Research Article

Received: 07 February, 2026
Accepted: 20 April, 2026
Published: 27 April, 2026

Levels of Some Heavy Metals in Meat Products and Health Risk Assessment

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Cite this article:

Merie, K. M., & Mohammed, A. B. (2026). Levels of some Heavy metals in meat products and health risk assessment. Cultura Científica, (24), pp. 210–219.

Abstract

Heavy elements are dense, naturally occurring elements that pose health risks through their accumulation in the environment and living organisms. This study aimed to evaluate heavy metal levels and assess health risk levels in processed meats in Kirkuk Governorate. Meat samples were collected from various sources in the markets of Kirkuk Governorate between December 1, 2024, and February 1, 2025. These included Mumtaz Iraqi frozen chicken burger, Sadia frozen Brazilian beef burger, fresh Iraqi beef burger, frozen Turkish pastrami, and Iraqi pastrami. Five samples were taken from each type of meat, with 30–50 g collected from each sample. The concentrations of the studied heavy elements were measured using inductively coupled plasma-optical emission spectrometry (ICP-OES) at the University of Kufa, Najaf. Cadmium and chromium showed high mean levels in Iraqi pastrami (20.60 ± 5.11, 30.74 ± 12.90), respectively, while nickel and lead were highest in Mumtaz Iraqi frozen chicken burger (3.17 ± 0.14, 0.58 ± 0.06), respectively. Zinc and manganese were highest in Sadia frozen Brazilian beef burger (17.76 ± 0.19, 102.77 ± 9.09), respectively, whereas cobalt was highest in fresh Iraqi beef burger (0.56 ± 0.24). The main sources of risk in frozen chicken burgers were cadmium and chromium, with THQ values exceeding the recommended limit (THQ > 1), indicating potential health risks with continuous consumption. The remaining elements were within safe limits, but the combined effect of HI = 10.532 may be harmful. Cadmium in frozen chicken patties had an EDI value of 0.0082 mg/day, which was significantly higher than the tolerable limit (TDI = 0.001 mg/day), indicating a health risk. Chromium also exceeded the required limit, with an EDI of 0.0042 mg/day. Other elements, including nickel, lead, cobalt, and zinc, were within safe limits. Due to high cadmium and chromium contamination, the processed meat samples were found to be unsafe. Iraqi pastrami showed the greatest contamination and EDI, exceeding international standards. The Target Hazard Quotient (THQ) calculations indicated values greater than one for both elements in all samples, resulting in a high cumulative Hazard Index (HI) ranging from 10.53 to 22.99. These results exceed the acceptable limit, indicating substantial health risks from systemic and renal toxicity. Meanwhile, zinc, nickel, lead, cobalt, and manganese were considered safe for human consumption.

Keywords: hazardous target quota, cumulative hazard index, beef burger, pastrami

1. INTRODUCTION

Pollution is a major challenge facing our environment due to the introduction of different substances (heavy metals, organic compounds) from different sources, such as industrialization, urban expansion, and human population growth [1, 2]. Food is a fundamental source of important nutrients for the body; nevertheless, it may also contain non-nutritive substances that are unnecessary and potentially detrimental to human health. In addition to the diverse minerals included in our everyday diet, harmful heavy metals such as cadmium, lead, mercury, and nickel may be present in food products. These elements may be hazardous, even at comparatively low concentrations [3].

Heavy elements are dense, naturally occurring elements that pose health risks through their accumulation in the environment and living organisms. Some elements, such as arsenic (As), possess properties of both metals and nonmetals and are known as metalloids. They are classified as heavy elements due to their metal-like toxicity [4].

A common list of non-essential heavy elements that cause toxicity includes arsenic (As), cadmium (Cd), lead (Pb), and mercury (Hg), as well as elements essential to humans in trace amounts for various cellular activities, such as cobalt (Co), copper (Cu), chromium (Cr), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), selenium (Se), and zinc (Zn) [5].

