

The concentration of potentially toxic elements (PTEs) in the coffee products: a systematic review and meta-analysis

by Trias Mahmudiono

Submission date: 09-Mar-2023 11:21AM (UTC+0800)

Submission ID: 2032654379

File name: A2.pdf (669.33K)

Word count: 10589

Character count: 50716



The concentration of potentially toxic elements (PTEs) in the coffee products: a systematic review and meta-analysis

Amin Mousavi Khaneghah¹ · Trias Mahmudiono² · Fardin Javanmardi³ · Behrouz Tajdar-oranj⁴ · Amene Nematollahi⁵ · Mohadeseh Pirhadi⁶ · Yadolah Fakhri⁷

Received: 12 May 2022 / Accepted: 14 September 2022 / Published online: 30 September 2022
© The Author(s), under exclusive licence to Springer-Verlag GmbH Germany, part of Springer Nature 2022

Abstract

Coffee is one of the most consumed products globally, and its contamination with potentially toxic elements (PTEs) occurs throughout the production chain and production. Therefore, the current meta-analysis study aimed to estimate the concentration of essential elements (Cu and Co) and the contamination of PTEs (Ni, Cr, Pb, As, and Cd) in coffee. The recommended databases, including PubMed, Scopus, and ScienceDirect were investigated to collect data regarding the contamination of PTEs in coffee products from 2010 to 2021. Among 644 retrieved citations in the identification step, 34 articles were included in the meta-analysis. The pooled mean concentration of essential elements in coffee products is much higher than that of toxic elements (Co (447.106 µg/kg, 95% CI: 445.695–448.518 µg/kg) > Ni (324.175 µg/kg, 95% CI: 322.072–326.278 µg/kg) > Cu (136.171 µg/kg, 95% CI: 134.840–137.503 µg/kg) > Cr (106.865 µg/kg, 95% CI: 105.309–108.421 µg/kg) > Pb (21.027 µg/kg, 95% CI: 20.824–21.231 µg/kg) > As (3.158 µg/kg, 95% CI: 3.097–3.219 µg/kg) > Cd (0.308 µg/kg; 95% CI: 0.284–0.332 µg/kg)). Results showed high differences between pooled concentrations of all PTEs in coffee products of different countries.

Keywords Potential toxic elements · Coffee products · PTEs · Systematic review · Meta-analysis

Responsible Editor: Philippe Garrigues

✉ Amin Mousavi Khaneghah
amin.mousavi@ibprs.pl; mousavi.amin@gmail.com

¹ Department of Fruit and Vegetable Product Technology, Prof. Waclaw Dąbrowski Institute of Agricultural and Food Biotechnology, Warsaw, Poland

² Department of Nutrition, Faculty of Public Health, Universitas Airlangga, Surabaya, Indonesia

³ Department of Food Science and Technology, Faculty of Nutrition Science and Food Technology, Shahid Beheshti University of Medical Sciences, Tehran, Iran

⁴ Food and Drug Administration, Iran Ministry of Health and Medical Education, Tehran, Iran

⁵ Department of Food Safety and Hygiene, School of Health, Fasa University of Medical Sciences, Fasa, Iran

⁶ Department of Environmental Health Engineering, Division of Food Safety & Hygiene, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran

⁷ Food Health Research Center, Hormozgan University of Medical Sciences, Bandar Abbas, Iran

Introduction

Chemical pollution of the environment (Guan et al. 2021; Li et al. 2021; Lin et al. 2021; Liu et al. 2011, 2020; Quan et al. 2021; Shi et al. 2021) followed by food contamination (Liu et al. 2022; Sun et al. 2022; Wang et al. 2022) has become a global concern. Coffee is an attractive beverage worldwide because of its pleasant aroma and taste. Coffee consumption varies according to geographical location (Godos et al. 2014). Flanders in Northern Europe and Bosnia and Herzegovina in Southern Europe are the largest consumers of coffee. The World Coffee Organization states that 500 billion cups of coffee are consumed annually (Dieng et al. 2017). Coffee and tea have been consumed for hundreds of years and have become an important part of cultural traditions and social life. In addition, people use coffee drinks to increase alertness and work productivity (Samet et al. 2018). The highest caffeine consumption in a typical meal is coffee, energy drinks, and caffeinated pills. The intermediate level is tea, and the lowest amount of soda (Rattan et al. 2015; van Dam et al. 2020). Caffeine is an alkaloid belonging to methylxanthine. It is also a chemical stimulant found naturally (Wolde 2014). Studies showed that coffee consumption has

chronic and acute effects on human health (Nędzarek et al. 2013). Caffeine acts as an antioxidant to prevent diseases. Caffeine also can reduce the risk of several chronic diseases such as liver cancer, diabetes, coronary heart disease, osteoporosis, and gastritis (Nartea et al. 2022). Moreover, the absorption of many vital nutrients such as vitamin B₆ is reduced by caffeine intake and the absorption of essential minerals such as magnesium (Mg), iron (Fe), and calcium (Ca) (de Mejia and Ramirez-Mares 2014; Escott-Stump 2008; Wolde 2014). However, consuming large amounts of this drink is not recommended because of some contaminants, including mycotoxins and potentially toxic elements (PTEs), besides adverse effects of caffeine (Barrea et al. 2021; Batrinou et al. 2020; Berman et al. 2022; Khaneghah et al. 2019; Nourbakhsh and Tajbakhsh 2021; Pavithra 2021; Yazdanpanah et al. 2022).

It needs about 20 essential elements for the proper functioning of the human body. The list of metallic elements that are essential for the human body include sodium (Na), potassium (K), Mg, Ca, manganese (Mn), Fe, cobalt (Co), copper (Cu), zinc (Zn), molybdenum (Mo), and elements like tin (Sn), nickel (Ni), and vanadium (V), and are assumed not to be necessary for humans, according to chromium (Cr); based on experimental animal results, these metals were considered essential for the human body in the past (Zoroddu et al. 2019). Cu and Co are essential elements in the human body, a small amount of which plays a vital role in the body. The amount of Co we need is minimal, and only about 2 mg of it is needed for humans. High levels of Cu can cause cardiovascular disease such as cardiac arrhythmias. In addition, high levels of Cu lead to dementia, lung cancer, and lymphoma (Bost et al. 2016). The presence of Cu in the body interferes with the nervous system and causes Wilson's disease, and also, the presence of Cu in the brain leads to brain damage (Kalita et al. 2019).

PTEs are a serious and worrying environmental problem (Bounar et al. 2020; Gao et al. 2022; Mirmahdi et al. 2022). They are widely distributed in the environment thus intake by humans through water, air, soil, and even the food chain (Alkheraz et al. 2019; Heshmati et al. 2020). Accumulating PTEs in the body has negatively affected human health (Fu and Xi 2020; Mirmahdi et al. 2021). These effects include interfering with the immune and nervous systems, endocrine disorders, and malformations (Khaneghah et al. 2020). Organic compounds of lead (Pb) can be absorbed through the skin and enter the brain, causing toxins in the central nervous system. Pb also causes oxidative stress and causes cells to lose antioxidants (Fu and Xi 2020). Adverse effects of Pb include chromosome aberrations, mutations, DNA breakdown, and inhibition of DNA synthesis (Ibrahem et al. 2020). Cadmium (Cd) is a toxic and dangerous metal. The World Health Organization limited the tolerable weekly Cd exposure to 50 µg

and recommended it as 0.007 µg/kg body weight (World Health Organization 2000). Depending on the route of exposure and duration, Cd can cause damage to the lung, liver, kidney, bone, testicle, and placenta (Hocaoğlu-Ozyiğit and Genç 2020). Arsenic (As) is another PTE that causes damage and changes in DNA synthesis and cancer, cardiovascular and lung diseases, reproductive outcomes, and cognitive impairment in adults and children (Hu et al. 2022). Studies show that chronic exposure to As causes lung cancer, breast cancer, and bladder, kidney, and larynx diseases. It causes respiratory problems, infertility in adults, and premature birth in infants (Delgado Quezada et al. 2020; Khan et al. 2020; Pullella and Kotsopoulos 2020). Cr has a different effect on human health depending on the target dose and organ. Effects include respiratory problems, asthma, lung cancer, skin diseases such as dry skin, allergies, dizziness, general weakness, eye irritation, kidney stones, liver problems, gastrointestinal disorders, heart problems, blood disorders, reproduction problems, growth problems, nostril problems, and corneal damage (Ameri et al. 2021). Dental malformations such as discoloration and erosion are accompanied by high concentrations of Cr in the tongue papilla (Achmad and Auerkari 2017; Martineli et al. 2022; Teklay 2016). Ni is an element that may be widely derived from natural resources and human activities in the environment, air, water, and soil. Ni exposure causes digestive diseases, lung problems, lung cancer, and cardiovascular disease (Genchi et al. 2020).

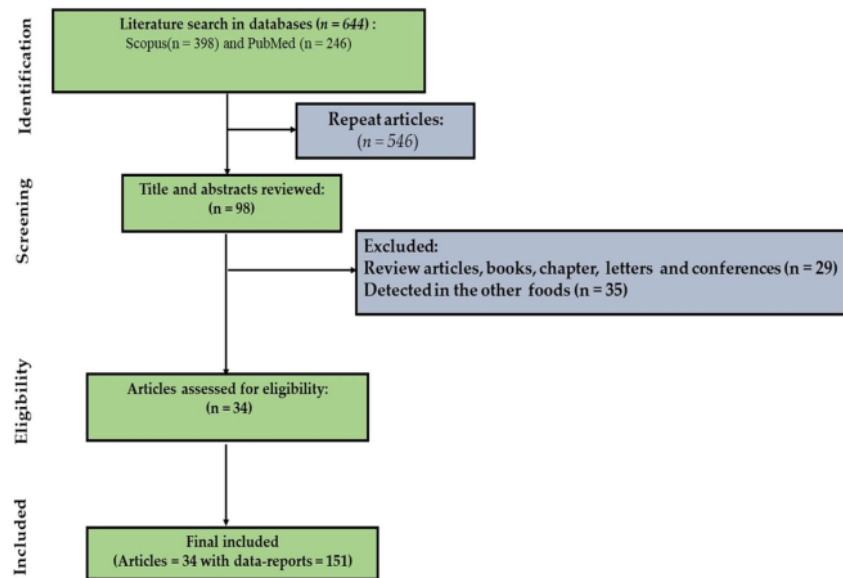
This study systematically reviewed the prevalence of essential elements (Cu and Co) and potentially toxic elements (Cr, Cd, Pb, and Ni) in coffee products. Also, another goal of this study was to meta-analyze the results and identified the elements and geographical areas with the highest prevalence.

