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Research Article

Elemental Impurity Analysis in Five Different Types of Coffee: Assessment of Carcinogenic and Non-carcinogenic Risks

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ABSTRACT

In the study, the levels of Cd, Pb, As, and Hg elemental impurities potentially present in coffee bean samples from Indonesia, Kenya, Colombia, Guatemala, and Türkiye were determined using chromatographic analysis, and the analysis results were utilized to assess the risks on human health. The risk assessment of coffee was calculated for one or three servings per day for 365 days a year. Exposure to coffee consumption was calculated according to age groups of young adults and middle-aged adults (20-65 years). When Cd, Pb, As and Hg levels in coffee samples were analyzed, Cd in coffee samples was found to be in the range of approximately 3.70 - 5.89 µg/kg, Pb in the range of 25.68-41.11 µg/kg, As in the range of 1.45-6.64 µg/kg and Hg in the range of 1.06-5.06 µg/kg. Hazard Index (HI) values for all elements in the assessment of non-carcinogenic risks were found to be <1.0. When the cancer risk (CR) value was calculated for Cd, Pb, and As, it was found that the CR value did not exceed the United States Environmental Protection Agency (USEPA) criteria in all coffee samples in both scenarios. Considering the assessment of the health risks of elemental impurities in five different coffee bean samples, it was concluded that all samples' CR and HI values did not exceed the USEPA criteria.

1. Introduction

The spread of coffee worldwide gained momentum with its origins in Northeast Africa, then transitioned to the Middle East in the 15th century and subsequently to Europe. Coffee consumption has become a part of daily life on a global scale. The average annual consumption per capita in America and Europe is 5.1 kg/year [1]. The botanical family of coffee plants comprises approximately 500 genera and over 6000 species. The commercially most significant genus is Coffea (Rubiaceae family). Among the prominent species within this genus are Coffea arabica (Arabica) and Coffea canephora (Robusta) [2, 3].

However, all types of coffee have pharmacologically bioactive ingredients [4]. Coffee serves as a significant source of essential elements required daily, such as copper (Cu), manganese (Mn), magnesium (Mg), calcium (Ca), iron (Fe), potassium (K), phosphorus (P), and zinc (Zn). However, some heavy metals found in coffee, such as cadmium (Cd), lead (Pb), arsenic (As), and mercury (Hg), can be harmful to health [5]. The type and level of elements in plants are directly related to factors such as the geographical area where the plant grows, climate, altitude, soil properties, and crop cultivation methods [5, 6].

The accumulation of heavy metals in plants is also affected by these processes. Therefore, heavy metal levels in coffee content may vary depending on these factors. These heavy metals have the risk of being accumulated in coffee and reaching the consumer directly [6].

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Various guidelines exist for the risk assessment of metal toxicity in foods like coffee [7, 8]. These guidelines direct the assessment of heavy metal content to ensure food safety and protect consumer health. For instance, the U.S. Food and Drug Administration (USFDA) provides specific guidelines (USP <232>, USP <233>) for assessing metal content in foods [9]. These USFDA guidelines establish permissible levels of toxic elements in foods and provide food producers with appropriate testing methods and monitoring strategies.

The European Food Safety Authority (EFSA) also sets guidelines and standards for evaluating metal content in foods [8]. EFSA's guidelines rely on scientific data to identify risks of metal toxicity in foods and offer food producers suitable testing methods and monitoring strategies. These guidelines serve as fundamental sources used to assess metal toxicity in foods. Risk assessments conducted by these guidelines are crucial for ensuring consumers consume safe and healthy foods. Elemental impurities in foods are classified into specific categories based on their toxic effects and potential risks to human health. These classifications are often based on the type of element, its toxicity, and the routes of exposure to the human body.

Organizations like the USFDA and EFSA generally use three classes when determining the permissible maximum levels of metal elements in foods. Class 1: This class typically includes elements with the highest toxicity and pose the greatest risk to human health. Elements such as Cd, Pb, As, and Hg may be included in this category. Class 2: This class includes elements that pose a lower risk to human health. Class 3: This class generally includes elements with low risk to human health. These elements typically do not have any significant toxic effects on human health at typical levels of food-related exposure or have very low toxicity [10].