The prevalence of heavy metal contamination in the environment and the food chain is extensive. Chemical pollutants may be assimilated by plants, thereby infiltrating the food chain and exposing humans to these substances. Heavy metals can be ordered according to their toxicity to living creatures in the following order: Hg > Cu > Zn > Ni > Pb > Cd > Cr > Sn > Fe > Mn > Al [6]. Sarsembayeva et al. [7] reported that the concentration of pollutants in food raw materials has escalated about fivefold over the past five years, with harmful substances detected in 90% of frequently analyzed food products. Therefore, it is essential to enhance our comprehension of the mechanisms by which food becomes polluted with heavy metals and to refine processing methods to alleviate the detrimental impacts of food pollutants [8].

Toxicity can occur through inhalation, ingestion, and skin contamination. Humans can be exposed to mercury as a result of exploiting natural resources such as mining, fossil fuel burning, industry, agriculture, and the consumption of plants, seafood, and meat that have accumulated this toxic substance from contaminated soil, waterways, and seawater [9]. Toxicity from multiple mercury-containing substances can be more pronounced and cause significant illness. Some domestic medicinal preparations contain toxic amounts of mercury. Children are more susceptible than adults. While acute toxicity results from short-term exposure to large doses, long-term exposure to smaller amounts leads to chronic toxicity [10].

Heavy metal emissions, pollution, health risk evaluations, and mitigation techniques have all been the subject of substantial study over the last several decades. A thorough familiarity with the dangers that heavy metals pose to human health, together with the ability to identify new tendencies in the field, keep track of important study areas, and chart a course for future studies, is essential [11].

Rapid industrialization and urbanization since the 1940s have led to higher rates of heavy metal pollution in the environment, as their accumulation and transport rates in the environment have accelerated significantly. Natural sources in the environment include weathering of metal-bearing rocks and volcanic eruptions, while major human sources include industrial emissions, mining, smelting, and agricultural activities such as the use of pesticides and phosphate fertilizers [12]. The study aimed to evaluate heavy metal levels and assess health risk levels in processed meats in Kirkuk Governorate.

2. METHODS

A selection of meat products was obtained from various sources in the markets of Kirkuk Governorate between December 1, 2024, and February 1, 2025. These included Mumtaz Iraqi frozen chicken burger, Sadia frozen Brazilian beef burger, fresh Iraqi beef burger, frozen Turkish pastrami, and Iraqi pastrami. Five samples were taken from each type of meat, with 30–50 g collected from each sample. These samples were then placed in clean plastic bags and refrigerated boxes until they reached the laboratory, where they were stored at $-20°C$.

The samples were thoroughly washed with distilled water to remove any remaining impurities and then cut into small pieces using a ceramic knife. The samples were dried in an electric oven at $105°C$ for three hours. After drying, the samples were ground into a fine powder using a ceramic mortar. Approximately 1 g of this powder was used for elemental analysis, as described by Sneddon et al. [13].

The heavy metal samples were digested according to the 1983 Regional Organization for the Protection of the Marine Environment (ROPME) guidelines [14], using the dry digestion method to determine the minerals under investigation. The samples were digested to extract a selection of heavy metals, including lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), manganese (Mn), zinc (Zn), and cobalt (Co), from the studied tissues, based on the findings of Furr and ED [15] and Sadeghi et al. [16].

The concentrations of the studied heavy elements were measured using inductively coupled plasma-optical emission spectrometry (ICP-OES) at the University of Kufa, Najaf. This technique is an advanced analytical method used to determine the concentrations of major and trace elements in various samples. The device operates by introducing the sample solution into a high-energy argon plasma composed of electrons and positively charged argon ions. The sample is subjected to extremely high temperatures, reaching approximately 10,000 K, causing it to decompose into free atoms and ions. These atoms absorb thermal energy, and their electrons transition from a ground state to an excited state, then return to lower energy levels, emitting light radiation at wavelengths characteristic of each element. This radiation is measured and spectroscopically analyzed to determine the concentrations of different elements.

The HORIBA ICP-OES spectrometer was used to analyze the heavy metal content in meat and meat products. This method involves introducing liquid samples into very hot argon plasma in order to heat and excite the atoms of the metals. These atoms then emit light upon relaxation. The spectrometer analyzes these light signals to determine the type and quantity of each element in the sample. The main steps include sample preparation, aerosolization, introduction into the argon plasma, measurement of the emitted light, and calibration of the results to determine the concentration of the metals.

