ORIGINAL RESEARCH article

Estimation of heavy metal concentrations in imported frozen meat sold in the Libyan market

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Abstract: Heavy metals are chemical elements with a toxic effect on human and animal bodies. The expansion of industries has led to substantial increases in the levels of these heavy metals in the environment. This study examines the levels of heavy metal contamination in imported frozen meat, given its importance for food safety and consumer health. A total of 30 meat samples (including chicken, beef, lamb, and some processed products) were randomly collected from various commercial markets in Tripoli. Following acid digestion, concentrations of lead, cadmium, chromium, and copper were determined using Atomic Absorption Spectrophotometry. All samples complied with Libyan and International safety limits for cadmium, chromium or copper, while only one sample (3.3%) exceeded the permissible limit for lead. Statistical analysis revealed no significant variation in lead, cadmium, or chromium concentrations across meat types, cuts, or countries of origin. Copper levels, however, varied significantly by meat type. These findings indicate the overall safety of imported meat products regarding heavy metal contamination, although continuous monitoring remains essential.

Introduction

Meat plays a vital role in human nutrition due to its high-quality protein and essential micronutrient content, including iron, zinc, selenium, and vitamin B12 [1]. In Libya, meat-especially poultry, lamb, camel, and beef-is a central dietary component, with an estimated daily per capita availability of 86 grams [2]. Nevertheless, contamination of food, food supplements and meat with heavy metals poses significant public health risks [3-5]. These metals can enter the food chain through contaminated animal feed and water sources affected by industrial and agricultural pollutants. Due to their non-biodegradable nature and long biological half-lives, heavy metals accumulate in the environment and organisms [6]. Chronic dietary exposure to lead (Pb) and cadmium (Cd) has been associated with renal, hepatic, neurological, and cardiovascular diseases [7]. To address these risks, international bodies such as the World Health Organization (WHO) and Codex Alimentarius have established maximum allowable levels for heavy metals in food [8]. However, studies have revealed that meat products from many regions, particularly parts of Africa and Asia, often exceed these limits [9]. This study aims to quantify the concentrations of Pb, Cd, chromium (Cr), and copper (Cu) in imported frozen meat available in Tripoli markets and evaluate their compliance with established safety standards.

Materials and methods

Study design and sample collection: This cross-sectional study included 30 imported meat samples, comprising chicken, beef, lamb, and processed meat, randomly collected from various commercial markets in Tripoli, Libya between February 1st and May 15th, 2025. The meat products originated from Brazil, the United States, Jordan, Spain, and Australia. The analysis was conducted at the Center for Food and Drug Control. The collected meat types included: Boneless frozen beef (various cuts such as rib, neck, shoulder, chest), whole boneless frozen beef, frozen chicken without giblets (various cuts), chicken thighs and quarters, chicken products like zinger, crispy fillet, cordon bleu, nuggets, Bone-in frozen lamb (shoulder), and whole boneless frozen lamb.

For safety assessment, the concentrations were compared to the permissible limits established by Libyan and European standards for Pb, Cd, and Cr. As for Cu, due to the lack of a specific Libyan maximum allowable limit, the reference value of 1.0 mg/kg was adopted based on previous studies [10]. This is justified by the fact that Cu is an essential trace element for the human body, and its health effects are usually evaluated based on daily intake levels rather than its concentration in food [11].

Sample preparation and analysis: Among the various available methods for detecting heavy metals in meat, this study utilized Atomic Absorption Spectrophotometry (AAS) for both quantitative and qualitative analysis. This technique measures the specific wavelengths of photons emitted by atoms, with each element emitting a unique set of wavelengths. By analyzing these wavelengths, the elements present in the sample can be identified and measured. Before analysis, samples were mechanically homogenized. 1.0 g of the dried sample was weighed and placed in a digestion flask. To each sample, 10.0 mL of concentrated nitric acid (HNO_3) was added and gently heated until the solution became clear. If necessary, a few drops of perchloric acid (HC_1O_4) or hydrogen peroxide (H_2O_2) were added during heating to complete digestion. After digestion and cooling, the solution was diluted to 50.0 mL using high-purity distilled water. The resulting solution was filtered appropriately to remove any solid particles and was then ready for metal absorption measurement using the AAS method.