These classifications are used to assess the risk of elements for food safety and are monitored by the food industry, regulators, and researchers. The detection of one or more elemental impurities, such as Cd, Pb, As, and Hg, particularly in coffee ingredients consumed globally, and the evaluation of their potentially harmful effects on health have increased the importance of elemental impurity analyses and risk assessments in the literature [11-13]. Exposure to these heavy metals is a silent threat to human life. They have the potential to damage almost every organ and body system. Excessive Cd exposure causes kidney, lung, liver, skeletal structure damage and cancer [14].

Target organs where Cd can accumulate in the body are bones, brain, blood, kidneys and thyroid gland. Pb exposure can cause high blood pressure, muscle weakness and headaches [15]. Inorganic As is acutely toxic and ingestion of large amounts can lead to peripheral vascular disease, severe central nervous system (CNS) disorders and cardiovascular disease. Long-term exposure to As increases the risk of lung, bladder and kidney cancer [16]. Long-term exposure to Hg compounds in humans and animals can cause toxic effects on the skin, cardiovascular, pulmonary, urinary, gastrointestinal and neurological systems [17].

In order to minimize these risks, it is important to ensure the continuity of metal risk assessment studies on foods, to share analysis results on the necessary platforms, to support field-based experiments and tests, and to develop risk management strategies. Therefore, the detection of elemental impurities in coffee, which has an important place in food consumption, and the evaluation of their potential toxic effects on health are of great importance for consumer awareness and quality control processes in the coffee industry.

In this study, it was aimed to determine the heavy metal concentrations in Turkish coffee, which is widely consumed in Türkiye, and coffees from Indonesia, Kenya, Colombia, Guatemala in the markets, to provide up-to-date data to the literature and to provide a perspective on the risk that coffee consumers may be exposed to through coffee consumption. Therefore, the levels of Cd, Pb, As, and Hg elemental impurities potentially present in coffee beans from Indonesia, Kenya, Colombia, Guatemala, and Türkiye were determined using chromatographic analysis, and the analysis results were used to evaluate the carcinogenic and non-carcinogenic risks on human health.

2. Materials and Methods

2.1. Material

Five different coffee beans (Coffea Arabica L.) samples were bought at grocery stores (Ozbek Kahvecisi, Çanakkale) in Türkiye, in April 2024.

2.2. Chemical analysis

Analyses were carried out by considering Inductively coupled plasma–mass spectrometry (ICP-MS) methods used in the literature for heavy metal analysis [10, 13, 18-20]. 0.3 g sample was weighed into polytetrafluoroethylene (PTFE) tubes, followed by the addition of 8 mL nitric acid (60% HNO_3) and 2 mL hydrogen peroxide (H_2O_2). After waiting for gas evolution for a while in a fume hood, the Teflon tubes were sealed, and the samples were digested for 30 minutes using a microwave digestion system (Ethos Easy, Milestone Srl., IT) (Table 1).

Table 1. The microwave digestion program

Time (minute)	Power (W)	Temperature (°C)
15	0 - 1800	30 - 200
15	1800	200

After the microwave digestion, the sample solutions were diluted to 30 mL with ultrapure water.

2.3. Inductively coupled plasma–mass spectrometry (ICP–MS) parameter

The ICP-MS analyses were conducted at İzmir Katip Çelebi University Central Research Laboratories Application and Research Center (İzmir, Türkiye). For the analyses, ICP–MS instrument (7800, Agilent Technologies Inc., US, CA) combined with a chiller (Agilent G3292A), autosampler (Agilent SPS4), vacuum pump system, and Mass Hunter 4.4 software was utilized. The device parameters are provided in Table 2.

2.4. Calculations

The safety of coffee was assessed based on consuming either one serving or three servings daily throughout the year [11]. Exposure to coffee consumption was calculated according to age groups of young adults and middle-aged adults (20-65 years) [21]. One portion was defined as the amount of the instant product advised by the manufacturers, as stated on the packaging. For one cup of Turkish coffee, 0.007 kg of Turkish coffee and 0.015 kg of coffee were prepared in 240 mL for other types of coffee. Calculations were made accordingly. The values utilized in assessing and evaluating carcinogenic and non-carcinogenic risks associated with elemental impurities are provided in Table 3.