The results for heavy metal concentrations in the tissues were calculated as described in ROPME [14]. By measuring the residual concentrations of the elements (mg/g), the results were calculated using the following equation:

$$\text{Element} = \frac{R \times D}{W},$$

where R is the element concentration reading (parts per million) on the instrument, D is the final volume of the prepared sample (mL), and W is the weight of the sample (g).

The potential health risks associated with consuming meat contaminated with heavy metals were assessed in terms of the Estimated Daily Intake (EDI) and Target Hazard Quotient (THQ), according to the U.S. Environmental Protection Agency (EPA) standards [17].

The Estimated Daily Intake (EDI) for the studied elements was calculated using the formula below, which is based on the U.S. EPA Human Health Assessment Manual [17]:

$$\text{EDI} = \frac{C \times FIR}{BW},$$

where EDI is the estimated daily intake based on μg/kg/day, C is the concentration of the element in the studied sample (mg/kg), FIR represents the average daily intake of muscle tissue, estimated at 32.8 g/day for a 70 kg person in Iraq, and BW is the body weight of adults and children in Iraq, estimated at 70 kg for adults and 30 kg for children.

The non-cancer target hazard quotient for both adults and children associated with the consumption of the tested sheep tissue was calculated according to the formula approved and recommended by the U.S. Environmental Protection Agency [18]:

$$\text{THQ} = \frac{C \times IR \times EF \times ED}{RfD \times BW \times AT}.$$

This equation relies on several factors to calculate the potential exposure level to chemicals through food relative to the reference dose, where C is the concentration of the heavy metal in the food (mg/kg), IR is the average daily food intake (kg/day) = 32.8 g/day (0.0328 kg/day) in Iraq [19], EF is the number of days per year consumed (days/year) = 365 days per year, ED is the duration of exposure in years = 70 years, RfD is the oral reference dose (mg/kg/day) of metals based on the U.S. Environmental Protection Agency [17], BW is the body weight of the person = 70 kg, and AT is the averaging time = 365 days $\times$ 70 years.

If the calculated THQ value is less than 1, this means that the non-carcinogenic health risks are very low or nonexistent. If the value is greater than or equal to 1, there is a possibility of adverse non-carcinogenic health effects occurring after consuming lamb meat [20].

Heavy metal intake is represented by the sum of the Hazard Index (HI), which ranges from 1 to 10 according to the recommendations of the U.S. Environmental Protection Agency [21]. The assessment of the effects of heavy metal intake is based on the HI value, where $HI < 1$ indicates mild or no adverse health effects, $HI \geq 1$ indicates adverse non-carcinogenic health effects, and $HI \geq 10$ indicates the potential for chronic toxic and carcinogenic effects.

The results were statistically analyzed using Analysis of Variance (ANOVA) and the Least Significant Difference (LSD) test at a significance level of 0.05, using SPSS version 26. Differences between sources were determined at a probability level of 0.05 ($P \leq 0.05$).

3. RESULTS

The results in Table 1 showed that cadmium had the highest mean level in Iraqi pastrami (20.60 ± 5.11), followed by frozen Turkish pastrami (19.34 ± 4.52). In contrast, the lowest mean level of cadmium was recorded in Mumtaz Iraqi frozen chicken burger (11.49 ± 5.96).

Table 1. *Cadmium levels in processed meat samples under study*

Cadmium	Mumtaz Iraqi frozen chicken burger	Sadia frozen Brazilian beef burger	fresh Iraqi beef burger	Frozen Turkish Pastrami	Frozen Turkish Pastrami	Iraqi Pastrami
Mean ± SD	11.49±5.96	11.69±4.94	13.85±2.22	19.34±4.52	19.34±4.52	20.60±5.11
T test	5.48	1.26	1.26	1.26	0.58	0.58
P value	0.0001***	0.22	0.22	0.22	0.56	0.56

The results in Table 2 showed that chromium had the highest mean level in Iraqi pastrami (30.74 ± 12.90) and Sadia frozen Brazilian beef burger (30.16 ± 15.87), compared with imported frozen Turkish pastrami (16.76 ± 10.51) and Mumtaz Iraqi frozen chicken burger (5.89 ± 4.06).