Reagents and instrument calibration: High-grade analytical reagents were used in this study, including deionized water (Millipore), concentrated nitric acid (65.0%), diluted nitric acid (0.1 M), concentrated perchloric acid (used when needed), and hydrogen peroxide (30.0%). Standard solutions (1000 mg/L) for Pb, Cd, Cu, and Cr were prepared by dissolving 1.000 g of pure metal in distilled nitric acid and diluting to 1.0 L. These stock solutions were used to prepare working standard solutions of known concentrations (in mcg/mL) using diluted nitric acid (0.1 M) for calibration purposes. No ethical approval is needed for this study; however, an initial approval was obtained from the committee of Rowad Alelm University, Tripoli, Libya (RAU, 0001-2025).

Statistical analysis: Statistical analysis was conducted using SPSS version 26. One-way ANOVA was used to assess the relationship between heavy metal concentrations (Pb, Cd, Cr, and Cu) and meat type, cut, and origin. The level was determined at $p<0.05$ to be considered statistically significant.

Results

Table 1 shows different range levels of the heavy metals according to the Libyan standards. Indeed, all the values of Cd and Cr are well below the Libyan permissible limits. However, only Pb exceeds the Libyan limit of 0.05 mg/kg in one sample (max=0.2570 mg/kg). On the other hand, Cu, although not regulated under the Libyan standards, was assessed using a reference value of 1.0 mg/kg and was found to be within safe limits in all samples.

Figure 1 shows that chicken samples made up half of the total samples, while beef and lamb samples were nearly evenly distributed (about 1/4 each).

Table 1: Mean, standard deviation, minimum, and maximum values of heavy metals

Heavy metal	Mean (mg/kg)	Std. deviation	Minimum	Maximum	Libyan Standard Limit (mg/kg)
Lead (Pb)	0.0145	0.0480	0.0020	0.2570	0.10
Cadmium (Cd)	0.0017	0.0003	0.0010	0.0023	0.05
Chromium (Cr)	0.0244	0.0204	0.0090	0.0830	1.00
Copper (Cu)	0.5142	0.2660	0.1187	0.9233	*Not specified*

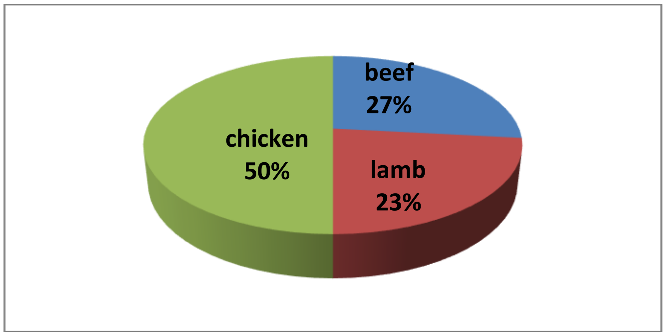

Figure 1: The percentage of the sample type

Figure 2 shows a wide variety of chicken products (47.0%). Cuts were chosen to represent the typical frozen meat products available commercially. Lamb was represented 33%, and Boneless beef was 17.0%, while 3.0% of whole boneless beef.