Table 2. The device parameters

Parameter	Value
RF Power	1500 W
RF Voltage	1.80 V
S/C Temperature	2 ºC
Skimmer Diameter	10 mm
Nebulizer Gas Flow Rate	1 L/min
Nebulizer Pump	0.10 rps
Internal standards	^{6}Li, ^{45}Sc, ^{72}Ge, ^{89}Y, ^{115}In, ^{159}Tb, ^{209}Bi
Tune solution	^{7}Li, ^{89}Y, ^{205}Tl

Table 3. Oral Reference dose factor (RfD), maximum permitted dose (PDE), and the cancer slope factor (CSF) limits for elemental impurities

Element	RfD (mg/kg/day)	PDE (mg/kg)	CSF $(mg/kg/day)^{-1}$	Reference
Cd	0.001	0.3	0.38	[12]
Pb	0.0035	10.0	0.0085	[11, 12]
As	0.0003	5.0	1.5	[12]
Hg	0.0005	0.2	-	[12]

RfD; Oral reference dose; mg/kg/day, PDE; maximum permitted dose (mg/kg), CSF; the cancer slope factor values ($(mg/kg/day)^{-1}$)

2.5. Health risks assessment

Many studies have examined how humans may be exposed to harmful substances by consuming contaminated food [10, 13]. In this study, the estimated daily intake (EDI), the target hazard quotient (THQ), the hazard index (HI), and the target cancer risk (CR) were determined to quantify the potential adverse health effects.

THQ was employed to assess the non-carcinogenic health risks associated with elemental impurities in adult populations during non-carcinogenic risk evaluations. To compute the THQ, the first step was establishing each element's EDI value. The EDI value was determined using Equation 1, assuming a body weight of 70 kg for a typical adult [10].

EDI (mg/kg/day)=(EF x ED x IR x MC) x CF /(BW xAT) (1)

EF: Exposure frequency (365 days/year) [22], ED: Exposure duration (45 years for young adults and middle-aged adults) [10, 21], IR: The amount of coffee recommended by the manufacturer when preparing one cup or one serving of coffee, MC: Amount of elemental impurity in the coffee; µg/kg, BW: Body weight; 70 kg for adults [10], AT: Average time (days), which is ED × EF [22], CF: Conversion coefficient (from µg to mg; 10^{-3})

The THQ value was determined by calculating each elemental impurity's EDI and RfD values (Equation 2), according to Winiarska-Mieczan et al. [11].

THQ = EDI/RfD (2)

THQ: The target hazard quotient
EDI: Estimated daily intake dose (mg/kg/day)
RfD: Oral reference dose (mg/kg/day)

The THQ ≥ 1 suggests that the exposed element risks human health [2].

Equation 3 calculated the HI of the combined risk related to the metals examined by totaling the THQs for Cd, Pb, As, and Hg in each sample [10].

HI=THQ (Cd) + THQ (Pb)+THQ (As)+THQ (Hg) (3)

HI: The hazard index
THQ: The target hazard quotient
An HI value of 1 or lower indicates no harmful effects will occur due to metal exposure [2].

Regular contact with certain substances that may cause cancer can raise the risk of cancer in individuals. Equation 4 can calculate the cancer risk (CR) from chronic exposure to toxic elements over a lifetime [23].

CR= EDI x CSF (4)

CR: cancer risk
EDI: Estimated daily intake dose (mg/kg/day)
CSF: The cancer slope factor $(mg/kg/day)^{-1}$

CSF for carcinogenic metals, including Cd, Pb, and As, are 0.38, 0.0085, and 1.5 $(mg/kg/day)^{-1}$, respectively (Table 3) [11, 12, 23]. According to the USEPA, human exposure to CR values within 1×10^{-6} to 1×10^{-4} is acceptable. However, it is imperative that the CR value does not exceed 1×10^{-4} [10-12, 23].

2.6. Statistical evaluation

The statistical analysis of the MC in coffee samples was analyzed three times using the IBM SPSS 23 software. A normality test was conducted, and all data showing a normal distribution underwent intergroup comparison using One-Way ANOVA followed by Tukey's post-hoc test at 0.05 significance level.

3. Results

3.1. Heavy metals and toxicity levels

The microwave sample preparation method was used in the ICP-MS device to analyze four elemental impurities (Cd, Pb, As and Hg), classified as Class 1 elements in the USP <232> guideline. The samples were readied, assessed, and judged based on the standards outlined in the USP <232> and USP <233> regulations [9]. The quantification parameter data in Table 4 includes the calibration curve details for ICP-MS and the limit of detection (LOD) values derived from the calibration standards for the four elements. The method had a calibration range of 0.5-1000 µg/L for Cd, Pb, As. The range of calibration for Hg was 1.5-100 µg/L. The regression (R^2) value for each element was $R^2 \geq 0.9995$.