Table 2. *Chromium levels in processed meat samples under study*

Chromium	Mumtaz Iraqi frozen chicken burger	Sadia frozen Brazilian beef burger	fresh Iraqi beef burger	Frozen Turkish Pastrami	Frozen Turkish Pastrami	Iraqi Pastrami
Mean ± SD	5.89±4.06	30.16±15.87	28.70±4.34	16.76±10.51	16.76±10.51	30.74±12.90
T test	4.67	0.28	0.28	0.28	2.56	2.56
P value	0.0001***	0.78	0.78	0.78	0.016*	0.016*

The results in Table 3 showed that zinc had the highest mean level in Mumtaz Iraqi frozen chicken burger (17.10 ± 0.18) and Sadia frozen Brazilian beef burger (17.76 ± 0.19), compared with frozen Turkish pastrami (9.68 ± 0.10) and Iraqi pastrami (9.84 ± 1.49).

Table 3. *Zinc levels in processed meat samples under study*

Zinc	Mumtaz Iraqi frozen chicken burger	Sadia frozen Brazilian beef burger	fresh Iraqi beef burger	Frozen Turkish Pastrami	Iraqi Pastrami
Mean ± SD	17.10±0.18	17.76±0.19	16.48±0.27	9.68±0.10	9.84±1.49
T test	8.01	12.30	12.30	0.34	0.34
P value	0.0001***	0.05*	0.05*	0.74	0.74

The results in Table 4 showed that nickel had the highest mean level in Mumtaz Iraqi frozen chicken burger (3.17 ± 0.14) and Iraqi pastrami (2.16 ± 1.13), compared with frozen Turkish pastrami (1.59 ± 0.81) and Sadia frozen Brazilian beef burger (1.01 ± 0.55).

Table 4. *Nickel levels in processed meat samples under study*

Nickel	Mumtaz Iraqi frozen chicken burger	Sadia frozen Brazilian beef burger	fresh Iraqi beef burger	Frozen Turkish Pastrami	Frozen Turkish Pastrami	Iraqi Pastrami
Mean ± SD	3.17±0.14	1.01±0.55	0.93±0.66	1.59±0.81	1.59±0.81	2.16±1.13
T test	11.83	0.32	0.32	0.32	1.32	1.32
P value	0.0001***	0.75	0.75	0.75	0.20	0.20

The results in Table 5 showed that lead had the highest mean level in Mumtaz Iraqi frozen chicken burger (0.58 ± 0.06) and Sadia frozen Brazilian beef burger (0.52 ± 0.16), compared with frozen Turkish pastrami (0.12 ± 0.05) and Iraqi pastrami (0.36 ± 0.14).

Table 5. *Lead levels in processed meat samples under study*

Lead	Mumtaz Iraqi frozen chicken burger,	Sadia frozen Brazilian beef burger	fresh Iraqi beef burger	Frozen Turkish Pastrami	Iraqi Pastrami
Mean ± SD	0.58±0.06	0.52±0.16	0.39±0.08	0.12±0.05	0.36±0.14
T test	1.11	2.31	2.31	5.07	5.07
P value	0.28	0.03*	0.03*	0.0001***	0.0001***

The results showed that there was a significant difference in the mean level of cobalt among the processed meat samples. Fresh Iraqi beef burger recorded the highest mean level of cobalt (0.56 ± 0.24), followed by Iraqi pastrami (0.32 ± 0.12) and frozen Turkish pastrami (0.30 ± 0.04), as shown in Table 6.

Table 6. *Cobalt levels in processed meat samples under study*

Cobalt	Mumtaz Iraqi frozen chicken burger,	Sadia frozen Brazilian beef burger	fresh Iraqi beef burger	Frozen Turkish Pastrami	Frozen Turkish Pastrami	Iraqi Pastrami
Mean ± SD	0.09±0.04	0.04±0.0	0.56±0.24	0.30±0.04	0.30±0.04	0.32±0.12
T test	3.95	6.85	6.85	6.85	0.50	0.50
P value	0.001**	0.0001***	0.0001***	0.0001***	0.62	0.62

The results also showed that there was a significant difference in the mean level of manganese among the processed meat samples. Sadia frozen Brazilian beef burger had the highest mean level of manganese (102.77 ± 9.09), while Iraqi pastrami had the lowest level (3.30 ± 0.94), as shown in Table 7.

