Journal of Food Protection 86 (2023) 100048

Contents lists available at ScienceDirect

Journal of Food Protection

journal homepage: www.elsevier.com/locate/jfp

Review

# A Review of Heavy Metals Accumulation in Red Meat and Meat Products in the Middle East

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ARTICLE INFO

*Keywords:*
Heavy metals
Middle Eastern countries
Red Meat
Trace elements

ABSTRACT

The problem of food contamination is a matter of concern, which can cause health complications in consumers. Several international organizations have created standard permissible limits for heavy metals in meat products. Livestock such as sheep, cattle, camels, and goats are the most important sources of protein meat in the Middle East (ME) countries. Contamination of meat products with heavy metals (HMs) may be a threat to human health. Various scattered studies have been conducted in the Middle East on the contamination of red meat and meat products with HMs however, a comprehensive review on this subject has not yet been published. This study aimed to investigate the status of HMs in both raw and processed types of meat in the ME. The results of this narrative review revealed that in many ME countries, contamination of red meat with HMs was excessive. Therefore, more monitoring of livestock conditions and red meat products consumed in some Middle East countries seems necessary.

**Contents**



Meat and its products play an important role in human nutrition. Meat especially red meat is an excellent source of protein and contains minerals such as zinc (Zn), calcium (Ca), selenium (Se), iron (Fe), and vitamins (Haytowitz & Pehrsson, 2018). Red meat also has low intramuscular fat and cholesterol level, gaining preference among many meat consumers (Al-Zuhairi et al., 2015).

Despite these advantages, red meat can be a source of toxic substances by bioaccumulation of heavy metals (HMs) and trace elements

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https://doi.org/10.1016/j.jfp.2023.100048
Received 15 August 2022; Accepted 18 January 2023
Available online 4 February 2023
0362-028X/

(TEs) at a toxic level which can increase the risk of specific diseases (Demirezen & Uruç, 2006; Rudy, 2009). Elements are categorized as essential trace elements (i.e. Fe, Zn, and Se), macroelements (Sodium (Na), Ca, and Magnesium (Mg)), and toxic elements or HMs (i.e. arsenic (As), cadmium (Cd), lead (Pb), nickel (Ni), and mercury (Hg)) (Mikulewicz et al., 2013). TEs are considered essential elements which are present in very small quantities in the body and contribute to many biological and metabolic processes that are essential for body homeostasis, while inappropriate exposure to these elements may result in several health disorders (Divrikli et al., 2006).

Toxic elements or HMs are metallic elements with atomic weight between 63.5 and 200.6 and a specific gravity of more than 5 that have gradually

accumulated in the food chain with negative human health impacts. Many of these elements are not only nonessential for biological life but also have serious toxic properties and are involved in different signaling pathways in carcinogenesis (Chen & Costa, 2018; Dasgupta et al., 2020; Emami et al., 2022; Nkansah & Ansah, 2014). HMs are increasing with an increasingly advanced human civilization as well as the exploitation of geological resources (Aslam et al., 2011; Grodzińska et al., 2003; Valko et al., 2005). In the food chain, meat and meat-derived products polluted with HMs are an important route of exposure to toxic metals and may cause serious health problems (Badis et al., 2014; Obeid et al., 2016). HMs can neither be degraded nor can be destroyed and may accumulate in the tissues such as muscle, kidneys, and liver. On the other hand, these tissues clear the body from toxic elements, so these organs are known as target tissues for HM analysis (Abou-Arab, 2001).

Exposure of animals to the toxic elements and entrance of these elements into the animal's body happens in several ways, including inhalation of polluted air, or feeding by contaminated water and plants. Industrial activities for instance coal burning or metal smelting where animal pasture is grown can affect the cattle and their products (Beyer et al., 2007). Consequently, human consumption of this toxic meat could affect human health and increase the risk of serious threats to populations' health due to the nervous, metabolic, and cardiovascular adverse effects (Bhardwaj et al., 2021; Faroon et al., 1994; Freiberg et al., 1985; Mudgal et al., 2010).

The permissible concentrations of HMs in foodstuffs have been set by international organizations such as the Food and Agricultural Organization (FAO), World Health Organization (WHO), and US Environmental Protection Agency (US-EPA) (Joint et al., 2011). Recently, the presence of HMs in fresh, frozen, and processed meat has been reported in different countries of the Middle East (ME) region (WorldAtlas, 2022). Consuming food products contaminated with HMs is an important public health challenge because of HM bioaccumulation through food chains. Several studies have been conducted on HM concentrations in various livestock and their products in different countries in the ME region, but no literature review has been done. Thus, the present study summarizes findings of HM status in different types of red meat products consumed in the ME region and also discusses their possible sources and exposure pathways.

## Materials and methods

We undertook the present narrative review by searching all English scholarly literature through Google Scholar, Scopus, and PubMed. Given that a review article on this topic for ME countries has not yet been published, the year 2000 was selected as a starting point for relevant studies to include in this review. We searched for published articles that reported the HM intake and status in livestock and their products in ME. The databases were searched using Boolean words "OR" and "AND" with text word terms and/or the medical subject heading (MeSH) terms to obtain all relevant articles. The key terms were as follows: heavy metal(s), trace element(s), livestock, cattle, cow, sheep, goats, camel, buffalo, lamb, calves, red meat, and the Middle East countries. MEDLINE's list of countries was used as a base for Middle Eastern countries. The following information was extracted from the articles: first author(s), year of study, study region, animal species, and the sample size of the study, HM measuring method, evaluated metals/elements, outcoming data, and Digital Object Identifier (DOI) of the study. The characteristics of included studies and the extracted information from each study are summarized in.

## Results and discussion

**HM concentration studies.** The 43 studies in the Middle East have reported HM concentration in the various types of meat in different regions and/or different seasons. However, four of these studies were excluded, due to not being accessible through English searching (they were as the Persian articles or theses), or had incomplete information. Therefore, 39 studies were included in this study. A summary of the findings is presented in Table 1.

Based on our literature survey, the majority of HM studies among all livestock categories in the ME have been conducted in beef meat products, and studies on sheep or lamb meat products, goats, and camels came second, third, and fourth, respectively. Temporal classification of all 39 selected papers showed that the majority of them were published after 2015. About 18% of studies were published before 2015, while 82% were published in 2015 and thereafter. This may be due to the growing concern about HM pollution caused by the acceleration of industrialization in recent decades (Han et al., 2020).

Most studies reviewed reported a sample size > 30, but some of them have not determined the number of samples used in the analysis. Ten relevant studies were conducted in Iraq, eight in Egypt, and four in Iran, and Saudi Arabia. Three of them (Turkey, Lebanon, and Algeria) had two studies each, one from Kuwait, Jordan, Bahrain, Pakistan, Syria, Palestine, and Sudan. No studies were identified from other ME countries. The present study aimed to investigate the status of HMs in different types of red meat products consumed in ME countries, their probable sources, and pathways of their transmission to animals. This review study showed high levels of some toxic metals including Pb, Cd, Cu, and As in fresh, frozen, and canned meat exceeded the standards, which may play a role in the development of metabolic or nervous system diseases in the population of that contaminated area.