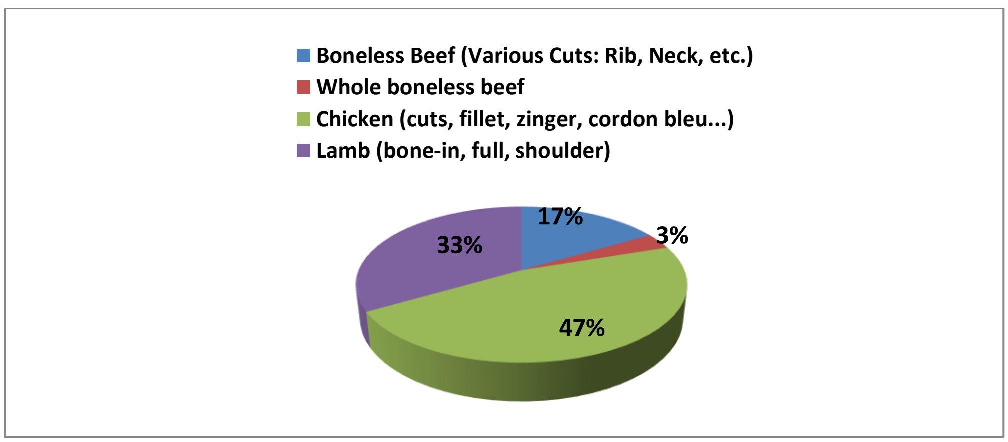

Figure 2: Different percentages of sample cuts

Figure 3 shows the origin of the samples in the Libyan market. Brazil was the largest exporter among the sampled products and the remaining countries had almost equal representation.

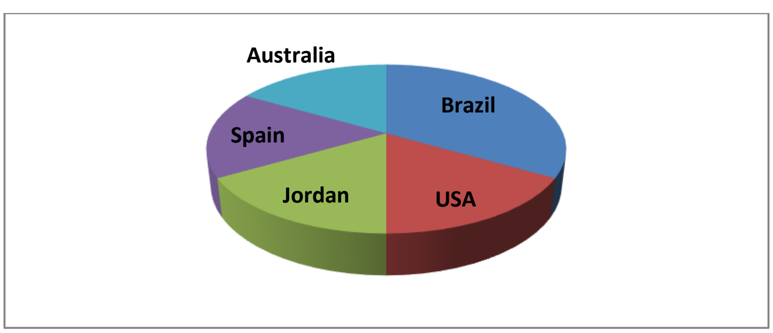

Figure 3: Frequency by country of origin

Table 2 shows that one sample (3.3%) had a Pd level exceeding the Libyan safe limit of 0.05 mg/kg and the remaining samples are within the limit. All the samples had Cd concentrations safely below the maximum permissible level (**Table 3**). Cr concentrations were well below safety thresholds in all samples (**Table 4**). Cu levels in all samples were below the reference safety level of 1.0 mg/kg (**Table 5**).

Table 2: Lead concentration levels

Lead level	Frequency	Percent
Below normal (<0.10)	29	96.7
Normal (=0.10)	0	0.0
Above normal (>0.10)	01	3.3
Total	**30**	**100**

Table 3: Cadmium concentration levels

Cadmium level	Frequency	Percent
Below normal (<0.05)	30	100
Normal (=0.05)	0	0.0
Above normal (>0.05)	0	0.0
Total	**30**	**100**

Table 4: Chromium concentration levels

Chromium level	Frequency	Percent
Below normal (<1.0)	30	100
Normal (=1.0)	0	0.0
Above normal (>1.0)	0	0.0
Total	**30**	**100**

Table 5: Copper concentration levels

Copper level	Frequency	Percent
Below 1.0 mg/kg	30	100
Equal to 1.0 mg/kg	0	0.0
Above 1.0 mg/kg	0	0.0
Total	**30**	**100**

As shown in **Table 6**, the chicken samples showed the highest Pd and Cd levels in this study, though still within the safe limits according to the Libyan Standards. Moreover, the beef samples had the highest Cr and Cu concentrations. **Table 7** shows that Jordan samples had significantly higher Pd concentrations with a mean of 0.07446 mg/kg. The USA samples had the highest Cd average. Cr was highest in high concentrations of Australian samples. Cu was most elevated in the Spanish samples. **Table 8** illustrates that Cu concentration varied significantly by meat type. Therefore, no significant difference in the metal concentrations based on the part of the meat sampled in the current study. Additionally, no significant differences in metal levels across different countries of origin.