Table 4. Quantification parameters for elemental impurities

Element	Isotop	LOD (µg/L)	Calibration range (µg/L)	Calibration curve regression (R^2) value
Cd	111	0.005	0.5-1000	1.0000
Pb	208	0.02	0.5-1000	0.9996
As	75	0.02	0.5-1000	0.9998
Hg	201	1.168	1.5-100	0.9995

LOD; Limit of dedection

When Cd, Pb, As and Hg levels in coffee samples were analyzed, Cd was detected in coffee samples in the range of approximately 3.70 - 5.89 µg/kg. Colombian coffee beans were found to have the highest Cd level (Table 5). Colombia is followed by Indonesia, Kenya, Turkish, and Guatemala coffee beans. Statistically significant differences were observed among the Cd levels in all coffees ($p < 0.05$) (Table 5).

The Pb level in the coffee samples was approximately 25.68-41.11 µg/kg. The coffee with the highest Pb levels was Indonesian coffee. The Pb levels in the other coffee beans ranged from highest to lowest in Türkiye, Guatemala, Colombia and Kenya, respectively. The Pb level in Indonesia was statistically different ($p < 0.05$) from Kenya, Colombia and Guatemala (Table 5).

The As level in coffee samples was approximately 1.45-6.64 µg/kg. The highest As level was found in Indonesian coffee. Other coffees had trace levels of As. The As level in Indonesian coffee was statistically different ($p < 0.05$) from the As level in Kenyan, Colombian and Guatemalan as well as Turkish coffees (Table 5).

Table 5. Levels of elemental impurities and carcinogenic and non-carcinogenic results in five different coffee beans

Sample	MC (µg/kg) (mean±std. dev.)			
	Cd	Pb	As	Hg
Indonesia	4.95±0.02^{a}	41.11±3.22^{a}	6.64±0.71^{a}	5.06±0.32^{a}
Kenya	4.38±0.03^{b}	25.68±1.70^{b}	1.99±0.03^{b}	2.12±0.43$^{b, c}$
Colombia	5.89±0.02^{c}	26.53±1.41^{b}	1.45±0.02^{b}	3.11±0.21^{b}
Guatemala	3.70±0.04^{d}	30.05±1.70^{b}	1.74±0.01^{b}	1.06±0.02^{c}
Turkish	4.21±0.03^{e}	33.85±1.00$^{a, b}$	2.66±0.09^{b}	2.05±0.30$^{b, c}$

Risk assessment									
Sample	Element	EDI (mg/kgbw/day)	THQ	HI	CR	EDI (mg/kgbw/day)	THQ	HI	CR
Indonesia	Cd	1x10^{-6}	11x10^{-4}	104x10^{-4}	6.7 x10^{-6}	5x10^{-6}	53x10^{-4}	524x10^{-4}	3.3 x10^{-5}
	Pb	9x10^{-6}	25x10^{-4}		7.5 x10^{-8}	44x10^{-6}	126x10^{-4}		3.7x10^{-7}
	As	1x10^{-6}	47x10^{-4}		2.1 x10^{-6}	7x10^{-6}	237x10^{-4}		1.1x10^{-5}
	Hg	1x10^{-6}	21x10^{-4}		NC	5x10^{-6}	108x10^{-4}		NC
Kenya	Cd	1x10^{-6}	9x10^{-4}	48x10^{-4}	5.9 x10^{-6}	5x10^{-6}	47x10^{-4}	212x10^{-4}	3.0 x10^{-5}
	Pb	6x10^{-6}	16x10^{-4}		4.7 x10^{-8}	28x10^{-6}	79x10^{-4}		2.3x10^{-7}
	As	4x10^{-7}	14x10^{-4}		6.4 x10^{-7}	2x10^{-6}	71x10^{-4}		3.2 x10^{-6}
	Hg	4x10^{-7}	9x10^{-4}		NC	2x10^{-6}	45x10^{-4}		NC
Colombia	Cd	1x10^{-6}	13x10^{-4}	52x10^{-4}	7.9 x10^{-6}	6x10^{-6}	63x10^{-4}	233x10^{-4}	4.0 x10^{-5}
	Pb	6x10^{-6}	16x10^{-4}		4.8 x10^{-8}	28x10^{-6}	81x10^{-4}		2.4 x10^{-7}
	As	3x10^{-7}	10x10^{-4}		4.7 x10^{-7}	2x10^{-6}	52x10^{-4}		2.3 x10^{-6}
	Hg	1x10^{-6}	13x10^{-4}		NC	3x10^{-6}	67x10^{-4}		NC
Guatemala	Cd	1x10^{-6}	8x10^{-4}	42x10^{-4}	5 x10^{-6}	4x10^{-6}	40x10^{-4}	217x10^{-4}	2.5 x10^{-5}
	Pb	6x10^{-6}	18x10^{-4}		5.5 x10^{-8}	32x10^{-6}	92x10^{-4}		2.7 x10^{-7}
	As	3x10^{-7}	12x10^{-4}		5.6x10^{-7}	2x10^{-6}	62x10^{-4}		2.8 x10^{-6}
	Hg	2x10^{-7}	4x10^{-4}		NC	1x10^{-6}	23x10^{-4}		NC
Turkish	Cd	4x10^{-7}	4x10^{-4}	26x10^{-4}	2.6 x10^{-6}	2x10^{-6}	21x10^{-4}	134x10^{-4}	1.3 x10^{-5}
	Pb	3x10^{-6}	9x10^{-4}		2.9 x10^{-8}	17x10^{-6}	48x10^{-4}		1.4 x10^{-7}
	As	2x10^{-7}	9x10^{-4}		3.9 x10^{-7}	1x10^{-6}	44x10^{-4}		2.0 x10^{-6}
	Hg	2x10^{-7}	4x10^{-4}		NC	1x10^{-6}	21x10^{-4}		NC