Table 7. *Manganese levels in processed meat samples under study*

Manganese	Mumtaz Iraqi frozen chicken burger,	Sadia frozen Brazilian beef burger	fresh Iraqi beef burger	Frozen Turkish Pastrami	Frozen Turkish Pastrami	Iraqi Pastrami
Mean ± SD	83.28±8.35	102.77±9.09	18.30±2.61	14.45±0.96	14.45±0.96	3.30±0.94
T test	4.99	28.32	28.32	28.32	26.33	26.33
P value	0.0001***	0.0001***	0.0001***	0.0001***	0.0001***	0.0001***

3.1. POTENTIAL HEALTH RISKS OF HEAVY METALS

3.2. ESTIMATED DAILY INTAKE OF HEAVY METALS IN PROCESSED MEAT SAMPLES

Table 8 displays THQ and HI values for heavy metals in processed meat products, such as frozen chicken and beef burgers, fresh burgers, and frozen and Iraqi pastrami. The results demonstrate that risk levels vary among samples, with certain factors greatly increasing the risk index.

Table 8. *Estimated Daily Intake (EDI) of Heavy Metals in processed Meat samples*

Sample	Elements	EDI	Mean	SD	TDI
Mumtaz Iraqi frozen chicken burger	Cd	0.0082	11.4923	5.9615	0.0010
	Cr	0.0042	5.8932	4.0615	0.0030
	Zn	0.0122	17.1060	0.1898	0.3000
	Ni	0.0023	3.1737	0.1410	0.0200
	Pb	0.0004	0.5899	0.0612	0.0035
	Co	0.0001	0.0930	0.0472	0.0003
	Mn	0.0595	83.2895	8.3512	0.1400
Sadia frozen Brazilian beef burger	Cd	0.0084	11.6966	4.9436	0.0010
	Cr	0.0215	30.1650	15.8791	0.0030
	Zn	0.0127	17.7645	0.1958	0.3000
	Ni	0.0007	1.0117	0.5581	0.0200
	Pb	0.0004	0.5299	0.1661	0.0035
	Co	0.0000	0.0459	0.0000	0.0003
	Mn	0.0734	102.7731	9.0936	0.1400
fresh Iraqi beef burger	Cd	0.0099	13.8538	2.2248	0.0010
	Cr	0.0205	28.7087	4.3419	0.0030
	Zn	0.0118	16.4872	0.2781	0.3000
	Ni	0.0007	0.9318	0.6659	0.0200
	Pb	0.0003	0.3974	0.0874	0.0035
	Co	0.0004	0.5647	0.2428	0.0003
	Mn	0.0131	18.3052	2.6140	0.1400
Frozen Turkish Pastrami	Cd	0.0138	19.3488	4.5268	0.0010
	Cr	0.0120	16.7670	10.5106	0.0030
	Zn	0.0069	9.6842	0.1067	0.3000
	Ni	0.0011	1.5992	0.8108	0.0200
	Pb	0.0001	0.1296	0.0584	0.0035
	Co	0.0002	0.3006	0.0462	0.0003
	Mn	0.0103	14.4554	0.9667	0.1400
Iraqi Pastrami	Cd	0.0147	20.6022	5.1180	0.0010
	Cr	0.0220	30.7476	12.9093	0.0030
	Zn	0.0070	9.8435	1.4958	0.3000
	Ni	0.0015	2.1669	1.1348	0.0200
	Pb	0.0003	0.3623	0.1473	0.0035
	Co	0.0002	0.3232	0.1296	0.0003
	Mn	0.0024	3.3005	0.9446	0.1400

The main sources of risk in frozen chicken burgers were cadmium and chromium, with THQ values exceeding the recommended limit (THQ > 1), indicating potential health risks with continuous consumption. The remaining elements were within safe limits, but the combined effect of HI = 10.532 may be harmful. The risk associated with Cd and Cr in frozen beef burgers increased dramatically compared with the previous sample, with THQ reaching 8.3547 and 7.1822. Due to the heavy metal concentrations in these products, the cumulative hazard index (HI) was 16.357, suggesting a greater risk level.