**Algeria: Nonprocessed meat (fresh meat).** Bendeddouche Badis et al. (2014) evaluated the concentrations of Fe, Cu, Zn, Pb, Cd, and Hg in fresh meat of beef, sheep, and camel in north and south of Algeria and reported that Pb and Cd levels in different meat samples were more than the maximum levels allowed by FAO for fresh meat, and Cu and Hg levels were below the accepted limits. Minimum and maximum concentrations of Zn in the northern area were for camel meat and in the southern area were for sheep meat and neither of the samples exceeded the recommended limit. In this study, the type of pasture, environmental conditions, and development of industrialization were mentioned as the effective factors for different levels of HMs detected in animal meat. Indeed, the high level of metals in Algerian meat products may be due to a polluted environment per se, or contamination from agricultural activities and animal feed. Contamination may be transmitted to animals through direct sewage and industrial effluents. Emissions from vehicles and dirty slaughterhouses can also be major sources of meat contamination. In another study in Algeria, the concentrations of Cd and Pb in the liver and kidney of bovine (older than 4 years) and ovine (older than 1 year) were analyzed (Zenad et al., 2020). In evaluated samples, Pb and Cd concentrations were more than the maximum limit proposed by the European Commission (EC) 2006. A significant difference in Cd concentrations was seen between age and sex groups so that the Cd levels in the liver and kidney were higher among the female animals older than four years. Zenad et al. (2020) concluded that sex and age significantly affect the accumula-

**Table 1**
Studies evaluated the accumulation of heavy metals/trace elements in fresh meat in the Middle East between (2000 and 2022)

| The first author(s) | Year | Country/Region (s) | Animal/ sample/ Number | Measuring method | Essential trace elements | Toxic elements | Outcoming data | DOI/PMCID/ISSN |
|---|---|---|---|---|---|---|---|---|
| Zenad, Wahiba (Valko et al., 2005) | 2020 | Algeria, east and north of Algeria | Ovine (n = 100)/ bovine (n = 80), liver/ kidney | GFAAS | | Cd, Pb | In some liver and kidney samples from bovine (>4 years of age) and ovine animals (>1 year of age), concentrations of Pb and Cd have exceeded the EC's maximum limit for 2006. Consumption of large amounts may result in a potential health risk. | 10.15835/buasvmcn-vm:2020.0002 |
| Bendeddouche Badis (Badis et al., 2014) | 2014 | Algeria, north, and south of Algeria | Beef/sheep/ camel, fresh meat (n = 360) | AAS | Fe, Cu, Zn, | Cd, Hg, Pb | A high and often exceeded health authorities' legal limits concentration of all essential elements (concentration order: Fe > Zn > Cu > Pb > Cd > Hg) was found in the chosen products. | 10.9734/ARRB/2014/7430 |
| Akotb Abou-Arab (Abou-Arab, 2001) | 2001 | Egypt | Bovine/ buffalo/elk/ sheep/goat , muscle/ liver/ kidney/ heart/ spleen (n = 270) | AAS | Mn, Cu , Fe Zn | Pb, Cd | Pb, Cd, Zn, Fe, M and n, and Cu in industrial area samples were higher than those in rural areas. | 10.1016/S0278-6915(00) 00176-9 |
| Samia EL-Safy (El-Ghareeb et al., 2019) | 2008 | Egypt | Beef, meat (n = not mentioned) | AAS | Cu, Co, Cr, Zn, Fe | Pb, Ni | Pb, Cd, and Zn concentrations were higher than the permissible limit. | 10.21608/ asejaiqjsae.2008.3177 |
| Wael Mohamed Lotfy (Ibraheem and Abdullah, 2014) | 2013 | Egypt | Buffalo, muscle/ liver (n = 36) | EAAS | Cu, Zn | Cd, Cr, Pb | Cu and Zn concentration in the liver was higher and lower than in muscles, respectively. | PMC4266119 |
| Amany Faried Hasballah (Grodzińska et al., 2003) | 2019 | Egypt | Cow, meat (n = 30) | F.A.A.S | Zn, Cu, Co, Fe | Pb, Cd | Cd concentration was within the safe limit, and Fe, Pb and Cu were higher than that. Concentrations of HMs had a variation followed the order: Zn > Fe > Cu > Pb > Cd > Co. | 10.21608/joese.2019.158399 |
| Behnaz Bazargani-Gilani (Bazargani-Gilani et al., 2016) | 2016 | Iran, Hamedan | Cattle /sheep / goats, liver/ kidney (n = 90) | AAS | Zn, , Cu, Mn, Fe | Cd, Pb | Pb was higher than the permitted limit. Cd was within the permitted limit, and Fe was normal. | 10.29252/arakmu.10.6.7 |
| Razzagh Mahmoudi (Joint et al., 2011) | 2018 | Iran, Ardebil, uromie,tabriz | Buffalos/ muscle (n = 30) | ASS | | Pb | Pb concentration (in 3.33% of samples were higher than the permissible limits | 10.19082/6148 |
| Majid Hashemi (Han et al., 2020) | 2018 | Iran, Shiraz | Cow, muscle/ liver / kidney (n = 216) | ICP-OES | Cu, Zn | Cd, Pb, Hg | Cd, Hg, Cu, and Zn concentrations (in muscle, liver, and kidney) and Pb concentrations (in liver and kidney) were below, and Pb concentrations in muscle were higher than the MRL. | 10.1016/j.ecoenv.2018.02.058 |
| Tayebeh Zeinali (Swaileh et al., 2009) | 2019 | Iran, Birjand | Beef/ sheep, liver/ kidney/muscle (n = 102) | ICP-OES | Cu, Cr | Cd, Pb, Ni | The highest target hazard quotients were for Pb. Cd in cow kidney had the highest carcinogenic rate. | /10.1007/s12011-019-1637-6 |
| M.W. Ibraheem (Haytowitz and Pehrsson, 2018) | 2014 | Iraq, Tikrit, Samarra, and Baiji | Sheep (n = not mentioned) | ROPME | Cu, Zn | Pb, Cd | Pb and Cd had no significant differences between the 3 regions but Cu had higher in Baiji and Zn had higher concentrations in Tikrit. | 45(4), 425-429 |
| Anees Ali Al-Hamzawi (Al-Hamzawi, 2017) | 2017 | Iraq | Beef/lamb, n = 12 | NAAT | | U | The uranium concentration in beef and lamb in southern Iraq was higher than central Iraq. | Journal the of the University of Babylon for Pure and Applied Sciences. 2017 Dec 1;25 (5):1786-92. |
| Shaimaa Aabbas Sabeeh (Oskarsson et al., 1992) | 2018 | Iraq | Goat/camel (n = 60) | Pyeunican Spa/air-acetylene flame atomic absorption spectrophotometric | | Hg, Pb, Ni, Cd | In goat meat Hg, Pb, Ni showed significant variance ($p < 0.05$) while Cd concentration was not significant. In camel meat, Hg and Pb showed significant variance ($p < 0.05$) in Al-Daghara. | P-ISSN 1818-5746 E-ISSN 2313-4429 |

(continued on next page)