Material and method

Searching strategy

According to PRISMA guidelines, our study conducted the search strategy (Fig. 1) (Moher et al. 2010). International databases, including Scopus and PubMed (January 2000 and 20 June 2021), were screened to get papers on PTE concentrations in coffee products. Keywords referred to in the title and abstract of citations were ["heavy metal" OR "potentially toxic elements" OR "toxic elements" OR "elements" OR "toxic metal"] AND ["coffee products" OR "coffee" OR "caffeine" OR "cappuccino" OR "espresso"]. The reference list of papers was assessed for possible papers missed in the title and abstract screening step.

Fig. 1 Process selection of papers based on PRISMA



55 Inclusion and exclusion criteria and extraction of data

Our criteria included the following: detection of PTE concentrations in coffee products, full text available, contamination or prevalence investigation, no language limitation, no restriction for the study location, and present of mean, standard deviation, and/or range concentration of PTEs. One study was excluded because it did not meet the above criteria. One of the authors extracted the data in the retrieved paper. Data extracted from each article included the country, sample size, the mean and standard deviation of concentration, and measurement method.

8 Meta-analysis of data

The concentration of PTEs in coffee products was meta-analyzed based on the standard error (SE) of the equation:

$$SE = \frac{SD}{\sqrt{n}} \quad (1)$$

where SD is the standard deviation and n is the number of samples when the I^2 index is higher than 50% and heterogeneity is considerable (Higgins et al. 2008; Higgins and Thompson 2002; Quan and Zhang 2003); hence, the random-effect model was used for the meta-analysis of the concentration of PTEs in coffee products. PTE concentration's mean and standard deviation were converted to $\mu\text{g}/\text{kg}$.

5 A data meta-analysis was performed using Stata, version 14 (Stata Corporation, College Station, TX).

Result and discussion

Our study included thirty-four papers with 151 data reports (Fig. 1). The overall rank order of PTEs in the coffee products was as follows: Co (447.106 $\mu\text{g}/\text{kg}$, 95% CI: 445.695–448.518 $\mu\text{g}/\text{kg}$) > Ni (324.175 $\mu\text{g}/\text{kg}$, 95% CI: 322.072–326.278 $\mu\text{g}/\text{kg}$) > Cu (136.171 $\mu\text{g}/\text{kg}$, 95% CI: 134.840–137.503 $\mu\text{g}/\text{kg}$) > Cr (106.865 $\mu\text{g}/\text{kg}$, 95% CI: 105.309–108.421 $\mu\text{g}/\text{kg}$) > Pb (21.027 $\mu\text{g}/\text{kg}$, 95% CI: 20.824–21.231 $\mu\text{g}/\text{kg}$) > As (3.158 $\mu\text{g}/\text{kg}$, 95% CI: 3.097–3.219 $\mu\text{g}/\text{kg}$) > Cd (0.308 $\mu\text{g}/\text{kg}$; 95% CI: 0.284–0.332 $\mu\text{g}/\text{kg}$). As it is obvious from this part of the result, the pooled mean concentration of essential elements in coffee products is much higher than that of toxic elements. Thus, the distribution of PTEs in coffee products is uneven because their content depends on numerous factors (Bost et al. 2016).

It should bear in mind that coffee plants need essential elements (like Co, Ni, and Cu) for their development, so they absorb them from water and soil selectively during growth which is influenced by the soil characteristics (chemical composition) in addition to the overall environmental growth conditions (climate, temperature, and agricultural practices) (Barbosa et al. 2014; Habte et al. 2016; Pigozzi et al. 2018). Petrović et al. (2020) also reported that the accumulation of

PTEs in plants relates to the plant's affinity to take up the appropriate element. Furthermore, there is usually a higher concentration of essential elements in the soil than toxic elements since they exist naturally in the rocks and release into water and soil through rock weathering and human activities (like mining) (Atamaleki et al. 2020; Pigozzi et al. 2018). Higher Co, Ni, and Cu pooled concentrations in the coffee products could also be attributed to the greater availability of these PTEs in the soils used for coffee plantation. Therefore, due to the active transmission of essential elements through the soil-root interface and their high content in the soil used for coffee cultivation, they might be readily absorbed by the plant and accumulated in the coffee beans compared with other PTEs (21). Silva et al. 2017). As also evident in a study of da Silva et al. (2017), the elements of Cu, Ni, and Zn are necessary to the growth of the coffee plant, being utilized in the soil or coffee leaf, and are subsequently present in the coffee beans. Furthermore, some PTEs like Cu exist in pesticide ingredients applied in cultivation which assists the uptake of the (58) PTEs by plants, validating its presence in coffee beans (da Silva et al. 2017). Albals et al. (2021) also noted that Co and Cu mainly exist at high concentrations in most plants when cultivated in contaminated soil. Cd is found at lower concentrations in such products than in fish.

PTE contamination in coffee products also has diverse forms associated with size, charge, hydrophobicity, activity, bioaccessibility, coffee variety, and type of (40) processing (Alkherraz et al. 2019; Pohl et al. 2014; Şemen et al. 2017). The concentration of PTEs in coffee is also related to its processing, especially the roasting of coffee beans and coffee beverages' preparation method (Tiep 2014). When it comes

to coffee infusions, several researchers reported that the releasing amount of different PTEs to coffee infusions from the solid sample is different based on coffee type, preparation method, and nature of the metal (leachability and rate of complex formation or interaction with (15) er components) (Ashu and Chandravanshi 2011; da Silva et al. 2017; Jeszka-Skowron et al. 2016; Welna et al. 2013; Winiarska-Mieczan et al. 2021).

Concentration of As

As, a widespread toxic environmental contaminant, enters into the environment (air, water, and soil) through natural and anthropogenic (mainly pesticides used in agricultural practices) sources and is found in the (59) natural world in organic, inorganic, and gaseous forms (Fu and Xi 2020; Petrović et al. 2020). Inorganic and gaseous forms of As are highly toxic, while organic As is considered relatively non-toxic in very low concentrations (Pullella and Kotsopoulos 2020). Exposure to As is of great concern. It has been related to adverse health effects, including cancer (skin, bladder, and lungs), damaged neurological growth, cardiovascular disorder, and diabetes (Pullella and Kotsopoulos 2020).

The rank order of countries based on the concentration of As in the coffee products was observed in the following: Brazil (4) 8.882 µg/kg > Netherland (74.981 µg/kg) > Greece (40.000 µg/kg) > Austria (20.050 µg/kg) > France (16.45) (2) µg/kg > Turkey (10.000 µg/kg) > Ethiopia (6.000 µg/kg) > It (17) (1.250 µg/kg) > Germany (0.259 µg/kg) > Indonesia (0.100 µg/kg) ~ Romania (0.100 µg/kg) ~ Rwanda (0.100 µg/kg) ~ Slovenia (0.100 µg/

Table 1 Meta-analysis concentration of As in the coffee products (µg/kg)

Country	ES	Lower	Upper	Weight (%)	Heterogeneity statistic	Degrees of freedom	P value	I ² (%)
Austria	20.050	2.350	59.152	4.43	58,897.79	1	<0.001	100.00
Brazil	178.882	128.720	229.043	0.39	4232.54	2	<0.001	100.00
Ethiopia	6.000	5.689	6.311	1.64	0.00	0		
France	16.451	15.290	17.612	7.27	92,121.16	2	<0.001	100.00
Germany	0.259	0.181	0.336	11.55	6968.40	5	<0.001	99.90
Greece	40.000	39.678	40.322	1.59	0.00	0		
Indonesia	0.100	0.094	0.106	2.84	0.00	0		
Italy	1.250	1.035	1.465	6.07	9419.07	4	<0.001	100.00
Netherland	74.981	6.382	143.580	1.62	1795.05	1	<0.001	99.90
Romania	0.100	0.097	0.103	5.68	0.00	1	1	0.00
Rwanda	0.100	0.096	0.104	2.84	0.00	0		
Slovenia	0.100	0.098	0.102	5.68	0.00	1	1	0.00
Turkey	10.000	8.303	11.697	0.12	0.00	0		
Western Balkan	0.100	0.094	0.106	48.28	554.78	18	<0.001	96.80
Overall	3.158	3.097	3.219	100.00	300,000.00	48	<0.001	100.00

ES effect size (mean of concentration)

kg) ~ Western Balkan (0.100 µg/kg) (Table 1). Since the maximum permitted level (MPL) of As in coffee is 1000 µg/kg (Petrović et al. 2020), it could be concluded that the As concentration of coffee products in all investigated countries does not show a risk to human health concerning this metal.

Concentration of Ni

Ni is naturally present in the soil and widespread distribution in the environment (Genchi et al. 2020). This metal has commercial and industrial applications, including metallurgy, electronics, batteries, jet turbines, and medical tools (Şaylan et al. 2020). As an essential element for all living things, Ni has several beneficial impacts on different body organs' functions and metabolism, up to the permitted level. In this regard, Ni influences the liver and pancreas performances, the Fe absorption/metabolism, and the hematopoietic process (Gogoasa et al. 2013). However, in elevated concentrations, Ni can be dangerous for human health by creating respiratory disorders, including lung embolism, respiratory malfunction, asthma, chronic bronchitis, and allergic reactions (Nędzarek et al. 2013). As high long-time exposure to Ni is related to the development of different kinds of cancer such as lung, larynx,

and prostate, it is recognized by the International Agency for Research on Cancer (IARC) as a carcinogen (Nędzarek et al. 2013; Voica et al. 2016).

The rank order of countries based on the concentration of Ni in the coffee products was as follows: Turkey (9695.861 µg/kg) > France (8615.085 µg/kg) > Netherlands (5881.104 µg/kg) > India (3665.463 µg/kg) > Italy (2846.081 µg/kg) > Greece (2540.000 µg/kg) > Austria (2274.536 µg/kg) > Romania (1782.844 µg/kg) > Kenya (1630.881 µg/kg) > Brazil (1128.809 µg/kg) > Poland (1046.963 µg/kg) > Lebanon (842.300 µg/kg) > Bosnia (780.000 µg/kg) > Ethiopia (777.455 µg/kg) > Honduras (580.784 µg/kg) > Pakistan (410.000 µg/kg) > Hawaii (356.879 µg/kg) > Colombia (34.796 µg/kg) > Germany (5.047 µg/kg) > Western Balkan (4.471 µg/kg) > Slovenia (0.100 µg/kg) (Table 2).