MC; Amount of elemental impurity in the coffee (µg/kg), EDI; Estimated daily intake dose (mg/kg/day), THQ; The target hazard quotient, HI; The hazard index, CR; Cancer risk, NC; Not calculated. The mean MC of samples followed by different letters in the same column are significantly different ($p < 0.05$).

The Hg level in the coffee samples was approximately 1.06-5.06 µg/kg. Hg levels were highest in Indonesian coffee. Hg levels in the other coffees were trace levels. The Hg level in Indonesian coffee was statistically different from that in all other coffees. A difference was also found between Colombian and Guatemalan coffees ($p < 0.05$) (Table 5).

3.2. The health risk assessment

In the study, the age range covering young adults and middle-aged adults (20-65 years) was considered as the exposure age range, and according to two different coffee consumption scenarios (one cup or three cups per day), EDI, THQ, and HI values were calculated (Table 5). The HI for the combined risk related to the examined metals was computed by adding the

THQs for Cd, Pb, As, and Hg in every coffee sample (Equation 3). When examining the HI values for all samples considering both scenarios in Table 5; the HI values for the first and second scenarios were respectively $104x10^{-4}$ and $524x10^{-4}$ in Indonesian coffee, $48x10^{-4}$ and $212x10^{-4}$ in Kenyan coffee, $52x10^{-4}$ and $233x10^{-4}$ in Colombian coffee, $42x10^{-4}$ and $217x10^{-4}$ in Guatemalan coffee, and $26x10^{-4}$ and $134x10^{-4}$ in Turkish coffee.

Since the HI value was less than one for all coffees, consuming one or three cups of coffee between the ages of 20-65 is not expected to cause adverse non-carcinogenic effects due to metal exposure. However, Turkish coffee has the lowest HI value among all coffee types. It has been determined that Guatemalan and Turkish coffees are more reliable than others in terms of metal levels and HI values. The level of the HI value for each coffee sample is directly affected by the IR amount of the coffee samples (For one cup of Turkish coffee, 0.007 kg of Turkish coffee and 0.015 kg of coffee were prepared in 240 mL for other types of coffee). The IR level of Turkish coffee was almost half of the IR level of other coffees.

When examining the carcinogenic risk assessment of the elements, it is observed that the CR values of Cd, Pb, and As elements in all samples are less than 10^{-4}. Considering the criteria, as the metal levels in the samples are within acceptable limits, no carcinogenic risk seems to be present due to the heavy metal content.