Cd, Cr, and Co all exceeded a THQ of 1 in fresh beef patties, with cobalt having the highest value (1.3446). An HI of 18.322, one of the highest reported, indicates a large cumulative risk. For frozen pastrami, Cd and Cr remained high-risk elements, but the remaining elements were within safe limits. The contributions of these two elements raised the HI to 18.708. Iraqi pastrami had the highest cumulative risk, with an HI of 22.997. This product is high-risk due to the marked increase in the THQ of cadmium and chromium, which are the main contributors.

Cadmium and chromium are the biggest health hazards in all processed meat products, whereas the other components were within safe limits. These findings emphasize the necessity of monitoring heavy metal levels in processed food products in order to reduce consumer health risks. Cadmium and chromium pose the greatest health risks in processed chicken meat, which is consistent with recent studies showing that long-term exposure to these metals can cause kidney and systemic problems in humans, especially with daily consumption [22].

3.3. TARGET HAZARD QUOTIENT (THQ) FOR HEAVY METALS IN PROCESSED MEAT

Table 9 compares EDI values for several heavy metals in processed meat to the Tolerable Daily Intake (TDI). This measure is crucial for monitoring consumer hazardous exposure through diet.

Cadmium in frozen chicken patties had an EDI value of 0.0082 mg/day, which was significantly higher than the tolerable limit (TDI = 0.001 mg/day), indicating a health risk. Chromium also exceeded the recommended level, with an EDI of 0.0042 mg/day. Other elements, including nickel, lead, cobalt, and zinc, were within safe limits. Manganese had the highest result (0.0595 mg/day) but remained below the TDI.

Like the chicken burger, the frozen beef burger had 0.0084 mg/day of cadmium, which exceeded the guidelines. Chromium had the highest EDI (0.0215 mg/day) across samples, surpassing the permitted limit and indicating possible exposure through this product. Zinc, Ni, Pb, and Co were acceptable. Manganese was similarly high (0.0734 mg/day) but remained safe. Cadmium consumption increased significantly (0.0099 mg/day) in fresh burger samples, exceeding the limit as in the previous types. Chromium (0.0205 mg/day) also had a high value, similar to the frozen burger, indicating continual exposure. All other elements were within acceptable limits. Compared to the other products, cobalt had a relatively high value (0.0004 mg/day) but was still below the TDI. Cadmium (0.0138 mg/day) and chromium (0.0120 mg/day) were above the limits in frozen pastrami. Although manganese (0.0103 mg/day) increased, nickel, lead, cobalt, and manganese remained within safe levels. Iraqi pastrami had the greatest cadmium intake (0.0147 mg/day), exceeding the limit. Iraqi pastrami also had the highest EDI (0.0220 mg/day) for chromium, making it the most hazardous product for both elements. While nickel and manganese were above the TDI, the others were within acceptable limits.

Table 9. *Target Hazard Quotient (THQ) for heavy metals in processed meat samples*