There is no MPL for Ni in coffee beans, although Brazilian legislation authorizes an MPL of 5000 µg/kg for Ni in typical foods (da Silva et al. 2017; Pigozzi et al. 2018). Our results showed that the Ni concentrations in the coffee samples of all countries do not surpass this maximum level except for the coffee samples of Turkey, France, and the Netherlands.

Table 2 Meta-analysis concentration of Ni in the coffee products (µg/kg)

Country	ES	Lower	Upper	Weight (%)	Heterogeneity statistic	Degrees of freedom	P value	I ² (%)
Austria	2274.536	344.647	4204.426	2.63	23,640.73	1	<0.001	100.00
Bosnia	780.000	731.668	828.332	0.18	0.00	0		
Brazil	1128.809	1033.256	1224.361	5.40	7,300,000.00	8	<0.001	100.00
Colombia	34.796	3.540	101.104	3.95	146.58	1	<0.001	99.30
Ethiopia	777.455	774.516	780.394	13.63	1,400,000.00	7	<0.001	100.00
France	8615.085	1490.616	16,000.000	0.03	3581.61	1	<0.001	100.00
Germany	5.047	4.391	5.704	7.05	87,862.69	5	<0.001	100.00
Greece	2540.000	2514.223	2565.777	0.53	0.00	0		
Hawaii	356.879	124.475	589.284	0.18	48.95	4	<0.001	91.80
Honduras	580.784	565.420	596.147	1.16	0.12	1	0.732	0.00
India	3665.463	3429.303	3901.623	0.01	0.04	1	0.836	0.00
Italy	2846.081	2002.296	3689.867	3.33	35,250.89	5	<0.001	100.00
Kenya	1630.881	1584.530	1677.232	0.19	0.05	1	0.83	0.00
Lebanon	842.300	833.284	851.316	1.71	0.00	0		
Netherlands	5881.104	5516.598	6245.610	0.07	4.38	1	0.036	77.20
Pakistan	410.000	300.242	519.758	0.04	0.00	0		
Poland	1046.963	698.597	1395.328	4.60	13,874.64	8	<0.001	99.90
Romania	1782.844	1304.206	2261.481	2.59	1295.84	5	<0.001	99.60
Slovenia	0.100	0.097	0.103	5.01	0.00	1	1	0.00
Turkey	9695.861	1993.787	17,000.000	0.17	43,968.77	3	<0.001	100.00
Western Balkan	4.471	4.339	4.604	47.56	360,000.00	18	<0.001	100.00
Overall	324.175	322.072	326.278	100.00	310,000,000.00	91	<0.001	100.00

ES effect size (mean of concentration)

Concentration of Cr

Both kinds of Cr (Cr^{3+} and Cr^{6+}) could enter the air, water, and soil through natural processes and industrial activities (like steel, leather, chemical, electronic, painting, and textile manufacturing) (Teklay 2016). Cr^{3+} , an essential element in the body, influences metabolism by adjusting blood sugar levels in relatively small amounts (Gogoasa et al. 2013; Nędzarek et al. 2013). It is worth noting that Cr^{6+} is more active and toxic than Cr^{3+} . This element occurs at many high levels in industrial activities, which could release Cr^{6+} into the environment (Achmad and Auerkari 2017). However, Cr^{3+} is ubiquitous in the environment (water and soil) and biological systems (Voica et al. 2016). It is reported that exposure to a high concentration of Cr could result in several physiological effects, including skin harm; respiratory injuries; gastrointestinal disorders; cardiovascular diseases; hepatic failure; carcinogenic, genotoxic, and neurotoxic mutagenic effects; and reproductive and developmental toxicity (Teklay 2016).

The rank order of countries based on the concentration of Cr in the coffee products was as follows: Netherland (34,000.000 $\mu\text{g}/\text{kg}$) > France (20,000.000 $\mu\text{g}/\text{kg}$) > Egypt (2500.000 $\mu\text{g}/\text{kg}$) > Kenya (714.922 $\mu\text{g}/\text{kg}$) > India (610.321 $\mu\text{g}/\text{kg}$) > Indonesia (600.000 $\mu\text{g}/\text{kg}$) > Honduras (290.000 $\mu\text{g}/\text{kg}$) > Ethiopia (246.854 $\mu\text{g}/\text{kg}$) > Hawaii (239.039 $\mu\text{g}/\text{kg}$) > Brazil (150.930 $\mu\text{g}/\text{kg}$) > Colombia

(121.610 $\mu\text{g}/\text{kg}$) > Poland (60.000 $\mu\text{g}/\text{kg}$) > Bosnia (40.000 $\mu\text{g}/\text{kg}$) > Lebanon (35.000 $\mu\text{g}/\text{kg}$) > Germany (0.643 $\mu\text{g}/\text{kg}$) > Italy (0.134 $\mu\text{g}/\text{kg}$) > Austria (0.100 $\mu\text{g}/\text{kg}$) ~ Greece (0.100 $\mu\text{g}/\text{kg}$) (Table 3).

Similar to Ni, there are no reported maximum levels for the existence of the Cr metal in coffee products. At the same time, Brazilian regulation has established a MPL of 100 $\mu\text{g}/\text{kg}$ for this element in the food (da Silva et al. 2017). Our results showed that the pooled concentrations of Cr in coffee products of all investigated countries exceed the maximum permitted level except Poland, Bosnia, Lebanon, Germany, Italy, Austria, and Greece.

Concentration of Cu

Cu is a vital element in numerous human body functions like antioxidant defense, Fe metabolism, enzyme functions, energy production, bone formation, and skin health in trace amounts (Bost et al. 2016; Gogoasa et al. 2017). Furthermore, lacking Cu may cause anemia, hair whitening, and bone distortion (Petrović et al. 2020). However, exposure to high concentrations of Cu is toxic and could result in stomach pain, nausea, diarrhea, peroxidation of macromolecules, and tissue injury (Anosike and Oranusi 2018; Bost et al. 2016).

The rank order of countries based on the concentration of Cu in the coffee products was Germany (38,000.000 $\mu\text{g}/\text{kg}$)

Table 3 Meta-analysis concentration of Cr in the coffee products ($\mu\text{g}/\text{kg}$)

Country	ES	Lower	Upper	Weight (%)	Heterogeneity statistic	Degrees of freedom	P value	I^2 (%)
Austria	0.100	0.098	0.102	11.70	0.00	1.00	1	0.00
Bosnia	40.000	28.181	51.819	1.34	0.00	0.00		
Brazil	150.930	139.951	161.908	13.08	54,518.83	8.00	<0.001	100.00
Colombia	121.610	102.443	140.778	11.82	3178.71	5.00	<0.001	99.80
Egypt	2500.000	2428.432	2571.568	0.05	0.00	0.00		
Ethiopia	246.854	209.473	284.236	19.86	1759.86	7.00	<0.001	99.60
France	20,000.000	220.000	46,000.000	0.01	4284.30	1.00	<0.001	100.00
Germany	0.643	0.258	1.028	12.37	30,137.84	5.00	<0.001	100.00
Greece	0.100	0.097	0.103	5.85	0.00	0.00		
Hawaii	239.039	54.928	423.150	2.30	142.07	4.00	<0.001	97.20
Honduras	290.000	279.191	300.809	1.65	0.00	1.00	1	0.00
India	610.321	308.647	911.996	1.62	744.43	3.00	<0.001	99.60
Indonesia	600.000	511.357	688.643	0.03	0.00	0.00		
Italy	0.134	-0.170	0.438	11.71	18,762.12	4.00	<0.001	100.00
Kenya	714.922	691.221	738.624	0.41	0.52	1.00	0.472	0.00
Lebanon	35.000	34.409	35.591	5.80	0.00	0.00		
Netherlands	34,000.000	233.240	79,000.000	0.00	4397.72	1.00	<0.001	100.00
Poland	60.000	36.362	83.638	0.40	0.00	0.00		
Overall	106.865	105.309	108.421	100.00	28,000,000.00	58.00	<0.001	100.00

ES effect size (mean of concentration)

kg) > Austria (20,000.000 µg/kg) > Kenya (19,000.000 µg/kg) ~ Netherland (19,000.000 µg/kg) > Honduras (17,000.000 µg/kg) > India (14,000.000 µg/kg) > Colombia (13,000.000 µg/kg) ~ Costa Rica (13,000.000 µg/kg) ~ Guatemala (13,000.000 µg/kg) ~ Poland (13,000.000 µg/kg) > Nicaragua (12,000.000 µg/kg) > Peru (12,000.000 µg/kg) > Ethiopia (2077.608 µg/kg) > Italy (6598.028 µg/kg) > Greece (6520.000 µg/kg) > Nigeria (3970.000 µg/kg) > France (3538.513 µg/kg) > Brazil (2804.322 µg/kg) > Egypt (2200.0 µg/kg) > Hawaii (146.762 µg/kg) > Indonesia (90.000 µg/kg) (Table 4).

Our results showed that the concentrations of Cu in coffee products of all studied countries meet the MPL for Cu, determined by Brazilian legislation (30,000 µg/kg) (Alkherraz et al. 2019; Anosike and Oranusi 2018), except in Germany. Cu is usually used in the composition of some pesticides used in coffee fields as an active substance in different forms (Pigozzi et al. 2018). It is necessary for plant growth and is absorbed by plants during cultivation. Senkondo et al. (2014) observed that Cu concentrations in the coffee samples grown in the Cu-based pesticide soils were much higher compared with those in untreated soils, probably due to more availability of Cu for plant uptake, which could be the main reason for observed differences in Cu concentrations in different

countries in the present study. However, the soil properties, climate conditions, and differences in coffee bean varieties are also influential factors (Alkherraz et al. 2019; Senkondo et al. 2014).

Concentration of Co

Co, another essential element, is a constituent of vitamin B₁₂, which is vital in creating red blood cells (RBCs). It also participates in the appropriate functions of the nervous system, the self-defense of the body, activation of specific enzymes, and prevention of anemia (Gogoasa et al. 2013; Voica et al. 2016). However, a high Co intake could produce toxic effects on human and animal health, especially in the heart and liver (Nędzarek et al. 2013; Zoroddu et al. 2019).