4. Discussion

Elemental impurities, common in nature, can accumulate in plants through soil, water, air, or other means. Since these elemental impurities can cause various health problems in the human body, non-toxic limits for these elements are specified in the guidelines [13]. Assessing the accumulation of elemental contaminants in coffee samples, one of the most widely consumed foods is very important to ensure human safety due to its widespread global consumption [24, 25]. In our study, the amounts of Cd, Pb, As, and Hg heavy metals classified as Class 1 in USP <232> in five different ground coffee beans grown in different geographical regions were determined by ICP-MS, and risk assessments were made according to the values obtained.

Monitoring elemental impurities potentially present in foods due to contamination is crucial for health purposes. Class 1 elements are toxic, and their levels should not exceed PDE limits. Cd is typically found at low levels in nature [10]. In our study, the range of Cd in all coffee samples was below the permitted limit set by the World Health Organization (WHO) of 0.3 mg/kg [12]. The mean Cd levels in the five different coffee beans included in the study ranged from 3.70 to 5.89 µg/kg. Cd levels were found to be in the order of Colombia > Indonesia > Kenya > Turkish > Guatemala. Cd levels were statistically different among all coffee samples (Table 5).

Our study showed a statistically significant difference in Cd levels between Colombia and Kenya coffee beans (Table 5). In the Albals et al. (2021) study, Cd levels in coffee beans originating from Colombia and Kenya were found to be 150 µg/kg and 140 µg/kg, respectively [24]. In the study by Kowalska (2021), Cd levels in eight different Arabica coffee bean varieties were found to be an average of 58 µg/kg [23]. In the study by Ali (2024), the average Cd level in 42 coffee samples collected from local markets in Iraq was 35 µg/kg [25]. Upon examination of the literature and our analysis results, it was determined that Cd levels are below the permitted range set by the WHO.

Pb is considered a toxic environmental pollutant, and its toxicity in humans has been associated with mental disorders, behavioral abnormalities, seizures, and other health issues. This metal can accumulate in tea leaves and coffee plants, raising consumer concerns [25]. The mean Pb level in our study's five different coffee beans ranged from 25.68 to 41.11 µg/kg. Pb levels were found to be in the order of Kenya > Colombia > Guatemala > Turkish > Indonesia. While the Pb level in Indonesian and Turkish coffee beans did not show a statistically significant difference, the Pb level in Indonesian coffee beans was statistically different from that in Kenya, Colombia, and Guatemala coffee samples (Table 5). In the study by Nędzarek et al. (2013), Pb levels in infusion coffee samples from Bosnia and Herzegovina, Brazil, Lebanon, and Poland were found to be 710-1050 µg/kg [4]. In the Albals et al. (2021) study, Pb levels in coffee beans originating from Colombia and Kenya were 1040 µg/kg and 1380 µg/kg, respectively [24]. Similarly to the literature, our study did not find a statistically significant difference in Pb levels between Colombia and Kenya coffee beans (Table 5). In the study by Guadalupe et al. (2023), Pb levels in parchment coffee beans obtained from the Peru region were between 640-670 µg/kg [2]. Our study and analytical data from the literature revealed that all samples contained low levels of Pb. These values were below the permitted limit of 10.0 mg/kg set by the WHO [12].

As is among the toxic elements capable of entering organisms via the consumption of water and food. As is a toxic element, and its chronic ingestion can cause many adverse health effects [10]. Among the coffee samples, As had concentrations ranging from 1.45-6.64 µg/kg, lower than the PDE (5 mg/kg) [12]. The mean As concentration in our study's five different ground coffee beans was determined to be in the order of Indonesia > Turkish > Kenya > Guatemala > Colombia. The As level in Indonesian coffee samples differed statistically from all other coffee samples (Table 5). In the study by Omer et al. (2019), the highest As level in coffee samples sold in Saudi markets was 0.107 mg/kg [26]. In the study by Taghizadeh et al. (2023), the highest As level among 29 different coffee samples was found to be 0.32 mg/kg [12]. Our study and analytical data from the literature revealed that all samples contained low levels of As. These values were below the permitted limit set by the WHO.