**Table 1** (*continued*)

| The first author(s) | Year | Country/Region (s) | Animal/ sample/ Number | Measuring method | Essential trace elements | Toxic elements | Outcoming data | DOI/PMCID/ISSN |
|---|---|---|---|---|---|---|---|---|
| | | | | apparatus | | | | |
| Nidhal Y. Ykup (Sabow et al., 2020) | 2018 | Iraq | Beef/ buffalo/ lamb (n = 30) | X-ray fluorescence spectrometer | Cu, Fe, Zn, Se, Co, | Ni, Hg, Pb, As | Fe, Co, and Se were within the tolerable limits among the essential metals. All the toxic metals except Hg were higher than international standards limits. | Vol. 26No. 6 (2018) |
| Basim A. Almayahi (Almayahi et al., 2019) | 2018 | Iraq | Cow/lamb (n = 20) | AAS and NAAT | | Cd, Pb | Gadeer sheep had the highest concentrations of Cd and the highest concentration were in waterways found in Kufa cows. | 10.22038/ ijmp.2018.30022.1335 |
| U7 | 2018 | Iraq, Kirkuk, Daqouq, Debis | Goat, muscle/ liver/ kidney (n = not mentioned) | ROPME | Cu, Co | Pb, Cd | The highest Pb concentration was in liver in winter and the lowest was in muscles in summer.<br>Highest level of Cd was in kidney during summer, and lowest was in liver during winter.<br>Cu and CO had the highest concentration in the liver during the summer and winter, respectively. The lowest concentration of Co was recorded in muscle in winter. | —— |
| Abdulghader A. Hussein (Hashemi, 2018) | 2021 | Iraq | Lamb/ yearling/ sheep/cattle, liver n = 232 | X-ray fluorescence spectrometer | Zn, Co | Pb, Ni | Pb concentration in liver of lamb, cattle, sheep, and yearling was higher than toxic level | 10.24017/science.2021.1.6 |
| Samir Mohammed ABD-Elghany (Abd-Elghany et al., 2020) | 2020 | Kuwait | Sheep, muscle/ liver/kidney (n = 600) | AAS | Cr | Hg, As, Pb, Cd | All metals except Cr exceeded the permissible limit. The target hazard quotient and hazard index values for Hg ($>1.0$) in the analyzed sheep samples suggest health risks for people in Kuwait. | 10.4315/0362-028X.JFP-19-265 |
| Pierre J. Obeid (Musaiger et al., 2007) | 2016 | Lebanon, North Lebanon | Beef/goat / lamb, muscle/ heart/ kidney/ liver (n = 240) | GFAAS | | Pb, Cd | No samples have exceeded the MAL for Pb, but livers and kidneys from all three organisms have exceeded the MAL for Cd. | 10.2495/EID160101 |
| Amina Arif (Arif et al., 2021) | 2021 | Pakistan, Lahore | Mutton/ beef, heart/liver/ muscle (n = not mentioned) | GFAAS | Fe, Cu, Zn, Co | Ni, Pb, Cd | There were no detectable levels of Co, Cd, or Pb in the meat samples collected.<br>Fe and Ni concentrations were under tolerable levels.<br>The highest concentration of Zn was present in beef liver. | 10.17582/journal.sajls/2021/ 9.1.1.9 |
| K. M. Swaileh (Rajeshkumar and Li, 2018) | 2009 | Palestine, West Bank | Cattle/sheep goat, liver/ kidneys/heart/ /lungs (n = 140) | GFAAS | Cr, Cu | Cd, Pb, | The results were comparable with or below the results reported from clean sites in different countries. | 10.1007/s00128-009-9704-x |
| Hatem Mohamed (Massadeh and Kharibeh, 2018) | 2017 | Saudi Arabia, Najran | Beef / camel/goat / lamb (n = 4) | ICP-MS | Cr | As, Cd, Pb | As, Cd and Pb concentrations were low in all samples, so red meat could be safe for consumers in Najran. | 0.3390/ijerph14121575 |
| Waleed Rizk El-Ghareeb (Divrikli et al., 2006) | 2019 | Saudi Arabia, Al-Ahsa | Camel/ sheep, muscle/ liver/ kidney (n = 120) | AAS | Cu, Zn, Fe | Pb, Cd, As | Except As residual concentrations of all metals examined were within the maximum permissible limits. | 10.14943/jjvr.67.1.5 |
| Hatem Mohamed (Gaetke et al., 2014) | 2019 | Saudi Arabia, Najran | Cow/ sheep/goat/ / camel, cooked meat (n = 25) | ICP-MS, ICP-OES, AAS | Se, Zn, Mn, Cu | | The elemental concentrations in all samples were within the WHO's recommended ranges. | 10.1186/s13065-019-0588-5 |
| Ghiyath H. Soliman (Pollock and | 2016 | Syria, western Syria (Latakia, | Calves (between 1-3 | AAS | | As | Jableh and Safita calves contained the lowest pollution levels of As. Samples of kidneys from calves from Latakia had the highest pollution | — |

**Table 1** (*continued*)

| The first author(s) | Year | Country/Region (s) | Animal/ sample/ Number | Measuring method | Essential trace elements | Toxic elements | Outcoming data | DOI/PMCID/ISSN |
|---|---|---|---|---|---|---|---|---|
| Roger, 2007) | | Tartus, Jableh and Safita) | years old, muscle/ kidney / liver n = 240 | | | | levels | |
| Onur Yayayürik (Sobhanardakani et al., 2012) | 2017 | Turkey, Izmir | Sheep/ cow, liver (n = not mentioned) | CVAFS for Hg, GFAAS for Cu, Cd, Fe, Mn, and FAAS for Pb | Cu, Fe, Mn, | Pb, Hg | Pb and Cd levels in the samples were below the detection limit of FAAS for all of the samples. Levels of copper in the sheep and cow were the highest in the animal livers examined. In some samples maximum, allowable limits for liver samples were exceeded. | 10.15237/gida.GD17018 |
| Tülay Oymak (Nkansah and Ansah, 2014) | 2017 | Turkey, Sivas | Cattle, lung/liver/ kidney/ muscle (n = 15) | ICP-MS and ICAP-Q | Al, Se, Cr, Mo, Mn, Cu, As | | Cr levels were lower and Cu values were higher than the FAO/WHO limit. | • 10.18596/jotcsa.292601 |

Note: Electrothermal atomic absorption spectrometry (ETAAS), Atomic absorption spectrophotometry (AAS), Nron Activation Analysis Technique (NAAT), The Regional Organization for the Protection of the Marine Environment (ROPME), Graphite Furnace Atomic Absorption Spectrophotometry (GFAAS), Inductively coupled plasma-mass spectrometry (ICP-MS), Flame atomic absorption spectrometry (FAAS), Cold-vapor atomic fluorescence spectrometry (CVAFS), Inductively coupled plasma-optical emission spectrometry (ICP/OES), Food and Agriculture Organization (FAO), World Health Organization (WHO), Maximum permissible levels (MALs)

tion of toxic metals. In addition, in 26.66% of cattle offal, levels of Pb and Cd were above the European-certified reference value and cattle offal was more affected by HMs compared to sheep offal. The authors argued that bioaccumulation of HMs such as Pb and Cd in the liver and kidneys was highly relevant to the contaminated animal feed. Besides, slow removal rates of HMs may lead to accumulation in tissues after prolonged exposure to low levels in the polluted environment.

**Bahrain: Processed meat (fast food).** In a study in Bahrain, HM concentration (Pb, Cd, manganese (Mn), Fe, copper (Cu), aluminum (Al), and Zn) in pizza, liver sandwiches, beef burgers, sausage sandwiches, and minced beef sandwiches (khima) was assessed. The results showed that Cu, Fe, and Zn were predominant in the liver sandwiches while low Cd content was found in this sandwich. The sausage sandwich exhibited low concentrations of Cu, Mn, Fe, and Pb. In pizza, the predominant metal was Pb, and Al was most concentrated in beef hamburgers. The highest Mn and Cu content were in the minced beef sandwich and the beef burger, respectively. Cd was identified only in the liver sandwich of all the evaluated fast foods. The authors attributed adequate contents of Fe and Zn in meat-based foods especially liver sandwiches to the high level of these metals in the liver. Contamination of meat-based foods by HMs may be the result of environmental pollution and the use of contaminated vegetables by livestock in Bahrain (Musaiger et al., 2007).

**Egypt: Nonprocessed meat (fresh meat).** The oldest relevant study in Egypt analyzed the concentrations of six metal elements in the muscle, liver, kidney, heart, and spleen of bovine, buffalo, elk, sheep, and goats (Abou-Arab, 2001). The results showed that Zn was at the highest concentration in muscle samples and the highest concentrations of Pb and Cd were detected in the kidney samples. However, the highest concentrations of Fe, Mn, and Cu were found in the liver. They suggested that a high level of Cd is related to the species of the animal, the concentration of Cd in the feed, as well as binding of Cd to sulfhydryl groups in the protein metallothionein in the kidney and liver organs (Abou-Arab, 2001). Another study by Wael Mohamed Lotfy et al. in Egypt (Lotfy et al., 2013) revealed that among the healthy buffaloes, Cu concentration in the liver was higher than in muscle, while Zn had a lower concentration in the liver tissues. However, Samia EL-Safy et al. reported that Co and Cu concentrations were undetectable in beef meat samples in Egypt (El-Safy & El-Sayed, 2008). Nevertheless, the maximum mean concentration of Zn and average concentration of Cd in beef were higher than the permissible limit, and Pb concentration was over the WHO (2000) allowable limits.