The rank order of countries based on the concentration of Co in the coffee products was Ethiopia (2686.563 µg/kg) > France (865.526 µg/kg) > Austria (589.968 µg/kg) > Poland (428.061 µg/kg) > Italy (419.919 µg/kg) > Netherland (314.897 µg/kg) > Germany (308.238 µg/kg) > Hawaii (221.329 µg/kg) > Turkey (140.20 µg/kg) > Slovenia (124.982 µg/kg) > Greece (110.000 µg/kg) > Lebanon (66.000 µg/kg) > Bosnia (60.000 µg/kg) > Brazil (34.913 µg/kg) > Romania (0.102 µg/kg) (Table 5). There are no safety

Table 4 Meta-analysis concentration of Cu in the coffee products (µg/kg)

Country	ES	Lower	Upper	Weight (%)	Heterogeneity statistic	Degrees of freedom	P value	I ² (%)
Austria	20,000.000	6970.172	34,000.000	0.00	2702.34	1	<0.001	100.00
Brazil	2804.322	2712.544	2896.099	25.44	33,702.51	11	<0.001	100.00
Colombia	13,000.000	10,000.000	15,000.000	0.00	345.48	6	<0.001	98.30
Costa Rica	13,000.000	11,000.000	15,000.000	0.00	0.00	0		
Egypt	2200.000	2164.216	2235.784	0.14	0.00	0		
Ethiopia	9097.608	9004.660	9190.556	34.79	350,000.00	18	<0.001	100.00
France	3538.513	2483.860	4593.166	13.73	17,261.65	3	<0.001	100.00
Germany	38,000.000	27,000.000	48,000.000	0.35	66,115.44	5	<0.001	100.00
Greece	6520.000	6420.113	6619.887	0.02	0.00	0		
Guatemala	13,000.000	9995.342	16,000.000	0.00	5.05	1	0.025	80.20
Hawaii	146.762	53.569	239.955	0.02	0.05	4	1	0.00
Honduras	17,000.000	16,000.000	17,000.000	0.00	0.08	1	0.783	0.00
India	14,000.000	11,000.000	16,000.000	0.00	184.80	4	<0.001	97.80
Indonesia	90.000	76.704	103.296	0.93	0.00	0		
Italy	6598.028	6425.142	6770.915	23.38	64,400.57	6	<0.001	100.00
Kenya	19,000.000	19,000.000	20,000.000	0.00	0.14	1	0.704	0.00
Netherlands	19,000.000	16,000.000	21,000.000	0.00	115.12	1	<0.001	99.10
Nicaragua	12,000.000	10,000.000	13,000.000	0.00	1.39	1	0.238	28.20
Nigeria	3970.000	3958.240	3981.760	1.17	0.00	0		
Peru	12,000.000	11,000.000	14,000.000	0.00	0.00	0		
Poland	13,000.000	12,000.000	14,000.000	0.00	0.00	0		
Overall	136.171	134.840	137.503	100.00	1,300,000.00	83	<0.001	100.00

ES effect size (mean of concentration)

Table 5 Meta-analysis concentration of Co in the coffee products ($\mu\text{g}/\text{kg}$)

Country	ES	Lower	Upper	Weight (%)	Heterogeneity statistic	Degrees of freedom	P value	I ² (%)
Austria	589.968	2.354	1217.157	4.34	8914.82	1	< 0.001	100.00
Bosnia	60.000	53.556	66.444	2.23	0.00	0		
Brazil	34.913	2.478	103.251	5.80	256.51	1	< 0.001	99.60
Ethiopia	2686.563	2464.899	2908.227	20.99	4,300,000.00	10	< 0.001	100.00
France	865.526	738.133	992.919	1.20	75.70	1	< 0.001	98.70
Germany	308.238	257.686	358.790	17.02	5516.66	5	< 0.001	99.90
Greece	110.000	106.778	113.222	3.41	0.00	0		
Hawaii	221.329	140.513	302.144	0.48	56.44	4	< 0.001	92.90
Italy	419.919	291.202	548.637	13.43	16,640.50	4	< 0.001	100.00
Lebanon	66.000	63.256	68.744	3.59	0.00	0		
Netherlands	314.897	89.501	540.293	4.24	1003.74	1	< 0.001	99.90
Poland	428.061	1.654	863.858	2.41	333.91	2	< 0.001	99.40
Romania	0.102	0.047	0.156	12.72	815.60	5	< 0.001	99.40
Slovenia	124.982	56.383	193.581	7.50	1693.64	1	< 0.001	99.90
Turkey	140.000	123.831	156.169	0.64	0.00	0		
Overall	447.106	445.695	448.518	100.00	4,800,000.00	49	< 0.001	100.00

ES effect size (mean of concentration)

limits established for Co concentration in coffee products. However, there is an MPL of 10 $\mu\text{g}/\text{kg}$ for this element in tea (Yaqub et al. 2018). Our results revealed that Co concentration in coffee samples of all countries is above this limit (except Romania), representing possible health risks to the population through coffee consumption.

Concentration of Cd

Cd is the most toxic PTE (Gogoasa et al. 2013; Voica et al. 2016). Research has not revealed any positive impacts of Cd on human and animal health (Alkherraz et al. 2019), while they could be exposed to Cd through food and water consumption or work conditions. This element could accumulate a high amount in the human organs during lifespan. It is detrimental to kidney function and could raise bone demineralization, even at low concentrations. Cd also could cause lung cancer with long-term exposure (Alkherraz et al. 2019). Given its water solubility trait, Cd could be released and spread quickly to the environment through natural rock weathering, agricultural practices, and industrial activities, including batteries, refining ores, metal alloys, and plastic, dye, ceramic, and glass production. This element is also present in phosphate manures and pesticides at small levels and subsequently could be taken up by plants from treated soils with such compounds (Alkherraz et al. 2019).

The rank order of countries based on the concentration of Cd in the coffee products was Indonesia (300.000 $\mu\text{g}/\text{kg}$) > Brazil (61.541 $\mu\text{g}/\text{kg}$) > Honduras (50.000 $\mu\text{g}/\text{kg}$) > India (40.000 $\mu\text{g}/\text{kg}$) > Colombia (25.010 $\mu\text{g}/\text{kg}$)

> Poland (13.000 $\mu\text{g}/\text{kg}$) > Kenya (10.200 $\mu\text{g}/\text{kg}$) > Netherlands (5.041 $\mu\text{g}/\text{kg}$) > Italy (1.160 $\mu\text{g}/\text{kg}$) > Germany (0.676 $\mu\text{g}/\text{kg}$) > Ethiopia (0.183 $\mu\text{g}/\text{kg}$) > Austria (0.100 $\mu\text{g}/\text{kg}$) ~ France (0.100 $\mu\text{g}/\text{kg}$) ~ Greece (0.100 $\mu\text{g}/\text{kg}$) ~ Jamaica (0.100 $\mu\text{g}/\text{kg}$) ~ Lebanon (0.100 $\mu\text{g}/\text{kg}$) ~ Malawi (0.100 $\mu\text{g}/\text{kg}$) ~ Pakistan (0.100 $\mu\text{g}/\text{kg}$) (Table 6).

The MPL for Cd set by the European Union (EU) is 100 $\mu\text{g}/\text{kg}$ in coffee products (da Silva et al. 2017). The results showed that the pooled concentration of Cd in coffee products of all studied countries meets the regulation limit except Indonesia.

To this end, geographical location in waste zones and industrial units that release Cd to the environment are critical in Cd concentration in food products. In this regard, synthetic fertilizers in farming sections, contaminated water, and agricultural fields with Cd could increase human exposure to this toxic element through food consumption (Fu and Xi 2020; Hocaoglu-Özyiğit and Genç 2020).

Concentration of Pb

Pb, another highly toxic element, could accumulate in the body (Gogoasa et al. 2013). It is a non-essential metal for living things (Wadhwa et al. 2014). Pb is present everywhere in the environment (Lee et al. 2020). Plants like coffee beans could easily absorb Pb from the soil, water, and air (Lee et al. 2020). The significant harmful effects of these PTEs on human and animal health are carcinogenicity, neurotoxicity, hepatotoxicity, endocrine toxicity, reproductive and developmental toxicity, cardiovascular diseases, and gastrointestinal

Table 6 Meta-analysis concentration of Cd in the coffee products ($\mu\text{g}/\text{kg}$)

Country	ES	Lower	Upper	Weight (%)	Heterogeneity statistic	Degrees of freedom	P value	I ² (%)
Austria	0.100	0.098	0.102	7.28	0.00	1	1	0.00
Brazil	61.541	45.578	77.503	0.26	3208.74	7	<0.001	99.80
Colombia	25.010	3.658	73.714	3.64	622.50	1	<0.001	99.80
Ethiopia	0.183	0.158	0.207	42.52	2660.06	13	<0.001	99.50
France	0.100	0.098	0.102	7.28	0.00	1	1	0.00
Germany	0.676	0.593	0.759	9.01	1743.32	5	<0.001	99.70
Greece	0.100	0.097	0.103	3.64	0.00	0		
Honduras	50.000	48.544	51.456	0.03	0.00	1	1	0.00
India	40.000	36.494	43.506	0.00	0.00	1	1	0.00
Indonesia	300.000	255.679	344.321	0.00	0.00	0		
Italy	1.160	0.982	1.339	7.61	7633.71	4	<0.001	99.90
Jamaica	0.100	0.096	0.104	3.64	0.00	0		
Kenya	10.000	9.649	10.351	0.44	0.00	1	1	0.00
Lebanon	0.100	0.094	0.106	3.64	0.00	0		
Malawi	0.100	0.096	0.104	3.64	0.00	0		
Netherlands	5.041	2.647	14.739	3.73	580.20	1	<0.001	99.80
Pakistan	0.100	0.091	0.109	3.63	0.00	0		
Poland	13.000	10.581	15.419	0.01	0.00	0		
Overall	0.308	0.284	0.332	100.00	25,346.57	53	<0.001	99.80

ES effect size (mean of concentration)

and hepatic disorders (da Silva et al. 2017; Pigozzi et al. 2018).