Hg is commonly present in various forms in the natural environment. Metallic and inorganic mercury are commonly found in nature. Mercury salts are naturally occurring forms of inorganic mercury. Microorganisms generate organic mercury through biological processes. Inorganic mercury is frequently utilized in the medical field, as well as in disinfectants and ointments. All types of Hg can lead to harmful effects [10]. The mean Hg level in our study's five different ground coffee beans ranged from 1.06–5.06 µg/kg. The Hg level was determined to be in the order of Indonesia > Colombia > Kenya > Turkish > Guatemala. The Hg level in Indonesian coffee beans differed statistically from all other coffees. The Hg level in Colombian and Guatemalan coffee beans was also statistically different (Table 5). In the study by Massoud et al. (2022), the Hg level in roasted coffee powder samples sold in Iran and Turkish markets was below 0.3 µg/kg [27]. In the study by Taghizadeh et al. (2023), the highest Hg level among 29 different coffee samples was found to be 0.94 mg/kg [12]. Our study and analytical data from the literature revealed that all samples contained low levels of Hg. These values were below the permitted limit set by the WHO [12].

Our study conducted carcinogenic and non-carcinogenic risk assessments considering consumption scenarios of one or three cups of coffee per day for individuals aged 20-65. The EDI, THQ, HI, and CR calculations were performed for all investigated metals in coffee. The calculated EDIs for all examined metals through the consumption of one or three cups of coffee are summarized in Table 5. According to the results, the EDI values for all elements were below the RfD, indicating no health risk associated with our samples. The THQ values for all samples were less than one, indicating no potential consumer health effects.

The HI, which represents the combined non-carcinogenic effects of the investigated heavy metals in coffee, was less than one in our samples. HI values of less than one indicate no significant health risks related to our samples. However, the HI values for coffee samples were determined to be in the order of Indonesia > Colombia > Kenya > Guatemala > Turkish. In a study by Winiarska-Mieczan et al. (2023) on the elemental impurity analysis of coffee beans, the THQ and HI values were found to be less than one for Cd and Pb, indicating that the risk of disease due to Cd and Pb exposure through coffee consumption could be considered very low [11]. Similarly, in another study by Taghizadeh et al. (2023) on coffee and tea, the THQ and HI values for Cd, Pb, As, and Hg were below 1.0 [12], consistent with our findings. When the risk assessment of heavy metal exposure in terms of human health is associated with coffee consumption, it is clear that no health risk is associated with the consumption of one or three cups of the coffees in our study. Considering that the recommended doses in coffee consumption directly affect the HI value, it is predicted that any health risk that may occur due to heavy metal exposure will not occur for the coffee types included in the study if the usage dose is not exceeded.

In our study, when the CR value was calculated for Cd, Pb, and As, it was found that the CR value did not exceed 1×10^{-4} in all coffee samples in both scenarios, meeting the USEPA criteria. Considering the risk assessment of elemental impurities in the five different ground coffee beans included in our study, it can be concluded based on our data that the consumption of Indonesia, Kenya, Colombia, Guatemala, and Turkish coffee varieties does not pose a health risk, as the CR and HI values for all samples did not exceed the USEPA criteria.

5. Conclusion

This study evaluated the risks associated with oral ingestion of four elemental impurities classified under Class 1 in USP<232> in five different ground coffee beans. The levels of elemental impurities in each sample were determined by chromatographic means, followed by risk calculations. In the assessment of non-carcinogenic risks, all elements had HI values <1.0. Therefore, elemental impurities in the coffee samples analyzed in our study do not pose non-carcinogenic health risks in terms of the heavy metals. For the carcinogenic risk calculation, the CR values of Cd, Pb and As elemental impurities were calculated and no health risks for coffee consumers were identified based on the CR values. The results of our analysis show that the level of elemental impurities that can enter the human body with the consumption of one to three cups of coffee does not pose a health risk. However, the cumulative assessment of elemental impurity levels from other foods in the diet is important for expanding the risk analysis. For this reason, planning and conducting comprehensive risk assessment studies that take into account individual differences and the presence of metal levels in other consumed foods will contribute to the literature in order to determine the levels of heavy metals that may be exposed through diet and to perform risk calculations.

Article Information Form

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The Declaration of Conflict of Interest/ Common Interest

No conflict of interest or common interest has been declared by the author.

The Declaration of Ethics Committee Approval

This study does not require ethics committee permission or any special permission.

The Declaration of Research and Publication Ethics

The author of the paper declares that she complies with the scientific, ethical, and quotation rules of SAUJS in all processes of the paper and that they do not make any falsification on the data collected. In addition, he declares that Sakarya University Journal of Science and its editorial board have no responsibility for any ethical violations that may be encountered and that this study has not been evaluated in any academic publication environment other than Sakarya University Journal of Science.

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