Table 6: Heavy metal average levels by meat type

Meat	Lead	Cadmium	Chromium	Copper
Beef	0.0025	0.00176	0.0280	0.7541
Lamb	0.00212	0.00151	0.0249	0.6728
Chicken	0.02667	0.00184	0.02237	0.31224

Table 7: Heavy metal average levels by country of origin

Country	Lead	Cadmium	Chromium	Copper
Brazil	0.00289	0.00182	0.0249	0.5835
USA	0.0027	0.001867	0.0265	0.2197
Jordan	0.07446	0.00182	0.01533	0.4500
Spain	0.00218	0.00132	0.02506	0.7360
Australia	0.002	0.001813	0.030067	0.51266

Table 8: Relationship between meat type and metal concentrations

Metal	P-value of Meat type	P-value of Meat cut	P-value of Country of origin
Lead	0.217	0.771	0.795
Cadmium	0.297	0.123	0.165
Chromium	0.535	0.934	0.821
Copper	0.000	0.978	0.596

Discussion

A total of 30 samples representing 16 types of imported and processed meat products (beef, lamb, and poultry) were collected from several retail outlets in Tripoli. This sampling approach was similar to a study conducted in the Eastern Province of Egypt [12], where 30 meat samples (15 chilled and 15 frozen) were collected from local markets and analyzed for heavy metal contamination. Comparable studies were also carried out in Libya, including one conducted in Al-Marj City [13], which aimed to assess the levels of heavy metals in imported processed meat products. The results of the current study indicated that all meat samples analyzed fell within the safe limits for heavy metal concentrations according to Libyan specifications, a finding consistent with a study conducted in Kazakhstan [14]. That study concluded that both local and imported poultry meats available on the market were safe for consumption. On the contrary, results diverged significantly from those found in a Nigerian [10], which reported that levels of Pd, Cu, and iron in processed meat exceeded the safety limits set by the World Health Organization. For example, Pd levels reached 1.018 mg/kg, far above the permissible limit of 0.05 mg/kg, suggesting potential health risks. In the current study, Cu had the highest mean concentration among all analyzed metals, ranging from 0.1187 to 0.9233 mg/kg, but remained within acceptable reference levels. Unlike Pd and Cd, Cu typically does not have a fixed maximum limit in most local or international standards (e.g., Libyan standards or WHO guidance), because Cu is an essential nutrient. The estimated average daily intake required by adults is 2-3 mg/day, and Cu toxicity usually depends on total daily exposure rather than its concentration in individual food products. The WHO has proposed a tolerable daily intake of 0.5 mg/kg body weight/day for Cu [8]. By comparison, the Nigerian study reported a Cu level of 1.445 mg/kg, which exceeds the values recorded in the present study. Similarly high levels were observed in a study conducted in Qalyubia, Egypt [15], where Cu levels reached 2.17 mg/kg in poultry meat, suggesting that contamination may originate from product components such as meat, additives, or spices. Regarding Cd, our study revealed moderate concentrations across 100% of the samples. However, it is important to note that the AAS used in this analysis cannot differentiate between Cr forms, Cr (III) and Cr (VI). Only total Cr is measured. Cr (III) is generally non-toxic and essential, while Cr (VI) is highly toxic and carcinogenic. For this reason, advanced analytical methods (e.g., chromatographic separation coupled with mass spectrometry) are recommended to determine the proportion of Cr (VI) [16]. The Cr concentrations observed in this study ranged between 0.0090 and 0.0830 mg/kg, remaining safely below the Libyan standard. These findings differed from the Libyan study in Al-Marj [13], which reported Cr levels ranging from 0.136 to 0.811 mg/L, exceeding WHO and Codex limits. For Pd, the minimum and maximum values ranged from 0.0020 to 0.2570 mg/kg, and one sample exceeded the Libyan limit. In contrast, Mohamed and others [9] in

Egypt found Pd levels as high as 0.89 mg/kg, with 66.6% of the samples exceeding permissible limits. These results are similar to those in a Lebanese study [17], which found that 61.0% of canned meat samples had Pd concentrations ranging from 0.2 to 816.1 µg/kg, suggesting that canned meats may contain higher heavy metal concentrations than other meat types. As for Cd, its concentrations ranged between 0.0010 and 0.0023 mg/kg, and 100% of samples were within safe limits. These results agree with findings in Astana, Kazakhstan [14], which reported Cd levels between 0.51 and 0.65 µg/kg, considered safe for consumption. However, they contradicted the results in Assiut, Egypt [18], where Cd levels ranged from 0.01 to 0.382 mg/kg, and 60.0% of pastrami and 36.67% of luncheon meat samples exceeded safe limits.