In 2019, Hasballah (2019) evaluated the concentrations of seven HMs in Cow's meat from five regions of Damietta governorate in Egypt country. A high variation of Pb, an intermediate variation of Cu and Fe, and no variation of Zn and Cd in the cow meat samples between different regions were reported. Average levels of Cu and Fe in all meat samples were higher than the regulatory limit (FAO/WHO, 2000). However, Zn concentrations were less than the regulatory limit (250 μg/g). This study also showed that boiling cow meat decreased concentrations of Pb, Cu, and Fe (44, 93, and 5% respectively), while increasing the concentration of Zn. In addition, grilling of cow's meat reduced concentrations of Pb and Cu (8 and 88%, respectively) and raised the concentrations of Zn and Fe. Increased Fe content could be attributed to the interactions of meat and the metal grid that's mostly made of Fe. Therefore, postgrilling Fe concentration in cow meat samples was higher than the regulatory limit for (FAO/WHO, 2000) (0.3) μg/g, but Zn concentration following boiling and grilling was lower than the regulatory limit (250 μg/g). The author suggested that heating may convert certain heavy metals into other compounds, and cooking procedures (ie. boiling, steaming, and frying) may alter toxic metal concentrations. Also, it has been suggested that the boiling method is much more effective than the grilling method to reduce some heavy metal concentrations (Haris et al., 2019). Different cooking methods can change the food levels of heavy metals in various ways including evaporation of water and volatile compounds, dissolv-

**Table 2**
Studies evaluated the accumulation of heavy metals/trace elements in fast food/imported meat in the middle east between (2000 and 2022)

| The first author (s) | Year | Country/ Region (s) | Animal/ sample/ Number | Measuring method | Essential trace elements | Toxic elements | Outcoming data | DOI/ PMCID/ ISSN |
|---|---|---|---|---|---|---|---|---|
| Abdulrahman O. Musaiger (Mikulewicz et al., 2013) | 2007 | Bahrain, 45 schools | Pizza/liver sandwich/beef burger/sausage sandwich / minced beef sandwich (n = not mentioned) | FAAS for Mn/dry ashing method for Fe, Zn, Cu/wet ashing method AAS for Pb, Cd, Al | Cu, Zn, Mn, Fe | ,Al, Cd, Pb | 89% of the foods were contaminated with Pb, but it was within allowable limits. Cd was identified only in liver sandwiches The liver contained adequate levels of Fe and Zn. | 10.1108/00346650710774613 |
| Mohamed Abdelfattah Maky (Lotfy et al., 82013) | 2020 | Egypt | Sausage/pastirma/ /luncheon (n = 20) | AAS | | Pb, Cd | Pastirma and sausage samples had the highest and lowest Pb concentrations, respectively. Sausage and luncheon samples had the highest and the lowest Cd concentrations, respectively. | 10.14202/IJOH.2020.61-68 |
| Mohamed Abdelfattah Maky (Mahmoudi et al., 2018) | 2020 | Egypt | Beef luncheon, (classified into three classes: A, B, and C based on their prices) (n = 60) | Spectrophotometry | Cu, Zn, Mn, Fe | | The beef luncheon was safe for consumers. Mg concentration was high in the class A luncheon. | 10.5455/javar.2020.g421. |
| Hind Suhail Abdulhay (Abdulhay and Salloom, 2015) | 2015 | Iraq | Canned meat (beef/hot dogs/ mixed beef and chicken) (n = not mentioned) | AAS | Zn, Fe | Pb, Sn | The studied elements were in an acceptable range depending on the Iraqi standard specification. | The 16th Science Conference. College of Basic Education. Al-Mustansiriyah University At Baghdad (Vol. 5). |
| Adnan M. Massadeh (Maky et al., 2020) | 2017 | Jordan, Irbid city, Northern Jordan | Canned beef ( Bos taurus Africanus), )n = 44( | AAS | Cd, Cr, Cu, Zn | Ni, Pb, As | Samples contained high concentrations of elements such as As, Cd, Cr, Ni, and Pb, exceeding the limits set by international health organizations. | 10.1007/s11356-017-0465-5 |
| Sarine EL Daouk (Chowdhury et al., 2011) | 2020 | Lebanon | Food items (n = 97) | FAAS | | Al | All consumption rates were below the internationally established thresholds of tolerable intake. | 10.1016/j.toxrep.2020.08.018 |
| Laila A. Nasser (Mohamed et al., 2017) | 2015 | Saudi Arabia, Riyadh City | Canned meat/ corned beef/ pure beef/ beef luncheon (n = not mentioned) | FAAS and ICP-AES | Fe, Zn, Cu | Cd, Pb, Ni | All samples had Zn and Cu levels below the maximum permissible limit, and Fe and Pb concentrations above that. | 10.1016/j.sjbs.2014.08.003 |

Note: Atomic absorption spectrophotometry (AAS), Inductively coupled plasma-mass spectrometry (ICP-MS), Flame atomic absorption spectrometry (FAAS), Maximum permissible levels (MALs).

**Table 3**
Studies evaluated the accumulation of heavy metals/trace elements in Fresh meat/ fast food/imported meat in the Middle East between (2000 and 2022)

| The first author(s) | Year | Country/ Region (s) | Animal/ sample/ Number | Measuring method | Essential trace elements | Toxic elements | Outcoming data | DOI/PMCID/ ISSN |
|---|---|---|---|---|---|---|---|---|
| Dalia A. Zahran (Soliman, 2016) | 2015 | Egypt | Beef, meat /sausage (n = 40) | (ICPOS) | Cu, Zn, Se, Mn, Cr, Fe | As, Cd, Pb, Al, Ag, Sr, Cs, v, Ni, Ba | The sausage had the highest concentrations of the studied elements. | ISSN 2307-4531 |
| Samar E El-Wehedy (EL-Safy F, S., and S. M El-Sayed. , 2008) | 2018 | Egypt | Beef, raw/ cooked (n = 100) | hydride generation/ CVAASP (As), AAS: (Pb, Cd and Cu) | Cu | Pb, Cd, As | Pb, Cd, and As concentrations were higher than the han maximum permissible limit. | 10.4172/2157-7579.1the 000524 |
| Azad B. Sabow (Oymak et al., 2017) | 2020 | Iraq | Beef, fresh local/ imported/ imported frozen (Ukraine) (n = not mentioned) | X-ray fluorescence spectrometer | Fe, Co, Cu, Zn, | Ni, Hg, Pb, As | Among the essential metals, Fe showed a higher level of concentration in the fresh and frozen meat while the lowest belonged to Co. Among the toxic metals, As showed the highest and Hg had the lowest concentration in various meat samples. | 10.18488/journal.ar.2020.71.14.18 |
| H.S. Al-naeimi (Al-Naemi et al., 2020) | 2020 | Iraq | Local cattle /buffalo, imported cattle/ buffalo (n = 160) | AAS | Cr, Co | Pb, | The Pb and Cr level in local cattle meat were significantly higher than Co, while Pb concentration was higher than Cr and Co in imported cattle meat. Local and imported buffalo meat had no difference in studied elements. | 10.33899/ijvs.2019.126069.1224 |
| Humaeda (Hasballah, 2019) | 2018 | Sudan, Khartoum state | Beef/goat /camel, fresh meat /sausage (n = not mentioned) | AAS | Cu, Fe, Cr, Mn, Zn, | Ni, As Pb | All the samples were found to conform to international standards. | Corpus ID: 105959158 |

Note: Atomic absorption spectrophotometry (AAS), Inductively coupled plasma-mass spectrometry (ICP-MS), Maximum permissible levels (MALs).

ing some elements, and binding metals to other food components, especially some macronutrients such as proteins, carbohydrates, and lipids. (Hasballah, 2019)

**Egypt: Processed meat (fast food) and imported meat (frozen meat).** In 2020, Mohamed Abdelfattah Maky et al quantified the concentrations of Pb and Cd in frozen sausage, pastirma, and luncheon in Egypt (Maky et al., 2020). The results of that study indicated that 33%, 100%, and 82% of the sausage, pastirma, and luncheon samples had Pb concentrations higher than the maximum allowable limit (0.10 ppm). On the other hand, 72% of sausage samples had a Cd concentration higher than the maximum allowable limit but Cd levels were within allowable limits (0.050 ppm) in all pastirma and luncheon samples (Maky et al., 2020).

The target hazard quotient (THQ) is a dimensionless index of hazards associated with pollutant exposure. Based on THQs of Pb and Cd in different meat samples that were below one, the authors suggested that Pb and Cd had no health risks for consumers. This study recommended that monitoring meat chemical contaminants is a key health maintenance issue (Maky et al., 2020). These researchers in another study evaluated the concentrations of Cu, Zn, and, Fe in beef luncheon samples from Egyptian markets and classified them into three classes: A, B, and C based on their prices (Maky et al., 2020). Analysis of data showed that Zn was much higher in class A than in the other categories, which was lower than the study

conducted by Hasballah et al. in Iraq. The difference in Zn content between two studies may be due to variability in meat chemistry and different manufacturing operations. Based on the announcement of the central agency for standardization and quality control, the concentration of Zn in the lunch should be no more than 50 ppm (Maky et al., 2020). On the other hand, concentrations of Cu in both class A and class B lunch samples were higher than in class C samples. In addition, these samples contained more Fe than raw meat (1.2 mg/100 g) which could be related to adulteration by the plant with a high amount of Fe, especially soybean (14.5 mg/100 g). According to the results of this study, the authors suggested that the real content of HMs/TEs should be declared on the label of the luncheon so that it could support the consumers in achieving a balanced diet (Maky et al., 2020).