samples	Elements	Risk	Cumulative risk index	THQ	Mean concentration	SD	RfD (mg/kg/day)
Mumtaz Iraqi frozen chicken burger	Cd	Health risk	Hi > 1	8.2088	11.4923	5.9615	0.0010
	Cr	Health risk	Hi > 1	1.4031	5.8932	4.0615	0.0030
	Zn	No Health risk	Hi < 1	0.0407	17.1060	0.1898	0.3000
	Ni	No Health risk	Hi < 1	0.1133	3.1737	0.1410	0.0200
	Pb	No Health risk	Hi < 1	0.1204	0.5899	0.0612	0.0035
	Co	No Health risk	Hi < 1	0.2215	0.0930	0.0472	0.0003
	Mn	No Health risk	Hi < 1	0.4249	83.2895	8.3512	0.1400
			Hi	10.532			
Sadia frozen Brazilian beef burger	Cd	Health risk	Hi > 1	8.3547	11.6966	4.9436	0.0010
	Cr	Health risk	Hi > 1	7.1822	30.1650	15.879	0.0030
	Zn	No Health risk	Hi < 1	0.0423	17.7645	0.1958	0.3000
	Ni	No Health risk	Hi < 1	0.0361	1.0117	0.5581	0.0200
	Pb	No Health risk	Hi < 1	0.1081	0.5299	0.1661	0.0035
	Co	No Health risk	Hi < 1	0.1092	0.0459	0.0000	0.0003
	Mn	No Health risk	Hi < 1	0.5244	102.7731	9.0936	0.1400
			Hi	16.357			
fresh Iraqi beef burger	Cd	Health risk	Hi > 1	9.8956	13.8538	2.2248	0.0010
	Cr	Health risk	Hi > 1	6.8354	28.7087	4.3419	0.0030
	Zn	No Health risk	Hi < 1	0.0393	16.4872	0.2781	0.3000
	Ni	No Health risk	Hi < 1	0.0333	0.9318	0.6659	0.0200
	Pb	No Health risk	Hi < 1	0.0811	0.3974	0.0874	0.0035
	Co	Health risk	Hi > 1	1.3446	0.5647	0.2428	0.0003
	Mn	No Health risk	Hi < 1	0.0934	18.3052	2.6140	0.1400
			Hi	18.322			
Frozen Turkish Pastrami	Cd	Health risk	Hi > 1	13.8206	19.3488	4.5268	0.0010
	Cr	Health risk	Hi > 1	3.9921	16.7670	10.5106	0.0030
	Zn	No Health risk	Hi < 1	0.0231	9.6842	0.1067	0.3000
	Ni	No Health risk	Hi < 1	0.0571	1.5992	0.8108	0.0200
	Pb	No Health risk	Hi < 1	0.0264	0.1296	0.0584	0.0035
	Co	No Health risk	Hi < 1	0.7156	0.3006	0.0462	0.0003
	Mn	No Health risk	Hi < 1	0.0738	14.4554	0.9667	0.1400
			Hi	18.708			
Iraqi Pastrami	Cd	Health risk	Hi > 1	14.7158	20.6022	5.1180	0.0010
	Cr	Health risk	Hi > 1	7.3209	30.7476	12.9093	0.0030
	Zn	No Health risk	Hi < 1	0.0234	9.8435	1.4958	0.3000
	Ni	No Health risk	Hi < 1	0.0774	2.1669	1.1348	0.0200
	Pb	No Health risk	Hi < 1	0.0739	0.3623	0.1473	0.0035
	Co	No Health risk	Hi < 1	0.7695	0.3232	0.1296	0.0003
	Mn	No Health risk	Hi < 1	0.0168	3.3005	0.9446	0.1400
			Hi	22.997			

4. DISCUSSION

In frozen chicken burgers, manganese was present at the highest level, zinc was the second highest, while lead and cobalt were the lowest. Iwegbue et al. [23] found elevated manganese and zinc concentrations in processed poultry products compared to other heavy metals. Korish and Attia [24] identified zinc in meat products, although within health standards. The current chromium and nickel levels in chicken meat and its products are comparable to those reported by Karaaslan and Yaman [25], who found moderate amounts. The present lead and cobalt levels are lower than those reported by Emami et al. [26], showing that contamination levels depend on manufacturing procedures and raw material sources. These results show that frozen chicken burgers may contain heavy metals, but most do not exceed internationally recommended maximum limits, indicating that contamination is often related to the agricultural environment, feed sources, and drinking water.

Manganese was found in maximum amounts in frozen beef burgers, while cobalt, lead, and nickel were present at the lowest levels. This matches the findings of Albashr et al. [27]. A study in Egypt found that imported frozen Brazilian, Colombian, and Indian beef burgers had average cadmium concentrations of 0.06 ± 0.01 mg/kg, 0.14 ± 0.01 mg/kg, and 0.19 ± 0.01 mg/kg, respectively. The average lead concentration in imported frozen Brazilian, Colombian, and Indian beef samples was 0.35 ± 0.02 mg/kg, 0.41 ± 0.02 mg/kg, and 0.52 ± 0.03 mg/kg, respectively. Compared to the maximum permissible limits set by the Egyptian General Authority for Standardization and Metrology (EOS) [28], imported frozen Indian meat had the highest residual concentration of heavy metals (cadmium and lead), followed by Colombian and Brazilian meat [29].