The statistical analysis in the current study revealed no significant relationship between the type of meat (chicken, beef, or lamb) and the concentrations of Pd, Cd, or Cr, suggesting that these metals are evenly distributed across meat types. These results differed from a study in Erbil, Iraq [19], which found significant variations in heavy metal concentrations among beef, lamb, and buffalo meat. However, a highly significant relationship was observed between meat type and Cu concentration, indicating that Cu levels are influenced by the type of meat. This supports findings in Egypt [15], where significant variation in Cu levels was linked to poultry processing methods and ingredients. There was no significant relationship between the concentration of any of the four metals (Pd, Cd, Cu, Cr) and the meat part (e.g., shoulder, thigh, breast). These findings contradict those in Sebha, Libya [20], who found that Cu levels in chicken bones were significantly higher than in flesh or skin. Likewise, the current results showed no significant association between metal concentrations and country of origin, indicating that differences between exporting countries did not influence contamination levels. This matches the previous findings [14], who found no significant differences in the metal content of poultry meat from various countries. On the other hand, a global meta-analysis reported regional variation in contamination levels, particularly elevated Pd and Cd levels in red meat from Asia and Africa, often exceeding international safety limits [9]. This suggests that the country of origin may play a significant role in contamination risk, especially in countries with poor environmental and food safety regulations.

Conclusion: This study focused on evaluating the contamination levels of heavy metals in imported red meat and poultry products available in Tripoli markets. Although the findings suggest that most samples are within safe limits, there remains an urgent need for enhanced regulation and stricter monitoring of the quality of imported meat, both red and white types. Importing companies must adopt more rigorous quality assurance procedures to ensure that their products are free from hazardous heavy metals and safe for consumption.

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تقدير تركيزات المعادن الثقيلة في اللحوم المجمدة المستوردة المباعة في السوق الليبية

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1 قسم التكنولوجيا الطبية، جامعة رواد العلم، و2 مركز الرقابة على الأغذية والأدوية، طرابلس، ليبيا
*** المؤلف المسؤول عن المراسلات**

الملخص: المعادن الثقيلة عناصر كيميائية ذات تأثير سام على جسم الإنسان والحيوان. وقد أدى التوسع الصناعي إلى زيادات كبيرة في مستويات هذه المعادن في البيئة. تتناول هذه الدراسة مستويات تلوث المعادن الثقيلة في اللحوم المجمدة المستوردة، نظرًا لأهميتها في سلامة الغذاء وصحة المستهلك. جُمعت 30 عينة من اللحوم (بما في ذلك الدجاج ولحم البقر ولحم الضأن وبعض المنتجات المصنعة) عشوائيًا من أسواق تجارية مختلفة في طرابلس. بعد الهضم الحمضي، حُددت تركيزات الرصاص والكادميوم والكروم والنحاس باستخدام مطياف الامتصاص الذري. امتثلت جميع العينات لحدود السلامة الليبية والدولية للكادميوم والكروم والنحاس، بينما تجاوزت عينة واحدة فقط (3.3%) الحد المسموح به للرصاص. لم يُظهر التحليل الإحصائي أي اختلاف يُعتد به إحصائيًا في تركيزات الرصاص أو الكادميوم أو الكروم بين أنواع اللحوم أو القطع أو بلدان المنشأ. ومع ذلك، اختلفت مستويات النحاس اختلافًا كبيرًا باختلاف نوع اللحم. تشير هذه النتائج إلى سلامة منتجات اللحوم المستوردة بشكل عام فيما يتعلق بتلوث المعادن الثقيلة، على الرغم من أن المراقبة المستمرة تظل ضرورية.