The rank order of countries based on the concentration of Pd in the coffee products was Indonesia (3900.000 $\mu\text{g}/\text{kg}$) > Syria (2492.013 $\mu\text{g}/\text{kg}$) > Egypt (1900.000 $\mu\text{g}/\text{kg}$) > Bosnia (1050.000 $\mu\text{g}/\text{kg}$) > Lebanon (693.000 $\mu\text{g}/\text{kg}$) > Austria (350.000 $\mu\text{g}/\text{kg}$) > Netherland (274.986 $\mu\text{g}/\text{kg}$) > Italy (221.898 $\mu\text{g}/\text{kg}$) > Brazil (203.618 $\mu\text{g}/\text{kg}$) > Greece (200.000 $\mu\text{g}/\text{kg}$) > Germany (183.279 $\mu\text{g}/\text{kg}$) > Turkey (120.000 $\mu\text{g}/\text{kg}$) > India (92.630 $\mu\text{g}/\text{kg}$) > Slovenia (74.000 $\mu\text{g}/\text{kg}$) > Poland (60.934 $\mu\text{g}/\text{kg}$) > France (23.829 $\mu\text{g}/\text{kg}$) > Pakistan (20.000 $\mu\text{g}/\text{kg}$) > Honduras (15.039 $\mu\text{g}/\text{kg}$) > Colombia (13.48 $\mu\text{g}/\text{kg}$) > Kenya (9.949 $\mu\text{g}/\text{kg}$) > Hawaii (8.895 $\mu\text{g}/\text{kg}$) > Romania (0.459 $\mu\text{g}/\text{kg}$) > South Korea (0.240 $\mu\text{g}/\text{kg}$) > Western Balkan (0.137 $\mu\text{g}/\text{kg}$) > Ethiopia (0.104 $\mu\text{g}/\text{kg}$) (Table 7).

Polish food legislation, Brazilian legislation, and the EU have set the MPLs for Pb in coffee products as 1000 $\mu\text{g}/\text{kg}$, 500 $\mu\text{g}/\text{kg}$, and 200 $\mu\text{g}/\text{kg}$, respectively (Albals et al. 2021; Azam et al. 2021; Jeszka-Skowron et al. 2016). It could be concluded that the investigated coffees of all countries are not dangerous to human health except for Indonesia, Syria, Egypt, and Bosnia. However, using Brazil and EU safe limits, one country (Lebanon) and 5 other countries (Lebanon, Austria, Netherland, Italy, Brazil, and Greece) do not meet these regulation limits, respectively.

As observed previously, there are high differences between pooled concentrations of all PTEs in coffee products of different countries. Different factors are influential in these differences, which are discussed in the following.

First of all, coffee characteristics include variety, species (Arabica or Robusta), ripeness, type (brand/raw or roasted/ground or instant/infusion or powder), size, and processing conditions such as grinding, drying, roasting, mixing, and brewing methods which are effective in the observed difference in the content of PTEs in coffee products in different countries (Albals et al. 2021; Gure et al. 2017). Furthermore, the origin of the coffee regarding environmental conditions, including soil properties (type of soil, organic matter concentration, pH, drainage grade), geographical location (climate condition), and agricultural practices (using fertilizers and pesticides, organic or conventional farming), has a crucial impact on the content of PTEs in coffee beans (da Silva et al. 2017; Habte et al. 2016).

It is worth noting that both PTEs' gains and losses may occur during coffee processing which can be another source of observed differences in their concentration in different countries. The type of water used for infusion is also effective (Ashu and Chandravanshi 2011). In the case of the type of coffee products, it is reported that mixtures of coffee substitutes or surrogates (cereal grains) with coffee (20–66%) intermediate exhibit contents. At the same time,

Table 7 Meta-analysis concentration of Pb in the coffee products ($\mu\text{g}/\text{kg}$)

Country	ES	Lower	Upper	Weight (%)	Heterogeneity statistic	Degrees of freedom	P value	I^2 (%)
Austria	350.000	310.801	389.199	0.19	74.00	1	< 0.001	98.60
Bosnia	1050.000	919.991	1180.009	0.00	0.00	0		
Brazil	203.618	199.095	208.142	4.41	2,700,000.00	11	< 0.001	100.00
Colombia	13.488	2.091	24.886	3.46	853.99	5	< 0.001	99.40
Egypt	1900.000	1896.422	1903.578	0.28	0.00	0		
Ethiopia	0.104	0.084	0.123	23.89	2152.79	12	< 0.001	99.40
France	23.829	22.977	24.681	4.94	23,091.15	3	< 0.001	100.00
Germany	183.279	117.326	249.233	3.94	41,156.25	5	< 0.001	100.00
Greece	200.000	196.778	203.222	0.33	0.00	0		
Hawaii	8.895	3.437	14.352	0.46	7.36	4	0.118	45.70
Honduras	15.039	3.457	44.322	2.85	1396.88	1	< 0.001	99.90
India	92.630	46.659	138.602	2.19	575.47	3	< 0.001	99.50
Indonesia	3900.000	3323.822	4476.178	0.00	0.00	0		
Italy	221.898	125.044	318.752	2.39	24,069.10	4	< 0.001	100.00
Kenya	9.949	3.546	29.371	2.19	99.00	1	< 0.001	99.00
Lebanon	693.000	681.772	704.228	0.03	0.00	0		
Netherlands	274.986	4.560	617.980	0.80	10,395.51	1	< 0.001	100.00
Pakistan	20.000	9.265	30.735	0.04	0.00	0		
Poland	60.934	38.272	83.597	3.04	1529.02	3	< 0.001	99.80
Romania	0.459	0.338	0.579	10.41	11,222.07	6	< 0.001	99.90
Slovenia	70.000	69.089	70.911	2.19	0.00	1	1	0.00
South Korea	0.240	0.198	0.282	1.95	0.00	0		
Syria	2492.013	2231.473	2752.552	0.00	0.56	1	0.453	0.00
Turkey	120.000	103.026	136.974	0.01	0.00	0		
Western Balkan	0.137	0.116	0.158	30.01	4431.90	18	< 0.001	99.60
Overall	21.027	20.824	21.231	100.00	4,100,000.00	104	< 0.001	100.00

ES effect size (mean of concentration)

lower amounts determined in coffee surrogates without coffee addition (Oliveira et al. 2012).

In the case of the brewing method, it is reported that the extraction levels of most PTEs are highest in the Turkish coffee method in which coffee is boiled together with water (Neđzarek et al. 2013; Şemen et al. 2017). Regarding the type of coffee in terms of raw or roasted, it is noteworthy that the concentrations of PTEs in green coffee are typically lower than those determined in roasted coffees, probably due to moving water and volatile constituents (Amorim Filho et al. 2007; da Silva et al. 2017). Moreover, Şemen et al. (2017) concluded that studied PTEs are leached to the infusion more difficult from roasted coffee than from green coffee. Ashu and Chandravanshi (2011) also observed that the infusions contain lower PTEs than the roasted coffee. Moreover, Welna et al. (2013) noted that the transfer degree of PTEs into brew might vary probably related to coffee type (instant and ground coffees). Amorim Filho et al. (2007) also observed that the concentration of Fe and Cr is highest in steel grinders because of releasing these metals into

the coffee samples via the mill overheating. Additionally, Neđzarek et al. (2013) reported that potential contamination with PTEs may originate from packaging materials containing metals during coffee storage. There is also a negative relationship between the size of the coffee powder and the extraction rate of PTEs into the infusion (Pigozzi et al. 2018).

Moreover, Ashu and Chandravanshi (2011) report that the concentration of PTEs in coffee varies among coffee varieties cultivated in diverse parts of the world with different environments, soil, and fertilizers.

Further, differences in sampling, sample preparation, and analytical techniques used in different studies significantly impact the concentration of PTEs (Ashu and Chandravanshi 2011). The contents of PTEs in the ground coffee are different from those in instant (soluble) coffee, probably due to processing differences (Vo et al. 2016). There are different kinds of methods used for the determination of PTEs in coffee products, including atomic absorption spectrometry (AAS), inductively coupled plasma-optical emission

spectrometry (ICP-OES), inductively coupled plasma-mass spectrometry (ICP-MS), atomic fluorescence spectrometry (AFS), and electrodes. Among these methods, ICP-OES and ICP-MS are the most remarkably applied because of their high sensitivity, specificity, selectivity, low detection limits (LODs), ease of setup, less time, and low cost (Albals et al. 2021; Alkheraz et al. 2019). However, to overcome the disadvantages of AFS methods, the pre-concentration methods could be utilized during sample preparation, including solid-phase extraction (SPE), liquid–liquid extraction (LLE), as well as microextraction procedures like dispersive liquid–liquid microextraction (DLLME) (Şaylan et al. 2020).

Conclusion

This study meta-analyzed the prevalence of potentially toxic elements in coffee products in different countries. The pooled mean concentration of essential elements in coffee products is much higher than that of toxic elements (Co > Ni > Cu > Cr > Pb > As > Cd). The result showed that the pooled mean concentration of essential elements in coffee products is much higher than that of toxic elements. Also, high differences between pooled concentrations of all PTEs were reported in coffee products of different countries. Various concentrations of potentially toxic elements in different studies may be due to several factors, including environmental growth conditions (climate, temperature, and agricultural practices), type of processing, coffee variety, preparation method, agricultural practices (using fertilizers and pesticides, organic or conventional farming), and analytical techniques. Therefore, more studies are needed to investigate the effect of mentioned factors on the prevalence of PTEs in coffee products in the future.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s11356-022-23110-9>.

Author contribution Tahar Mahmudiono, Fardin Javanmardi, and Behrouz Tajdar-oranj: investigation, data curation, resources, conceptualization, methodology, and writing of original draft. Amene Nematollahi and Mohadeseh Pirhadi: literature searching, writing, and editing. Amin Mousavi Khaneghah and Yadollah Fakhri: supervision, conceptualization, data analysis, and review and editing.

Data availability Not applicable.

Declarations

Ethics approval and consent to participate Ethics approval is not applicable. The authors declare their consent to participate in this article.

Consent for publication The authors declare their consent for publication of this article.

Competing interests The authors declare no competing interests.