**Egypt: Nonprocessed meat (fresh meat) and processed meat (fast food).** In the other study on beef meat and sausage in Egypt, concentrations of 16 metals/elements were quantified. In that study, silver (Ag) was at a lower level of detection in all meat samples and Cd and Pb were higher than the maximum levels (MLs) of contaminants in the international standard in some meat and sausage samples which may be due to the content of these elements in the soil and plants consumed by the animals (Zahrana and Hendy, 2015). Cd in meat and sausages was higher than FAO limits (0.1 ppm) and EC regulations (0.05 ppm wet weight for beef) and in meat, samples tended to rise with increasing age. The authors concluded that most of the studied metals were higher than the tolerable levels cited by international committees and may have health risks. In a study by Samar E El-Wehedy et al., concentrations of four HMs were analyzed in raw and cooked beef (El-Wehedy et al., 2018). In this study, 66.7%, 58.8%, and 80% of the samples had Pb, Cd, and As higher than maximum permissible limits (MPLs), (0.1, 0.05, and 0.01 ppm), respectively, and none of the examined samples had Cu concentration higher than MPL (40 ppm) (Codex Alimentarius Commission). In addition, cooked beef had higher toxic metals than raw beef, therefore, they suggested that cooking can alter HM concentrations through evaporation and loss of water in the cooked tissue (El-Wehedy et al., 2018).

**Iran: Nonprocessed meat (fresh meat).** Four studies were carried out to determine the status of HMs in red meats between 2016 and 2020 in Iran. In a study in Hamedan, Iran by Behnaz Bazargani-Gilani et al., the concentration of six HMs was quantified in the liver and kidneys of cattle, sheep, and goats (Bazargani-Gilani et al., 2016). All samples had Pb concentrations higher than the acceptable limit (>1 ppm), and it was not significantly different between male and female species. The level of Pb in the liver of young sheep (less than 3 years) was higher than the older ones which could be related to the age factor. In addition, except for cattle and sheep kidneys, the Cd concentration in all species was below the allowable limit, and in the kidneys of animals was much higher than in their liver that which could be due to the excretory function of the kidneys. Elevated concentrations of Pb and Cd in those samples may be related to the presence of Pb and Cd mines in grazing areas. HMs could transfer from the soil to the animal food chain. In this study, the kidneys of female goats contained significantly higher Cd contents than male goats. Moreover, except for cattle, Cd was higher in the liver and kidneys of animals older than 3 years than the younger ones. This study also showed that Mn accumulated in the liver was markedly higher than those in the kidneys, however, it was lower than the accepted toxicity levels (23 ppm w/w). It could be because the liver is the main organ for Mn accumulation. In addition, consistent with this study, some studies had found no age differences in Mn levels in different deer, domestic, and laboratory animals (Pollock & Roger, 2007; Vikøren et al., 2011). Furthermore, all values of Zn in samples were below the permissible limit ( < 150 ppm), set by Australian and New Zealand Food Authority (ANZFA). According to the author's suggestion, the low tissue content of Zn may be attributed to Zn deficiency in the farm soils. In this study, the Zn levels in the liver of female sheep were significantly greater than that in male livers. Likewise, the liver Zn level in older sheep was significantly higher than that compared to younger sheep. Their findings were consistent with other studies, which showed the effects of sex and age factors on Zn concentration in the liver and kidneys of studied animals. Cu concentrations in all samples were below the 200 ppm permissible limit. Besides, sheep livers and kidneys contained the highest Cu content among the samples, followed by cattle and goats. Ruminants, especially sheep, have a greater potential to accumulate copper in their livers than other species and are more sensitive to Cu toxicity. Sex did not interfere with Cu accumulation in body organs; however, liver levels of copper in female and older sheep were significantly higher than that of male and younger sheep, respectively. The permissible limit for Fe in food is typically 30–150 ppm, but in sheep livers and kidneys, it had exceeded this range. There was no significant difference in Fe concentration in liver and kidney between male and female cattle; however, female sheep livers and kidneys had significantly higher Fe contents than male sheep. The Fe content in the liver of male goats was significantly higher than that of female goats; however, the kidneys of both sex were not significantly different. This study showed no significant difference between cattle and goats in Fe concentrations in the liver and kidneys of younger and older animals, while the livers and kidneys of older sheep had considerably higher Fe content ($P < 0.05$) than younger ones. In conclusion, the authors classified organs depending on the metal richness in the following order: liver > kidney > heart > lungs > muscles. They claimed that the liver and kidneys are responsible for eliminating toxic metals from the body, therefore, these two organs had the highest metal contamination in studied animals (Bazargani-Gilani et al., 2016).

Another study in Shiraz, Iran detected the concentrations of five metal elements in the meat, liver, and kidney of cows (Hashemi, 2018). The mean observed Pb concentration in the liver and kidney was below (0.415 ppm in the liver and 0.534 ppm in the kidney) the maximum residue limits (MRLs) (0.500 ppm), which were less than another study report in Iran (Sobhanardakani et al., 2012). They argued that this difference was likely due to different environmental contamination, feed sources, and animal ages. Furthermore, mean concentrations of Cd in muscles, liver, and kidneys were less than the MRL in this study, However, Cd concentrations in kidney samples were significantly higher than that of liver and muscle samples. Hashemi (2018) in this study suggested that the excretory function of the kidney may contribute to the higher concentration of Cd in the kidney because toxicants move from body tissues to the kidney for excretion. In addition, livestock age and Cd levels in livestock feeds can affect Cd levels in animal tissues. Cd as a contaminant of the environment is easily absorbed by plants from the soil and transmitted indirectly to animals through plant intake. Based on their results and other related studies, this study suggested that Cd is mainly accumulated in the kidney, Cu in the liver, and Zn in the liver and muscles of animals. The average concentrations of Cu and Zn in the muscle were 1 and 37 ppm, respectively. Their data indicated that Cu and Zn concentrations were scarce in studied cattle in this province. Levels of Zn in kidney samples collected in unpolluted areas were higher than that in the polluted area. This may be due to the fact that trace elements including Zn are affected by environmental pollution, in a way that the presence of heavy metals may strengthen the reciprocal interference with trace elements and decrease their bioavailability. Also, there was no seasonal impact on Hg levels in this study. The highest concentrations of Pb and Cd in the samples were reported in the summer, and these values were much higher than those observed in winter and spring. During the past decades and especially in recent years, dust storms in the Middle East have caused problems in the southern and southwestern parts of Iran and the ME region (Najafi et al., 2014). The dust phenomenon would occur from Iraq to Iran, especially in spring and summer. Dust particles can absorb heavy metals created by industrial activities and vehicles and increase air pollution and as a result, animals can inhale it more easily (Elahe et al., 2020). Summer is the driest period of the year, and rain begins at the end of the fall and continues into early spring in the study area. This rainfall trend might influence the levels of Pb and Cd on the plant surface that are consumed by animals. Cu and Zn accumulation were highest in all tissue samples during the early rainy season (fall). Although the mean concentrations of Pb, Cd, Hg, Cu, and Zn did not exceed the MRLs in tissues (except Pb in muscle) or feed, 15.3% and 13.9% of liver and kidney samples showed Pb concentrations above European maximum concentrations. Cd levels in 8.3% of muscular samples exceeded the MRL (Sobhanardakani et al., 2012).