Chromium was highest in fresh hamburger meat, manganese was second, and lead and cobalt were the lowest, according to the study. This matches the findings of Asli et al. [30]. Badis et al. [31] tested fresh cow, sheep, and camel meat from northern and southern Algeria for iron, copper, zinc, lead, cadmium, and mercury. They found that lead and cadmium levels in meat samples surpassed FAO standards for fresh meat, whereas copper and mercury levels were below permissible limits. The lowest and greatest zinc amounts were reported in northern camel meat and southern sheep meat, respectively, with no samples exceeding the prescribed limits [32].

Lead and cadmium contents in the tests exceeded the European Commission's 2006 standard. The researchers believed that contaminated animal feed caused liver and kidney bioaccumulation of lead and cadmium. After continuous exposure to low levels in a contaminated environment, these elements may accumulate in tissues due to slow clearance. The heavy metal concentration study in frozen pastrami meat shows that hazardous and essential metal levels fluctuate. Cadmium (19.34 ± 4.52) had the highest concentration, followed by chromium (16.76 ± 10.51) and manganese (14.45 ± 0.96). Nickel and zinc were low, but lead and cobalt were very low. Cadmium accumulation in meat tissues can induce kidney failure and bone disease; therefore, high amounts are concerning. Khan et al. [22] found that cadmium in red meat sometimes exceeds WHO guidelines, underscoring the risks of eating contaminated meat. Osaili et al. [33] found lower cadmium levels in beef imported to Jordan than in pastrami, suggesting that processing or manufacturing conditions may boost cadmium accumulation.

Pastrami has high chromium values (16.76). Trivalent chromium (Cr III) has physiological benefits, whereas hexavalent chromium (Cr VI) is toxic and carcinogenic at high concentrations. Perveen et al. [34] found that heat-treated poultry meat may have higher chromium levels due to accidental contamination during slaughter or storage. Manganese levels were less problematic (14.45), although excessive levels can induce neurological issues, according to the WHO [35], when present in contaminated food. However, nickel (1.59) and zinc (9.68) were near normal values. Zinc is needed for enzyme function, but prolonged nickel toxicity can induce allergies and respiratory diseases, according to Mastromatteo [36]. Lead (0.2) and cobalt (0.30) were low, which is favorable because lead is one of the most dangerous pollutants associated with neurological disorders in consumers, as shown by Mushtaq et al. [37], who found much higher levels in beef slaughtered randomly in Pakistan.

EDI values for heavy metals in processed meat products, such as burgers and pastrami, both frozen and fresh, were typically below the TDI for most metals, indicating that consuming these products in moderation does not pose a major health risk [38]. Cadmium EDI values were much lower than the acceptable daily intake (1 µg/kg body weight/day), ranging from 0.0082 to 0.0147 µg/kg body weight/day. These findings support recent research showing that cadmium exposure from processed meat is generally within safe levels and does not harm public health [39].

Chromium levels in Iraqi pastrami reached 0.0220 µg/kgbw/day, but remained within the permitted limit of 3 µg/kgbw/day. Recent research has revealed that chromium in processed meats is usually minimal and that food intake poses few health hazards unless environmental pollution or metallic additives are involved [40]. EDI values for lead ranged from 0.0001 to 0.0004 µg/kgbw/day, which is below the allowed limit of 3.5 µg/kgbw/day. Some studies suggest that lead may accumulate in processed meat products if raw materials or preparation procedures are contaminated, requiring close monitoring of feed quality and raw materials. Zinc, nickel, manganese, and cobalt EDI values were within acceptable limits for most products, with manganese in frozen pastrami (0.0734 µg/kgbw/day) indicating the need to monitor mineral accumulation, particularly with repeated exposure or multiple food sources [24].

5. CONCLUSION

The health assessment revealed that consuming the studied processed meat samples poses a real risk to consumers due to excessive contamination with cadmium and chromium. Iraqi pastrami recorded the highest levels of contamination and daily intake (EDI), exceeding internationally permitted limits. Target Hazard Quotient (THQ) calculations showed values greater than one for these two elements in all samples, leading to a high cumulative hazard index (HI) ranging from 10.53 to 22.99. These values far exceed the safe limit and confirm the presence of cumulative health risks associated with systemic and renal toxicity. Meanwhile, the remaining elements (zinc, nickel, lead, cobalt, and manganese) remained within safe ranges for human consumption.

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