References

- Achmad RT, Auerkari EI (2017) Effects of chromium on human body. *Ann Res Rev Biol* 13:1–8
- Albals D, Al-Momani IF, Issa R, Yehya A (2021) Multi-element determination of essential and toxic metals in green and roasted coffee beans: a comparative study among different origins using ICP-MS. *Sci Prog* 104:003685042111026162
- Alkheraz A, Hashad O, Elsherif K (2019) Heavy metals contents in some commercially available coffee, tea, and cocoa samples in Misurata City -Libya. *Prog Chem Biochem Res* 2:99–107
- Ameri Z, Hoodaji M, Rajaie M, Ataabadi M (2021) Optimizing modified rice bran for treating aqueous solutions polluted by Cr (VI) ions: isotherm and kinetics analyses. *Qual Assur Saf Crops Foods* 13:1–11
- Amorim Filho VR, Polito WL, Gomes Neto JA (2007) Comparative studies of the sample decomposition of green and roasted coffee for determination of nutrients and data exploratory analysis. *J Braz Chem Soc* 18:47–53
- Anosike S, Oranusi S (2018) Assessment of microbiological and chemical qualities of selected cocoa, tea and coffee brands in Nigerian markets. *Afr J Clin Exp Microbiol* 19:186–194
- Ashu R, Chandravanshi BS (2011) Concentration levels of metals in commercially available Ethiopian roasted coffee powders and their infusions. *Bull Chem Soc Ethiopia*. <https://doi.org/10.4314/bcse.v25i1.63356>
- Atamaleki A, Sadani M, Raoofi A, Miri A, Bajestani SG, Fakhri Y, Heidarinejad Z, Khaneghah AM (2020) The concentration of potentially toxic elements (PTEs) in eggs: a global systematic review, meta-analysis and probabilistic health risk assessment. *Trends Food Sci Technol* 95:1–9
- Azam K, Akhtar S, Gong YY, Routledge MN, Ismail A, Oliveira CA, Iqbal SZ, Ali H (2021) Evaluation of the impact of activated carbon-based filtration system on the concentration of aflatoxins and selected heavy metals in roasted coffee. *Food Control* 121:107583
- Barbosa RM, Batista BL, Varrique RM, Coelho VA, Campiglia AD, Barbosa F Jr (2014) The use of advanced chemometric techniques and trace element levels for controlling the authenticity of organic coffee. *Food Res Int* 61:246–251
- Barrea L, Pugliese G, Frias-Toral E, El Ghoch M, Castellucci B, Chapela SP, Carignano MdlA, Laudisio D, Savastano S, Colao A (2021) Coffee consumption, health benefits and side effects: a narrative review and update for dietitians and nutritionists. *Crit Rev Food Sci Nutr* 1–24
- Batrinou A, Houhoula D, Papageorgiou E (2020) Rapid detection of mycotoxins on foods and beverages with enzyme-linked immunosorbent assay. *Qual Assur Saf Crops Foods* 12:40–49
- Berman N, Honig S, Cronstein B, Pillinger M (2022) The effects of caffeine on bone mineral density and fracture risk. *Osteoporos Int* 33:1235–1241
- Bost M, Houdart S, Oberli M, Kalonji E, Huneau J-F, Margaritis I (2016) Dietary copper and human health: current evidence and unresolved issues. *J Trace Elem Med Biol* 35:107–115
- Bounar A, Boukaka K, Leghouchi E (2020) Determination of heavy metals in tomatoes cultivated under green houses and human health risk assessment. *Qual Assur Saf Crops Foods* 12:76–86
- da Silva SA, Mendes F, Queiroz I, Reis MR, Passos FR, de Carvalho AMX, de Oliveira Rocha KR, Pinto FG (2017) Determination of heavy metals in the roasted and ground coffee beans and brew. *Afr J Agric Res* 12:221–228
- de Mejia EG, Ramirez-Mares MV (2014) Impact of caffeine and coffee on our health. *Trends Endocrinol Metab* 25:489–492

- Delgado Quezada V, Altamirano Espinoza M, Bundschuh J (2020) Arsenic in geoenvironments of Nicaragua: exposure, health effects, mitigation and future needs. *Sci Total Environ* 716:136527
- Dieng H, Ellias SB, Satho T, Ahmad AH, Abang F, Ghani IA, Noor S, Ahmad H, Zuharah WF, Morales Vargas RE (2017) Coffee, its roasted form, and their residues cause birth failure and shorten lifespan in dengue vectors. *Environ Sci Pollut Res* 24:14782–14794
- Escott-Stump S (2008) Nutrition and diagnosis-related care. *Lippincott Williams & Wilkins*
- Fu Z, Xi S (2020) The effects of heavy metals on human metabolism. *Toxicol Mech Methods* 30:167–176
- Gao L, Huang X, Wang P, Chen Z, Hao Q, Bai S, Tang S, Li C, Qin D (2022) Concentrations and health risk assessment of 24 residual heavy metals in Chinese mitten crab (*Eriocheir sinensis*). *Qual Assur Saf Crops Foods* 14:82–91
- Genchi G, Carocci A, Lauria G, Sinicropi MS, Catalano A (2020) Nickel: human health and environmental toxicology. *Int J Environ Res Public Health* 17:679
- Godos J, Pluchinotta FR, Marventano S, Buscemi S, Li Volti G, Galvano F, Grosso G (2014) Coffee components and cardiovascular risk: beneficial and detrimental effects. *Int J Food Sci Nutr* 65:925–936
- Gogoasa I, Pirvu A, Alda L, Velciov A, Rada M, Bordean D, Moigradean D, Simion A, Gergen I (2013) The mineral content of different coffee brands. *J Hortic For Biotechnol* 17:68–71
- Gogoasa I, Adina B, Adina N, Maria R, Antoanela C, Liana A (2017) Determination of trace elements in commercially available instant coffees. *J Hortic For Biotechnol* 21:1–5
- Guan Q, Zeng G, Song J, Liu C, Wang Z, Wu S (2021) Ultrasonic power combined with seed materials for recovery of phosphorus from swine wastewater via struvite crystallization process. *J Environ Manage* 293:112961
- Gure A, Chandravanshi BS, Godeto TW (2017) Metals in green coffee beans from major coffee-growing regions of Ethiopia. *Chem Int* 3:359–369
- Habte G, Hwang IM, Kim JS, Hong JH, Hong YS, Choi JY, Nho EY, Jamila N, Khan N, Kim KS (2016) Elemental profiling and geographical differentiation of Ethiopian coffee samples through inductively coupled plasma-optical emission spectroscopy (ICP-OES), ICP-mass spectrometry (ICP-MS) and direct mercury analyzer (DMA). *Food Chem* 212:512–520
- Heshmati A, Mehri F, Karami-Momtaz J, Khaneghah AM (2020) The concentration and health risk of potentially toxic elements in black and green tea—both bagged and loose-leaf. *Qual Assur Saf Crops Foods* 12:140–150
- Higgins JPT, Thompson SG (2002) Quantifying heterogeneity in a meta-analysis. *Stat Med* 21:1539–1558
- Higgins J, White IR, Anzueto-Cabrera J (2008) Meta-analysis of skewed data: combining results reported on log-transformed or raw scales. *Stat Med* 27:6072–6092
- Hocaoğlu-Özyiğit A, Genç BN (2020) Cadmium in plants, humans and the environment. *Front Life Sci Relat Technol* 1:12–21
- Hu L, Wang X, Zou Y, Wu D, Gao G, Zhong Z, Liu Y, Hu S, Fan H, Zhang B (2022) Effects of inorganic and organic selenium intervention on resistance of radish to arsenic stress. *Ital J Food Sci* 34:44–58
- Ibrahim S, Hassan M, Ibraheem Q, Arif K (2020) Genotoxic effect of lead and cadmium on workers at wastewater plant in Iraq. *J Environ Public Health* 20:1–9
- Jeszka-Skowron M, Stanisz E, De Peña MP (2016) Relationship between antioxidant capacity, chlorogenic acids and elemental composition of green coffee. *LWT* 73:243–250
- Kalita J, Kumar V, Misra UK, Bora HK (2019) Movement disorder in copper toxicity rat model: role of inflammation and apoptosis in the corpus striatum. *Neurotox Res* 37:904–912
- Khan KM, Chakraborty R, Bundschuh J, Bhattacharya P, Parvez F (2020) Health effects of arsenic exposure in Latin America: an overview of the past eight years of research. *Sci Total Environ* 710:136071
- Khaneghah AM, Fakhri Y, Abdi L, Coppa CFSC, Franco LT, de Oliveira CAF (2019) The concentration and prevalence of ochratoxin A in coffee and coffee-based products: a global systematic review, meta-analysis and meta-regression. *Fungal Biol* 123:611–617
- Khaneghah AM, Fakhri Y, Nematollahi A, Pirhadi M (2020) Potentially toxic elements (PTEs) in cereal-based foods: a systematic review and meta-analysis. *Trends Food Sci Technol* 96:30–44
- Lee J-G, Hwang J-Y, Lee H-E, Choi J-D, Kang G-J (2020) Comparative analysis of lead content during food processing. *Food Sci Biotechnol* 29:1063–1069
- Li W, Shi Y, Zhu D, Wang W, Liu H, Li J, Shi N, Ma L, Fu S (2021) Fine root biomass and morphology in a temperate forest are influenced more by the nitrogen treatment approach than the rate. *Ecol Ind* 130:108031
- Lin X, Lu K, Hardison AK, Liu Z, Xu X, Gao D, Gong J, Gardner WS (2021) Membrane inlet mass spectrometry method (REOX/MIMS) to measure 15N-nitrate in isotope-enrichment experiments. *Ecol Ind* 126:107639
- Liu W, Huang F, Wang Y, Zou T, Zheng J, Lin Z (2011) Recycling Mg(OH)₂ nanoadsorbent during treating the low concentration of Cr^{VI}. *Environ Sci Technol* 45:1955–1961
- Liu W, Li J, Zheng J, Song Y, Shi Z, Lin Z, Chai L (2020) Different pathways for Cr(III) oxidation: implications for Cr(VI) reoccurrence in reduced chromite ore processing residue. *Environ Sci Technol* 54:11971–11979
- Liu G, Nie R, Liu Y, Mehmood A (2022) Combined antimicrobial effect of bacteriocins with other hurdles of physicochemical and microbiome to prolong shelf life of food: a review. *Sci Total Environ* 825:154058
- Martineli L, da Silva Berilli S, Amaro de Sales R, da Cunha M, Monaco PAVL, de Jesus Freitas S, Martineli M, Gabriel Berilli APC, Pireda S, da Silva Oliveira D (2022) Influence of chromium and sodium on development, physiology, and anatomy of Conilon coffee seedlings. *Environ Sci Pollut Res* 29:44986–44997
- Mirmahdi RS, Zoghi A, Mohammadi F, Khosravi-Darani K, Jazaieri S, Mohammadi R, Rehman Y (2021) Biodecontamination of milk and dairy products by probiotics: boon for bane. *Ital J Food Sci* 33:78–91
- Mirmahdi RS, Mofid V, Zoghi A, Khosravi_Darani K, Mortazavian AM (2022) Risk of low stability *Saccharomyces cerevisiae* ATCC 9763-heavy metals complex in gastrointestinal simulated conditions. *Heliyon* 8:e09452
- Moher D, Liberati A, Tetzlaff J, Altman DG, Group P (2010) Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Int J Surg* 8:336–341
- Nartea A, Lucci P, Loizzo MR, Tundis R, Leporini M, Gervasi L, Fanesi B, Núñez O, Frega NG, Fiorini D (2022) Is coffee powder extract a possible functional ingredient useful in food and nutraceutical industries? *Ital J Food Sci* 34:140–148
- Ńędzarek A, Tórz A, Karakiewicz B, Clark JS, Laszczyńska M, Kaleta A, Adler G (2013) Concentrations of heavy metals (Mn, Co, Ni, Cr, Ag, Pb) in coffee. *Acta Biochim Pol* 60:623–627
- Nourbakhsh F, Tajbakhsh E (2021) Neurotoxicity mechanism of ochratoxin A. *Qual Assur Saf Crops Foods* 13:34–45
- Oliveira M, Casal S, Morais S, Alves C, Dias F, Ramos S, Mendes E, Delerue-Matos C, Oliveira MBP (2012) Intra- and interspecific mineral composition variability of commercial instant coffees and coffee substitutes: contribution to mineral intake. *Food Chem* 130:702–709