Another study analyzed the concentrations of Pb in buffalo muscle in three provinces in the north-west of Iran (Mahmoudi et al., 2018). Pb was detected in 80.33% of the buffalo muscle samples, and the Pb concentration was higher than the EC-permitted limits. The authors argued that industrial and chemical factories (via air inhaled by animals) may be the main sources of pollution. However, WHO (2000) announced that the maximum allowable weekly intake of Pb was 25 ppb-bw per week. The average daily consumption of red meat in Iran - has been reported as about 50–90 g, and the mean Pb concentration in buffalo muscle samples in this study was 0.043 ppm. Therefore, they suggested that eating 50 g of muscle per day can provide 0.02 ppm Pb per day, and an individual with an average body weight of 60 kg may receive less than the defined Pb limit. However, another study in the east of Iran (Birjand) found that the average concentration of Pb was below the WHO and EU MRLs in all samples including offal and meat of beef and sheep (Zeinali et al., 2019). In addition, the mean concentration of Cd in muscle, liver, and kidney samples of studied animals was below the recommended MRL by WHO and EU (0.05, 0.5, and 1 ppm, respectively). The mean metal concentrations during the hot (summer) and cold (winter) seasons were the same in all samples except that in sheep liver, where the average concentration of Cd in the cold season was significantly higher than that in the hot season. They argued that although the average levels of Cd and Pb were below the MRLs, bioaccumulation of these metals in the organism could increase toxicity to national and international consumers over a longer period. Pb THQs in cow and sheep muscles which are an important part of the ordinal diet of the population in this area were higher for both children and adults and the carcinogenic risks (CR) for Cd were numerically above the unacceptable range for the studied samples. Consumption of these toxic metals in offal and meat over an extended period may cause toxicity because of the nature of the accumulation of those metals in the body. Therefore, that study suggested monitoring these toxic metal residues in the meat, liver, and kidneys of these animals for human consumption in that region. Similar to other relevant studies, this study showed that the average Cd concentration in the kidney samples was significantly higher than liver and muscles which can be attributed to the binding of some free protein-thiol groups in this organ to Cd (Zeinali et al., 2019).

**Iraq: Nonprocessed meat (fresh meat).** Camel and goat are the main sources of red meat in some countries of the middle east and are characterized by low fat and the main source of protein, respectively (Association, 2008; Gaetke et al., 2014). Analysis of Ni, Pb, Hg, and Cd elements in the meat from goat (n = 30) and camel (n = 30) in a study in Al-Qadisiyah province, Iraq revealed that Pb (0.9975 ppm) and Ni (0.5960 ppm) had a significant variance in goat compared with camel meat (Sabeeh, 2018). In goat meat, Hg, Pb, and Ni showed significant variance while Cd concentration was not significant. Another study compared HM (Pb, Cu, Cd, and Co) concentration in goat meat in the winter and summer in different regions (Kirkuk, Daqouq, Debis) of Iraq (Alperkhdri et al., 2018). The results showed that Pb had significantly the highest concentration in the center of Kirkuk during winter. The highest Pb concentration was in goat liver in winter (7.925 ppm) while the lowest concentration was in muscles in summer (0.983 ppm). These results are not consistent with the findings of Hashemi, M.

The reason might be that the interaction between multiple factors may affect the level of heavy metals including season, location, and the body organ that has been evaluated. This study also showed that the highest level of Cd was in the kidney of goats (aged 6–8 months) in the Daqouq region during summer (3.430 ppm), and the lowest was in the liver in Debis during winter (2.228 ppm). The Cu in the liver downtown during the summer significantly had the highest concentration (20.734 ppm). The Co concentration had the highest level in liver and muscle in the summer. The animal liver showed the highest concentration of Co (5.926 ppm), and the lowest concentration was recorded in muscle in the winter (0.864 ppm) (Alperkhdri et al., 2018).

An earlier report in 2014 (Ibraheem & Abdullah, 2014) investigated HMs in the lambs from three different regions (Tikrit, Samarra, and Baiji) in Iraq, and the results showed a low concentration of HMs in Samarra compared with Tikrit and Baiji. These diverse HM contamination reported may be due to diverse environmental pollution in different areas in terms of industry and population density. Okoye et al. showed that different levels of elements can be due to different concentrations in plants and soil or various source of food (Okoye & Ugwu, 2010). Inhaled or ingested alpha particles like ionizing rays can hurt the mucous membrane (Peter et al., 2012). In a blood-ionizing process, alpha-ionized particles enter the blood cells and cause leukemia (Valković, 2000).

Almayahi et al. in 2018 determined the alpha particles and HM (Pb, Cd) concentration in the meat of animals including cow and lamb from five different parts of Najaf, Iraq (Almayahi et al., 2019). The mean concentration of Pb (0.343 ± 0.043) was higher than the mean concentration of Cd (0.129 ± 0.023), although both were within the permissible limits. About the alpha particles, the highest emission rate was in sheep meat from the Ascary region (0.0204 ± 0.0014mBq cm-2). The Pb concentration was lower than that reported in Egypt and (Rajeshkumar & Li, 2018; Zahrana & Hendy, 2015), but the Cd concentration was equivalent to the value measured in (Zahrana & Hendy, 2015); however, it was in contrast with the results from Egypt. These different results from different countries may be due to breed variation (Chowdhury et al., 2011). Alpha particle emission rates were lower than the detectable level and were approximately compatible with the result reported in Malaysia (Almayahi et al., 2012) while were lower than the value obtained from Turkey (Mendil & Uluözlü, 2007). So, the rates of alpha particles in Iraq would not be raised compared to international studies.

Uranium can induce various health problems and affect the human body by ingestion of polluted water and food (ATSDR, 2000). A study in 2017 measured the uranium concentration in beef and lamb meat from six selected regions in Iraq (Al-Hamzawi, 2017). The mean value of uranium concentration showed that beef meat was 1.46 times higher (10.14 ± 0.36) compared with lamb meat (6.95 ± 0.31). Furthermore, a higher value of uranium in samples (beef and lamb) from southern Iraq (11.85 ± 0.36 and 8.03 ± 0.40, respectively) compared with the central part (8.43 ± 0.33 and 5.86 ± 0.22) was observed. The main reason can be due to the age of the cow which was correlated to uranium content (of Committee, 1995). A higher value of uranium in samples from southern Iraq was suggested because of the radiological contamination of soil and military activities (Al-Hamzawi et al., 2015).

A similar study in that region which analyzed essential and toxic metals used in imported red meat showed the highest levels of Fe in imported beef from Ukraine and Paraguay (147.981 ± 6.39 and 132.250 ± 1.75, respectively) (Yakupa et al., 2018). Among the toxic elements, Ni (7.386 ± 0.92), Hg (0.020 ± 0.00), and Pb (0.733 ± 0.08) were higher than other imported meat, and As was highest in buffalo from India (2.059 ± 0.00). Beef meat from Ukraine and Paraguay had higher levels of essential and toxic metals while buffalo meat from India had lower concentrations of all essential and toxic elements. Among the essential metals (Fe, Co, Cu, Zn, Se), Fe, Co, and Se were within tolerable limits. All the toxic metals except Hg were higher than international standard limits.

In 2018, a study investigated the concentration of essential and toxic metals in imported red meats in Iraq. The results demonstrated that among the essential metals (Fe, Co, Cu, Zn, Se), Fe, Co, and Se were within tolerable limits. All the toxic metals except Hg were higher than international standards (Yakupa et al., 2018).

**Iraq: Processed meat (fast food).** Nowadays, canned meat is used in many countries as it is commercially considered a safe food because of its processing under controlled conditions (Abdulhay & Salloom, 2015). However, it can be toxic if not properly processed (Bernstein, 2004). The result from a study in Iraq that investigated HMs such as Pb, Hg, Zn, and Fe in canned meat indicated the presence of these elements in the acceptable range of Iraqi standard specifications (Abdulhay & Salloom, 2015). The differences in the concentration of HMs in animals of the same species were attributed to various factors such as food and water sources, age of animals, meat origin, and conditions of meat transportation (Chowdhury et al., 2011).

