Accessed: October 28, 2024.

28 Agency for Toxic Substances and Disease Registry. *Calculating Hazard Quotients and Cancer Risk Estimates*. 2022. https://www.atsdr.cdc.gov/pha-guidance/conducting_scientific_evaluations/epcs_and_exposure_calculations/hazardquotients_cancerrisk.html. Accessed: October 28, 2024.

29 US EPA United States Environmental Protection Agency. *Zinc and Compounds*. 2005. https://cfpub.epa.gov/ncea/iris2/chemicallanding.cfm?substance_nmbr=426. Accessed: October 28, 2024.

30 US EPA United States Environmental Protection Agency. *Nickel, soluble salts*. 1991. https://cfpub.epa.gov/ncea/iris2/chemicallanding.cfm?substance_nmbr=271. Accessed: October 28, 2024.

31 US EPA United States Environmental Protection Agency. *Chromium VI*. https://iris.epa.gov/ChemicalLanding/&substance_nmbr=144. Published January 8, 2024. Accessed October 28, 2024.

32 US EPA United States Environmental Protection Agency. *How do I calculate the Hazard Index?* https://www.epa.gov/system/files/documents/2023-03/How%20do%20I%20calculate%20the%20Hazard%20Index._3.14.23.pdf. Accessed: October 28, 2024.

33 Sazakli E. Human health effects of oral exposure to chromium: a systematic review of the epidemiological evidence. *Int J Environ Res Public Health*. 2024;21:406. https://doi.org/10.3390/ijerph21040406.

34 Triwardhani A, Amanda YA, Hamid T, Nugraha AP, Steventhie L, Hariati IVD. Biocompatibility stainless steel brackets with nickel and chromium ions: a scoping review. *Res J Pharm Technol*. 2023;16(7):3251–6. https://doi.org/10.52711/0974-360X.2023.00534

35 Abudayyak M, GÜzel E, Özhan G. Cytotoxic, genotoxic, and apoptotic effects of nickel oxide nanoparticles in intestinal epithelial cells. *Turk J Pharm Sci*. 2020;17(4):446. https://doi.org/10.4274/tjps.galenos.2019.76376.

36 Gure A, Chandravanshi BS, Godeto TW. Assessment of metals in roasted indigenous coffee varieties of ethiopia. *Bull Chem Soc Ethiop*. 2018;32(1):27–38. https://dx.doi.org/10.4314/bcse.v32i1.3.

37 Morgano MA, Pauluci LF, Mantovani DMB, Mory EEM. Determination of minerals in raw coffee. *Food Sci Technol*. 2002;22:19–23. https://doi.org/10.1590/S0101-20612002000100004.

38 Grembecka M, Malinowska E, Szefer P. Differentiation of market coffee and its infusions in view of their mineral composition. *Sci Total Environ*. 2007;383:59–69. https://doi.org/10.1016/j.scitotenv.2007.04.031.

39 Gupta RK, Pipliya S, Karunanithi S, et al. Migration of Chemical Compounds from Packaging Materials into Packaged Foods: Interaction, Mechanism, Assessment, and Regulations. *Foods*. 2024;13(19):3125. https://doi.org/10.3390/foods13193125.

40 Teixeira Pigozzi M, Passos FR, Mendes F. Quality of commercial coffees: heavy metal and ash contents. J. Food Qual. 2018;(1):1–7. https://doi.org/10.1155/2018/5908463.

41 Nędzarek A, Tórz A, Karakiewicz B, et al. Concentrations of heavy metals (Mn, Co, Ni, Cr, Ag, Pb) in coffee. *Acta Biochim Pol*. 2013;16(4):623–627.

42 Berego YS, Sota SS, Ulsido M, Beyene EM. The contents of essential and toxic metals in coffee beans and soil in Dale Woreda, Sidama Regional State, Southern Ethiopia. *Peer J*. 2023;11:4789. https://doi.org/10.7717/peerj.14789.

43 Guadalupe GA, Chavez SG, Arellanos E, Doménech E. Probabilistic risk characterization of heavy metals in peruvian coffee: implications of variety, region and processing. *Foods*. 2023; 12(17):3254. https://doi.org/10.3390/foods12173254.

44 Alkherraz AM, Hashad OM, Elsherif KM. Heavy metals contents in some commercially available coffee, tea, and cocoa samples in Misurata city – Libya. *Prog Chem Biochem Res*. 2019;2(3):99–107. https://doi.org/10.33945/SAMI/PCBR.2019.2.3.3.

45 Fareed G, Baig JA, Kazi TG, Afridi HI, Akhtar K, Solangi IB. Heavy metals contamination levels in the products of sugar industry along with their impact from sugar to the end users. *J Environ Anal Chem*. 2022;104(2):1–10. https://doi.org/10.1080/03067319.2022.2062238.

46 Mekassa B, Etana E, Merga LB. Proximate analysis, levels of trace heavy metals and associated human health risk assessments of Ethiopian white sugars. *J Agric Food Res*. 2024;16:101086. https://doi.org/10.1016/j.jafr.2024.101086.

47 Zhao B, Zhang J, Ma T, Qiu H, Ma S. Determination of heavy metal elements in different vegetable edible oils in China. *Asian J Chem*. 2017;29:937–939 http://dx.doi.org/10.14233/ajchem.2017.18675.

48 Scutaraşu EC, Trincă LC. Heavy metals in foods and beverages: global situation, health risks and reduction methods. *I*. 2023;12:3340. https://doi.org/10.3390/foods12183340.

49 Yan M, Niu C, Li X, et al. Heavy metal levels in milk and dairy products and health risk assessment: A systematic review of studies in China. *Sci Total Environ*. 2022;851:158161. https://doi.org/10.1016/j.scitotenv.2022.158161.