- Pavithra V (2021) Review article on caffeine activity. *J Nanotechnol Res* 3:1–5
- Petrović SM, Savić SR, Zvezdanović JB, Mladenović-Ranisavljević I, Cvetković DJ, Cvetanović AD (2020) Benefits and risks of commercially available coffee beverages from Western Balkan. *Chem Pap* 74:847–857
- Pigozzi MT, Passos FR, Mendes FQ (2018) Quality of commercial coffees: heavy metal and ash contents. *J Food Qual* 18:1–8
- Pohl P, Stelmach E, Szymczycha-Madeja A (2014) Simplified sample treatment for the determination of total concentrations and chemical fractionation forms of Ca, Fe, Mg and Mn in soluble coffees. *Food Chem* 163:31–36
- Pullella K, Kotsopoulos J (2020) Arsenic exposure and breast cancer risk: a re-evaluation of the literature. *Nutrients* 12:3305
- Quan H, Zhang J (2003) Estimate of standard deviation for a log-transformed variable using arithmetic means and standard deviations. *Stat Med* 22:2723–2736
- Quan Q, Gao S, Shang Y, Wang B (2021) Assessment of the sustainability of *Gymnocypripis eckloni* habitat under river damming in the source region of the Yellow River. *Sci Total Environ* 778:146312
- Rattan S, Parande AK, Nagaraju VD, Ghiwari GK (2015) A comprehensive review on utilization of wastewater from coffee processing. *Environ Sci Pollut Res* 22:6461–6472
- Samet M, Charfeddine M, Kamoun L, Nouri-Ellouze O, Gargouri-Bouid R (2018) Effect of compost tea containing phosphogypsum on potato plant growth and protection against *Fusarium solani* infection. *Environ Sci Pollut Res* 25:18921–18937
- Şaylan M, Zaman BT, Bakırdere EG, Bakırdere S (2020) Determination of trace nickel in chamomile tea and coffee samples by slotted quartz tube-flame atomic absorption spectrometry after preconcentration with dispersive liquid-liquid microextraction method using a Schiff base ligand. *J Food Compos Anal* 88:103454
- Şemen S, Mercan S, Yayla M, Açıkkol M (2017) Elemental composition of green coffee and its contribution to dietary intake. *Food Chem* 215:92–100
- Senkondo YH, Tack F, Semu E (2014) Copper accumulations in soils, coffee, banana, and bean plants following copper-based fungicides in coffee farms in Arusha and Kilimanjaro regions, Tanzania. *Commun Soil Sci Plant Anal* 45:2032–2045
- Shi C, Wu Z, Yang F, Tang Y (2021) Janus particles with pH switchable properties for high-efficiency adsorption of PPCPs in water. *Solid State Sci* 119:106702
- Sun Y, Li J, Zhu L, Jiang L (2022) Cooperation and competition between CRISPR-and omics-based technologies in foodborne pathogens detection: a state of the art review. *Curr Opin Food Sci* 44:100813
- Teklay A (2016) Physiological effect of chromium exposure: a review. *Int J Food Sci Nutr Diet* 7:1–11
- Tiep TD (2014) Effect of roasting conditions on concentration in elements of Vietnam robusta coffee. *Acta Univ Cibiniesis E Food Technol* 18:19–34
- van Dam RM, Hu FB, Willett WC (2020) Coffee, caffeine, and health. *N Engl J Med* 383:369–378
- Voica C, Feher I, Iordache A, Cristea G, Dehelean A, Magdas D, Mirel V (2016) Multielemental analysis of coffee by inductively coupled plasma-mass spectrometry. *Anal Lett* 49:2627–2643
- Wadhwa SK, Tuzen M, Kazi TG, Soyak M, Hazer B (2014) Polyhydroxybutyrate-b-polyethyleneglycol block copolymer for the solid phase extraction of lead and copper in water, baby foods, tea and coffee samples. *Food Chem* 152:75–80
- Wang Y, Wu X, Liu J, Zhai Z, Yang Z, Xia J, Deng S, Qu X, Zhang H, Wu D (2022) Mo-modified band structure and enhanced photocatalytic properties of tin oxide quantum dots for visible-light driven degradation of antibiotic contaminants. *J Environ Chem Eng* 10:107091
- Welna M, Szymczycha-Madeja A, Zyrnicki W (2013) Applicability of ICP-OES, UV-VIS, and FT-IR methods for the analysis of coffee products. *Anal Lett* 46:2927–2940
- Winiarska-Mieczan A, Kwiatkowska K, Kwiecień M, Zaricka E (2021) Assessment of the risk of exposure to cadmium and lead as a result of the consumption of coffee infusions. *Biol Trace Elem Res* 199:2420–2428
- Wolde T (2014) Effects of caffeine on health and nutrition: a review. *Food Sci Qual Manag* 30:59–65
- World Health Organization (2000) Evaluation of certain food additives and contaminants: fifty-third report of the Joint FAO/WHO Expert Committee on Food Additives. World Health Organization, Geneva
- Yaqub G, Ilyas F, Idrees M, Mariyam V (2018) Monitoring and risk assessment due to presence of heavy metals and pesticides in tea samples. *Food Sci Technol* 38:625–628
- Yazdanpanah S, Jokar S, Zandilak T, Haghighi M (2022) Evaluation and comparison of ochratoxin a contamination and metallic elements lead and arsenic in commercial instant coffee powders. *Iran Food Sci Technol Res J* 18:81–95
- Zoroddu MA, Aaseth J, Crisponi G, Medici S, Peana M, Nurchi VM (2019) The essential metals for humans: a brief overview. *J Inorg Biochem* 195:120–129

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

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

The concentration of potentially toxic elements (PTEs) in the coffee products: a systematic review and meta-analysis

ORIGINALITY REPORT

19%

SIMILARITY INDEX

13%

INTERNET SOURCES

16%

PUBLICATIONS

4%

STUDENT PAPERS

PRIMARY SOURCES

1	medworm.com Internet Source	1%
2	Yadolah Fakhri, Sharaf S. Omar, Fereshteh Mehri, Somayeh Hoseinvandtabar, Trias Mahmudiono. "Global systematic review and meta-analysis on prevalence and concentration of aflatoxins in peanuts oil and probabilistic risk assessment", <i>Reviews on Environmental Health</i> , 2022 Publication	1%
3	Submitted to University of Utah Student Paper	1%
4	Martin Weidenbörner. "Mycotoxins in Plants and Plant Products", Springer Science and Business Media LLC, 2017 Publication	1%
5	www.frontiersin.org Internet Source	1%

6

Amin Mousavi Khaneghah, Yadolah Fakhri, Leili Abdi, Carolina Fernanda Sengling Cebin Coppa et al. "The concentration and prevalence of ochratoxin A in coffee and coffee-based products: A global systematic review, meta-analysis and meta-regression", *Fungal Biology*, 2019

Publication

1 %

7

www.garj.org

Internet Source

1 %

8

Shima Khanverdilu, Elaheh Talebi-Ghane, Akram Ranjbar, Fereshteh Mehri. "Content of potentially toxic elements (PTEs) in various animal meats: a meta-analysis study, systematic review, and health risk assessment", *Environmental Science and Pollution Research*, 2022

Publication

1 %

9

Ahmad Farhadi, Yadolah Fakhri, Reza Kachuei, Yasser Vasseghian, Elcin Huseyn, Amin Mousavi Khaneghah. "Prevalence and concentration of fumonisins in cereal-based foods: a global systematic review and meta-analysis study", *Environmental Science and Pollution Research*, 2021

Publication

1 %

10

Ravi Pandiselvam, Rathnakumar Kaavya, Anandu Chandra Khanashyam, Valarivan

< 1 %

Divya et al. "Research trends and emerging physical processing technologies in mitigation of pesticide residues on various food products", Environmental Science and Pollution Research, 2022

Publication

11

acikerisim.istinye.edu.tr

Internet Source

<1 %

12

jfsh.tums.ac.ir

Internet Source

<1 %

13

Amin Mohammadpour, Zahra Emadi, Mohammad Reza Samaei, Khaiwal Ravindra et al. "The concentration of potentially toxic elements (PTEs) in drinking water from Shiraz, Iran: a health risk assessment of samples", Environmental Science and Pollution Research, 2022

Publication

<1 %

14

www.coursehero.com

Internet Source

<1 %

15

elearning.medistra.ac.id

Internet Source

<1 %

16

goums.ac.ir

Internet Source

<1 %

17

Mycotoxins in Foodstuffs, 2013.