**Iraq: Nonprocessed meat (fresh meat), processed meat (fast food), and imported meat (frozen meat).** A study in 2020 analyzed essential and toxic metals in imported and fresh beef meat in Erbil of Iraq (Sabow et al., 2020). Among the essential metals (Fe, cobalt (Co), Cu, Zn), Fe had a higher level of concentration (1200.400 ± 0.300, 120.500 ± 0.386, 131.210 ± 0.0250) while the lowest level was belonging to Co in the fresh and frozen meat, respectively (1.063 ± 0.025, 1.089 ± 0.022, 1.082 ± 0.006). Moreover, among the toxic metals (Ni, Hg, Pb, As), As showed the highest level of concentration (1.498 ± 0.052, 1.763 ± 0.076, 1.623 ± 0.045) and Hg had the lowest concentration (0.014 ± 0.004, 0.019 ± 0.004, 0.017 ± 0.001) in the fresh and frozen meat, respectively (Sabow et al., 2020).

A study in 2020 in Iraq revealed that Pb concentration in cow and buffalo meat was not different (Al-Naemi et al., 2020) which is totally in contrast with the results from a study by Abdel-Salam et al. (2013) that showed different concentrations of Pb, Cr, and Co in these two types of meat.

**Jordan: Processed meat (canned meat).** In the only relevant study conducted in Jordan, Adnan M. et al. analyzed the concentrations of seven HMs in canned beef to determine if the concentrations of HMs in the selected products manufactured and marketed in Jordan are safe (Massadeh & Kharibeh, 2018). It was revealed that Pb has the highest concentration levels in beef samples, while Cd has the lowest concentration levels. The order of average levels of HMs in beef sample were Pb > As > Cr > Ni > Cu > Zn > Cd. Moreover, except for Cu and Zn, the levels of the other HMs examined in this study were higher than the permissible limits set by health organizations (WHO, FAO, FDA, and US-EPA recommendations), and raised concerns. The authors concluded that canned meat products may not be safe for consumers in this region. This is more likely that prolonged maintenance of cans may result in physical damage such as corrosion, which can cause the release of metal contaminants into canned food. Thus, they recommended that both good manufacturing practices, as well as regular monitoring of HMs in canned food, should be applied to control toxic metals in canned products. Although the chromium (Cr) element is known as an essential metal and has a biological role in glucose metabolism but in high concentration and poisoning levels, it can be carcinogenic (Massadeh & Kharibeh, 2018).

**Kuwait: Nonprocessed meat (fresh meat).** A study in Kuwait in 2020 analyzed some HMs in the liver, muscle, and kidney of 600 sheep samples. The results revealed that Hg, As, Pb, Cd, and Cr exceeded the permissible limits by various international food agencies. Likewise, the THQ and hazard index (HI) values for Hg ( > 1.0) in the analyzed sheep samples suggest a threat to the public health in Kuwait. The fish meal in sheep feeding is considered a major source of Hg in their meat. The different results of Hg concentration in Kuwait compared with previous publications in different countries were attributed to various sheep breeds, feedstuff, and age (Abd-Elghany et al., 2020).

**Lebanon: Nonprocessed meat (fresh meat).** In 2016, levels of Pb and Cd in various tissues (muscle, lung, kidney, heart, fat, liver, bone marrow, and spleen) of fresh beef, goat, and lamb have been identified by Obeid PJ et al. in Lebanon (Obeid et al., 2016).

This study revealed that the concentration of Pb and Cd in beef meat tissues was lower than in goats or lamb. The reason can be attributed to the size of the animal, the distribution features of the elements in the organism, and the feeding habits under which the animals were raised. For example, the authors of this study declared that one of the feeding habits of animals in Lebanon is that cows are usually raised indoors, but goats and lambs are usually raised in pastures, and another study reported higher Pb levels in muscles of cows raised outdoors than that of those raised indoors (Oskarsson et al., 1992).

Furthermore, none of the samples analyzed had exceeded the MAL for Pb (100 μg/kg), however, the Cd levels in all of the liver and kidney samples exceeded the MAL for Cd (50 μg/kg).

The specific function of these two organs, kidney and liver, as excretory and storage organs can be the cause of the high concentration of Cd in these two organs.

They recommend minimizing the consumption of goat and lamb and highly minimizing consumption of liver and kidney tissues of studied livestock because these organs can accumulate the highest concentration of Cd and Pb. Goat and lamb, beef tissues were found to contain lower levels of the metals in question, suggesting that beef, in general, may be considered safer (Obeid et al., 2016).

**Lebanon: Processed meat (fast food).** A cross-sectional study was conducted by Daouk SE et al. which analyzed the levels of Al present in different dietary matrices including red meat (barbecue) in the Lebanese population. The results showed that the content of Al in the red meat was below the thresholds of international agencies (1 mg/kg/week). Although it was well below levels that could be considered a hazard, they recommended that serious consideration should be developed to improve food safety monitoring in Lebanon. (Daouk et al., 2020).

**Pakistan: Nonprocessed meat (fresh meat).** One study was done by Amina A et al. in 2021 on determination of HMs (Fe, Cu, Zn, Ni, Pb, Co, and Cd) in organ samples of heart, liver, and muscles, from red meat (mutton and beef) collected from local (fresh) and branded (Zenith, Menu) markets of Lahore, Pakistan (Arif et al., 2021). In this study, the Fe amount of beef (heart, liver, and muscle) was nearly the same. In this study, the maximum levels of Zn were detected in the heart and liver samples, especially freshly slaughtered beef liver samples. In this research, the highest level of Pb was detected in the Zenith heart mutton, and the maximum Ni containing the sample was Menu beef heart. Co, Cd, and Pb were not detected in the majority of meat samples. The Cu content of all meat samples was within the recommended limits (the standards of the Joint FAO/WHO Expert Committee on Food Additives (JECFA)). Although, the analyses of metals in this study were not reported completely. In addition, a comparison of HM levels with the standards of the Joint FAO/WHO JECFA was not represented in this study except for Cu. However, this study concluded that the metal values obtained in this study were related to the accumulation of metals in the living environment of the studied animals (Arif et al., 2021)

**Palestinian: Nonprocessed meat (fresh meat).** One study was done on the determination of HMs in red meats in Palestinians by Swaileh KM et al. in 2009 which analyzed levels of Cd, Pb, Cr, and Cu in liver, kidneys, heart, and lungs of cattle, sheep, and goat (Swaileh et al., 2009). In all three groups of study animals, the highest levels of metals were in the liver and concentrations of HMs in the other organs followed the pattern: kidneys > heart > lungs > muscles. It also showed that concentrations of HMs in studied organs decreased in the order of: Cu > Pb > Cr > Cd. Cattle kidneys contained significantly higher concentrations of Cd compared to kidneys of other studied groups, and Cd contents of sheep and goat lungs were much higher than those of the cattle. Concentrations of HMs reported in this study were somewhat similar to or less than those reported animal organs from clean sites (Swaileh et al., 2009).

**Saudi Arabia: Nonprocessed meat (Fresh meat).** In 2017, Mohamed H et al. analyzed the levels of As, Cd, Cr, and Pb by inductively coupled plasma-mass spectrometry (ICP-MS) in red meat (beef, camel, goat, and lamb) in Najran, Saudi Arabia (Mohamed et al., 2017). In this study, hazard quotients for As, Cd, Cr, and Pb (0.06 0.01 0.01 0.01) in red meat samples were less than one, therefore, red meat was concluded safe to eat for the people of Najran.

In another study later (2019), they quantified the levels of Se, Zn, Mn, and Cu in the loin of cooked meat (cow, sheep, goat, and camel) (Haris et al., 2019). The results revealed high levels of Zn; however, Se, Mn, and Cu levels were relatively low in all meat samples. The authors of this study concluded that the HM content of the evaluated samples did not exceed the WHO-recommended values.

The other study in Al-Ahsa, Saudi Arabia in 2019 was done by El-Ghareeb WR et al. which analyzed the levels of Pb, Cd, As, Cu, Zn, and Fe using atomic absorption spectroscopy (AAS) in muscle, livers, and kidneys of both camel and sheep (El-Ghareeb et al., 2019). This study indicated that camel liver and kidney tissues had the highest mean Cd concentrations than the sheep samples, however, the camel muscle contained the lowest Cd residues. Concentrations of Cd reported in this study were within the MPLs of Cd in the muscle and offal and also none of the samples analyzed in this study exceeded the MPLs of Pb established by the EC. Cu levels in this study were in the recommended range of MPLs (40 ppm WW). Likewise, levels of Zn and Fe reported in this study did not exceed the MPLs for Zn and Fe (10 ppm and 30 ppm wet weight, respectively). The elevated level of toxic metals and trace elements in the liver and kidneys of camel and sheep in this study relative to muscle can be ascribed to their important role in the metabolism of xenobiotics and detoxification. Additionally, interspecies differences in metal accumulation may be attributed to interspecies differences in their xenobiotic metabolizing enzymes and metal detoxification capabilities. The reasons for differences in metal accumulation models in this study and other regions of the world can be mostly attributed to the differences in environmental pollution scenarios as well as differences in livestock systems. This study also showed a very strong positive correlation between the age of studied animals and the load of HMs (Cd, Pb, and As); however, Zn showed a negative correlation with age in camels. The reason may be attributed to the interspecies differences in the metabolism of xenobiotics. In addition, their study revealed that except for As, all examined metal levels were within the MPL limits set by the EU Food and Agricultural Organization. Human health risk assessment showed no health hazard for the detected concentrations of Cd and Pb; however, because of the extreme consumption of meat in Saudi Arabia, they recommended care should be taken regarding As (El-Ghareeb et al., 2019).

**Saudi Arabia: Processed meat (fast food and canned meat).** Four studies were done on the determination of HMs in red meats in Saudi Arabia between 2015 and 2019. In 2015, Laila A. Nasser et al. measured Fe, Zn, Cu, Cd, Pb, and Ni in canned meat/corned beef, pure beef luncheon meats, and beef luncheons (Nasser, 2015). The beef product was imported from Brazil. Three samples (Corned beef of two brands, Brazil/ Pure Beef Luncheon meat, Brazil) had Cd contents exceeding the maximum permitted content. All samples had Pb concentrations over the maximum allowed level. Corned beef (Target, Brazil) samples had Ni levels over the maximum allowable level, and other samples had Ni concentrations that were undetectable. In this study, concentrations of HMs such as Pb and Cd in some canned meat products were above the maximum permitted concentrations. Pb contamination could mostly be attributed to soldering in the canning process. Several studies have shown that long-term exposure to high Pb levels is associated with adverse effects on the nervous system, kidneys, reproductive tract, and the immune system. An effect on neurobehavioral development in a vulnerable population, young children, after short-term, low-level exposure to lead has also been reported. Cd is poorly absorbed in the body so the major portion is excreted in the urine, but because of its slow excretion by the kidneys, it can cause renal damage by accumulation in the kidneys. Therefore, animal kidneys can be one of the main sources of Cd in the diet. Because canned foods are readily available and can be used easily, they can be very dangerous. To control these meat products, the authors recommend that more quality control be applied to them, and also the Saudi authorities should impose stricter guidelines on imported meat products contaminated with HMs (Nasser, 2015).

**Sudan: Nonprocessed meat (fresh meat) and processed meat (fast food).** In a relevant study, Humaeda WA et al. analyzed the concentration of Cr, Mn, Zn, Ni, Cu, Fe, Cd, Pb, Hg, and As in fresh meat and sausage of beef, goat, and camel in Khartoum state, Sudan (Humaeda, 2018). In this study, Ni, Cr, Cu, and Zn levels in beef samples were higher than those in goat and camel samples. Maximum Fe concentrations were found in beef meat, followed by camel and goat meat. Indeed, Pb, Cd, Hg, and As contents in fresh meat were lower than detection limits which conformed to some international standards such as FAO, 2002, as well as (EC 1881, 2006). All studied HMs (Pb, Cd, Hg, As) contained in sausages were below detection limits. Samples of beef sausage samples had the highest concentration of Ni, Zn, Cr, Mn, Fe, and Cu compared with goat and camel sausage samples. The findings of this study indicated that all studied samples including fresh meat and sausage were comparable to international standards and free of HMs, and essential elements in samples were lower than the limits of the standards (Humaeda, 2018).

**Syria: Nonprocessed meat (fresh meat).** One study by Soliman GH et al. in 2016 measured As using Graphite Furnace Atomic Absorption Spectrophotometry (FAAS) in muscle, liver, and kidney of calves from Western Syria (Latakia, Tartus, Jableh, and Safita) (Soliman, 2016). Elevated levels of As were found in the internal organs (kidneys and liver) and subsequently in meat (muscles). As levels varied depending on age, breed, and amount of feed consumed by calves. Based on the global permitted pollution limit of 0.4 ppm, the lowest level of pollution was obtained in calf samples from Jableh and Safita, and the highest pollution level was detected in the kidney calf samples from Latakia. Samples from Latakia and Tartus areas showed a higher concentration of As compared to Jableh and Safita, which could be due to the industrial activities. The lowest level of sample As contamination was observed in Safita and Jableh because of the distance from industrial activities and a remarkable decrease in As emissions. There was a significant difference in the As concentrations of various types of collected samples (kidney samples, muscle samples, and liver samples) across all areas ($p < 0.05$). As concentration in the kidneys was the highest level which is more likely due to their vital role in blood filtration and toxin removal, as well as the nature of these fat-containing tissues, and therefore more As accumulation. Moreover, As concentrations were high in liver samples because of its physiological activity in the storage of minerals, potassium, Fe, Zn, and fats, metabolization of toxins and biologically active substances as well as detoxification into safe substances in the body (Soliman, 2016).

**Turkey: Nonprocessed meat (fresh meat).** Two studies were carried out on the determination of HMs in red meats in Turkey. Yayayürük O et al. in 2017 analyzed Hg, Cu, Fe, Mn, Cd, and Pb in the liver of sheep and cows (Yayayürük & Yayayürük, 2017). The results of this study showed the highest concentration of Cu in the samples examined, followed by Fe, Mn, and Hg. In this study, the concentration of Pb and Cd in all the samples was less than the Graphite Furnace Atomic Absorption Spectrophotometry (FAAS) detection limit for all samples. The authors argued that sheep and cow liver samples in turkey in 2017 contained significant quantities of Cu, Fe, Mn, and Hg which could be the result of the breathing of polluted air and the consumption of contaminated food (Yayayürük & Yayayürük, 2017).

The other study in Turkey was done by Oymak T et al. in 2017 which determined the levels of Al, vanadium (V), Se, molybdenum (Mo), Mn, Cr, Cu, and As (mg/kg dry weight) in lung, liver, kidney, and muscle of cattle (Oymak et al., 2017). In this study, the Al content in the lungs was relatively higher than in other tissues. The Se absorbed in internal organs diminished in the following order: kidneys, liver, lungs, and muscles. The maximum level of Se was in the kidneys. Vanadium levels had a narrow range compared to other tissue elements. Results of the study demonstrated that the difference was not significant in the V concentration in all tissue of cattle. As's maximum concentration was in the kidney. The results demonstrate that As, V, and Se are predominantly concentrated in the kidney, Cu, Mn, and Mo in the liver, and Al, V in the lung. However, HM levels were lower than the FAO/WHO limit value. In both Turkish studies, the concentration of HMs in the samples was less than the permissible limit (the FAAS or FAO/WHO detection limits). The high level of HMs might be because the studied farm animals were raised on pastures which may increase the possibility of inhalation of polluted air and ingesting contaminated feed and consequently accumulation of HMs in their organs and tissues (Oymak et al., 2017).

## Conclusions

Consumption of meat contaminated with HMs is one of the most important sources of HM exposure in humans which may contribute to the development of different disorders. This review provided a picture of the status of heavy metal contamination in red meat in ME countries. The main possible sources of pollution in different studied countries were including industrialization, polluted environment (i.e. presence of mines in grazing areas, sewage, and industrial effluents, emissions from vehicles), contaminated animal feed, canning process, and different cooking methods. Most of the studies reviewed claimed that the HM levels in studied samples were higher than the recommended tolerable values proposed by WHO/FAO and US-EPA standards and may have health risks. Therefore, to reduce contamination in meat products in these countries, preventive and regulatory measures should be adopted regarding the sources of contamination mentioned above. Regular monitoring of HMs in the environment and livestock products, and following the standards of Good Manufacturing Practice for meat production is recommended. Moreover, it is necessary to take measures to control the extent of contamination and its sources in the future.

## Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

## Declarations of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgments

This study was supported by the Poursina Hakim Digestive Diseases Research center, Isfahan University of Medical Sciences.

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