Publication

<1 %

18	www.scilit.net Internet Source	<1 %
19	hero.epa.gov Internet Source	<1 %
20	De Girolamo, Annalisa, Salvatore Cervellieri, Angelo Visconti, and Michelangelo Pascale. "Rapid Analysis of Deoxynivalenol in Durum Wheat by FT-NIR Spectroscopy", Toxins, 2014. Publication	<1 %
21	pdfs.semanticscholar.org Internet Source	<1 %
22	www.pcbiochemres.com Internet Source	<1 %
23	www.mdpi.com Internet Source	<1 %
24	Ali Heshmati, Freshteh Mehri, Javad Karami-Momtaz, Amin Mousavi Khaneghah. "The concentration and health risk of potentially toxic elements in black and green tea—both bagged and loose-leaf", Quality Assurance and Safety of Crops & Foods, 2020 Publication	<1 %
25	rcastoragev2.blob.core.windows.net Internet Source	<1 %
26	assets.researchsquare.com Internet Source	<1 %

27	www.scielo.br Internet Source	<1 %
28	coek.info Internet Source	<1 %
29	<p>Angélica Vilas Boas da Frota, Breno Dias Vitorino, Josué Ribeiro da Silva Nunes, Carolina Joana da Silva. "An overview of the diet of the Great Black Hawk <i>Urubitinga urubitinga</i> (Accipitriformes: Accipitridae) and report of new prey species", <i>Ornithology Research</i>, 2021</p> Publication	<1 %
30	<p>Zahra Hashami, Negar Chabook, Fardin Javanmardi, Reza Mohammadi, Moein Bashiry, Amin Mousavi Khaneghah. "The concentration and prevalence of potentially toxic elements (PTEs) in cheese: a global systematic review and meta-analysis", <i>International Journal of Environmental Health Research</i>, 2022</p> Publication	<1 %
31	aarst.org Internet Source	<1 %
32	icn2013.com Internet Source	<1 %

33

Kwanele Kunene, Myalowenkosi Sabela, Suvadhan Kanchi, Mikhael Bechelany, Krishna Bisetty. " Functionalized Electrochemical Aptasensor for Sensing of Ochratoxin A in Cereals Supported by Adsorption Studies ", ACS Food Science & Technology, 2021

Publication

<1 %

34

Submitted to University of Sydney

Student Paper

<1 %

35

C. Voica, I. Feher, A. M. Iordache, G. Cristea, A. Dehelean, D. A. Magdas, V. Mirel.

"Multielemental Analysis of Coffee by Inductively Coupled Plasma-Mass Spectrometry", Analytical Letters, 2016

Publication

<1 %

36

Khadije Abdolmaleki, Fardin Javanmardi, Mohsen Gavahian, Yuthana Phimolsiripol et al. "Emerging technologies in combination with probiotics for aflatoxins removal: An updated review", International Journal of Food Science & Technology, 2022

Publication

<1 %

37

Yadolah Fakhri, Amene Nematollahi, Zohreh Abdi-Moghadam, Hasti Daraei, Seyed Mehdi Ghasemi, Van Nam Thai. "Concentration of Potentially Harmful Elements (PHEs) in Trout Fillet (Rainbow and Brown) Fish: a Global

<1 %

Systematic Review and Meta-analysis and Health Risk Assessment", Biological Trace Element Research, 2020

Publication

38

Amin Mohammadpour, Zahra Emadi, Mahsa Keshtkar, Leili Mohammadi et al. "Assessment of potentially toxic elements (PTEs) in fruits from Iranian market (Shiraz): A health risk assessment study", Journal of Food Composition and Analysis, 2022

Publication

<1 %

39

Khalid M. Khan, Rishika Chakraborty, Jochen Bundschuh, Prosun Bhattacharya, Faruque Parvez. "Health effects of arsenic exposure in Latin America: An overview of the past eight years of research", Science of The Total Environment, 2020

Publication

<1 %

40

biblio.ugent.be

Internet Source

<1 %

41

jast-journal.springeropen.com

Internet Source

<1 %

42

www.karger.com

Internet Source

<1 %

43

Seyed Ali Askarpour, Ebrahim Molaei-Aghaei, Maryam Ghaderi-Ghahfarokhi, Nabi Shariatifar et al. "Potentially Toxic Elements

<1 %

(PTEs) in Refined and Cold-Pressed Vegetable Oils Distributed in Ahvaz, Iran: a Probabilistic Health Risk Assessment", Biological Trace Element Research, 2022

Publication

44

journalarticle.ukm.my

Internet Source

<1 %

45

scidoc.org

Internet Source

<1 %

46

"Track 1 – Track 5", International Journal of Obesity, 05/2008

Publication

<1 %

47

Ali Atamaleki, Ahmadreza Yazdanbakhsh, Sevda Fallah, Mohsen Hesami, Aliasghar Neshat, Yadolah Fakhri. "Accumulation of potentially harmful elements (PHEs) in lettuce (*Lactuca sativa* L.) and coriander (*Coriandrum sativum* L.) irrigated with wastewater: a systematic review and meta-analysis and probabilistic health risk assessment", Environmental Science and Pollution Research, 2021

Publication

<1 %

48

Barbara Tomaszewska, Jochen Bundschuh, Leszek Pająk, Marta Dendys et al. "Use of low-enthalpy and waste geothermal energy sources to solve arsenic problems in freshwater production in selected regions of

<1 %

Latin America using a process membrane distillation – Research into model solutions", Science of The Total Environment, 2020

Publication

49

Mariola Samsonowicz, Ewa Regulska, Danuta Karpowicz, Barbara Leśniewska. "Antioxidant properties of coffee substitutes rich in polyphenols and minerals", Food Chemistry, 2018

Publication

<1 %

50

Meltem Şaylan, Buse Tuğba Zaman, Emine Gülhan Bakırdere, Sezgin Bakırdere. "Determination of trace nickel in chamomile tea and coffee samples by slotted quartz tube-flame atomic absorption spectrometry after preconcentration with dispersive liquid-liquid microextraction method using a Schiff base ligand", Journal of Food Composition and Analysis, 2020

Publication

<1 %

51

Yadolah Fakhri, Mehrnoush Abtahi, Ali Atamaleki, Amir Raoofi et al. "The concentration of potentially toxic elements (PTEs) in honey: A global systematic review and meta-analysis and risk assessment", Trends in Food Science & Technology, 2019

Publication

<1 %

52

[docshare.tips](https://www.docshare.tips)

Internet Source

<1 %

53

peerj.com

Internet Source

<1 %

54

Adriaan P. Ijzerman, Kenneth A. Jacobson, Christa E. Müller, Bruce N. Cronstein, Rodrigo A. Cunha. "International Union of Basic and Clinical Pharmacology. CXII: Adenosine Receptors: A Further Update", *Pharmacological Reviews*, 2022

Publication

<1 %

55

Ali Atamaleki, Mohsen Sadani, Amir Raoofi, Ali Miri et al. "The concentration of potentially toxic elements (PTEs) in eggs: A global systematic review, meta-analysis and probabilistic health risk assessment", *Trends in Food Science & Technology*, 2020

Publication

<1 %

56

Amin Mousavi Khaneghah, Ahmad Farhadi, Amene Nematollahi, Yasser Vasseghian, Yadolah Fakhri. "A systematic review and meta-analysis to investigate the concentration and prevalence of trichothecenes in the cereal-based food", *Trends in Food Science & Technology*, 2020

Publication

<1 %

57

Ghulam Mustafa Kamal, Maham Nadia Rehmani, Shahzad Zafar Iqbal, Jalal Uddin et al. "The determination of potentially toxic elements (PTEs) in milk from the Sothern Cities of Punjab, Pakistan: a health risk assessment study", Journal of Food Composition and Analysis, 2022

Publication

<1 %

58

Grzegorz Olszewski, Aleksandra Moniakowska, Dan Zhang, Dagmara Strumińska-Parulska. "On the radiotoxic ^{210}Po in coffee beans worldwide and the impact of roasting and brewing on its extraction into beverages: from the experiments to ^{210}Po content prediction", Environmental Science and Pollution Research, 2023

Publication

<1 %

59

J.N. Awoke, O.U. Orji, P.M. Aja, N.N. Ezeani, C. Alope, O.D. Obasi. "Ethanol leaf extract of *Ruspolia hypocrateriformis* abrogated hepatic redox imbalance and oxidative damage induced by heavy metal toxicity in rats", Arabian Journal of Chemistry, 2020

Publication

<1 %

60

Jianle Wang, Xueming Liu, Zhihua Zhu, Le Yuan, Dongye Zhao, Hong Deng, Zhang Lin. "Microwave-enhanced reductive

<1 %

immobilization of high concentrations of chromium in a field soil using iron polysulfide", Journal of Hazardous Materials, 2021

Publication

61

Jiayi Ma, Jinping Li, Hong He, Xiaoling Jin, Igor Cesarino, Wei Zeng, Zheng Li.

"Characterization of sensory properties of Yunnan coffee", Current Research in Food Science, 2022

Publication

62

Journal of Financial Economic Policy, Volume 5, Issue 2 (2013-05-27)

Publication

63

Samaila Saleh, Kamarudin Ahmad, Nor Zurairahetty Mohd Yunus, Muhammad Azril Hezmi. "Evaluating the toxicity of polyurethane during marine clay stabilisation", Environmental Science and Pollution Research, 2020

Publication

64

Vahideh Mahdavi, Hasti Gordan, Sara Ramezani, Amin Mousavi Khaneghah. "National probabilistic risk assessment of newly registered pesticides in agricultural products to propose maximum residue limit (MRL)", Environmental Science and Pollution Research, 2022

Publication

<1 %

<1 %

<1 %

<1 %

65

bradscholars.brad.ac.uk

Internet Source

<1 %

66

cyberleninka.org

Internet Source

<1 %

67

ebin.pub

Internet Source

<1 %

68

erepository.uonbi.ac.ke

Internet Source

<1 %

69

etd.aau.edu.et

Internet Source

<1 %

70

iris.unige.it

Internet Source

<1 %

71

ujcontent.uj.ac.za

Internet Source

<1 %

72

www.icb2018.com

Internet Source

<1 %

73

www.jesc.ac.cn

Internet Source

<1 %

74

www.locus.ufv.br

Internet Source

<1 %

75

www.qascf.com

Internet Source

<1 %

76

www.wjgnet.com

Internet Source

<1 %

77

Katarzyna Pytlakowska. "Preconcentration of Zn, Cu, and Ni Ions from Coffee Infusions via 8-Hydroxyquinoline Complexes on Graphene Prior to Energy Dispersive X-ray Fluorescence Spectrometry Determination", Applied Spectroscopy, 2016

Publication

<1 %

78

"Aflatoxins in Food", Springer Science and Business Media LLC, 2021

Publication

<1 %

79

"Fermentation Processes", Wiley, 2021

Publication

<1 %

80

Ewa Olechno, Anna Puścion-Jakubik, Katarzyna Socha, Małgorzata Elżbieta Zujko. "Coffee Infusions: Can They Be a Source of Microelements with Antioxidant Properties?", Antioxidants, 2021

Publication

<1 %

81

Yadolah Fakhri, Ali Atamaleki, Anvar Asadi, Seyed Mehdi Ghasemi, Amin Mousavi Khaneghah. " Bioaccumulation of potentially toxic elements (PTEs) in muscle spp fish: a systematic review, meta-analysis, and non-carcinogenic risk assessment ", Toxin Reviews, 2019

Publication

<1 %

Exclude quotes On

Exclude matches Off

Exclude bibliography On