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Review Article

Occurrence and Sources of Heavy Metal Contamination of Meat Products with a Focus on The Associated Health Risks: A Review

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Abstract

Meat products are essential sources of high-quality animal protein, essential amino acids, trace elements such as copper, zinc, and iron, and vitamins such as vitamin B group. However, meat products can be exposed to contamination with several xenobiotics including heavy metals. Several species of the heavy metal group have no physiological functions and their intake via contaminated food and water is associated with several adverse health effects that might reach even death. This review threw light on the occurrence of heavy metals and the sources of contamination of the meat products with these chemicals. Moreover, the potential adverse health effects associated with these chemicals were reviewed.

KEYWORDS
Meat, Meat products, Heavy metals, Sources of contamination, Public health

Introduction

Meat products such as mince, luncheon, sausage, and pasterma are among the most important sources of animal-derived protein, with significant quantities of bioactive peptides, vitamins, and energy (Morshdy *et al*., 2023). These products are also important sources of the trace elements copper (Cu) and zinc (Zn), which are essential for the normal physiological activities of the body systems (Darwish *et al*., 2014). Furthermore, meat products are particularly popular among children since they have a distinct aroma and flavor when compared to red meat (Elhelaly *et al*., 2022; Morshdy *et al*., 2022). However, food additives and other non-meat elements such as spices, olives, and so on are added during the manufacturing process of such goods. Such additions may make it easier for some chemical pollutants, such as heavy metals to contaminate the finished products.

Heavy metals' biomagnification and bioaccumulative characteristics are widely documented. Lead (Pb) and cadmium (Cd) are two dangerous elements whose physiological effects are unknown (Morshdy *et al*., 2022). Pb poisoning is responsible for numerous child deaths globally (Darwish *et al*., 2016). Pb is also neurotoxic, causing damage to the digestive system, kidneys, and other organs (Cunningham and Saigo, 1997).

Cd is another hazardous element that can enter people via the food chain (Morshdy *et al*., 2013). The latter was classified as a category B1 carcinogen by the US Environmental Protection Agency (IARC, 2016). Furthermore, Cd is the primary cause of itai-itai illness, which is characterized by renal failure and osteomalacia (Nishijo *et al*., 2017). Furthermore, long-term cadmium exposure has been linked to organ damage, including the liver, kidneys, testes, breast, and neurological system (Darwish *et al*., 2019).

More than 100 enzymes in the body rely on zinc as a trace element for catalytic activity. Zinc is also required for the regulation of the gene expression of several cell components. Furthermore, Zn is required for the maintenance of the cell wall. Zinc deficiency is a major problem in many developing countries. If it does, it has a range of unfavorable health consequences, including anemia, decreased immunity, hypogonadism, and dwarfism. Meat and dairy products are considered important zinc sources for human consumption (Pogorzelska-Nowicka *et al*., 2018; Roohani *et al*., 2013).

Copper is an essential element that has a substantial influence on the biochemistry and physiology of living things since it is a co-factor for many enzymes. Furthermore, Cu is required for cellular respiration. However, persistent Cu exposure may cause oxidative damage to cell organelles (Darwish *et al*., 2014).

Hazardous metals and trace elements were found at minute concentrations in numerous food matrices, including fish, meat, and edible offal (Morshdy *et al*., 2019; Darwish *et al*., 2015).

This review threw light on the occurrence of heavy metals and the sources of contamination of the meat products with these chemicals. Moreover, the potential adverse health effects associated with these chemicals were reviewed.

Occurrence of heavy metal residues in meat products

Onianwa *et al*. (2001) demonstrated that Cu levels ranged widely from 0.06 to 13.3 mg/kg, while Zn levels ranged from 0.06 to 56.9 mg/kg in various foods including meat products retailed in Ibadan city, Nigeria. González-Weller *et al*. (2006) reported that the mean concentrations of Pb and Cd in chicken meat product samples were 3.16 and 4.15 µg/kg, 4.89 and 6.50 µg/kg in pork meat products, 6.72 and 4.76 µg/kg in beef meat products, and 9.12 and 5.98 µg/kg in turkey meat product samples, respectively. Samples were collected from Tenerife Island, Spain. Essa *et al*. (2007) determined the heavy metal residues in 30 random samples of kofta and fried liver sandwiches in Assiut City. They found that the average values of Pb and Cd in the examined samples of kofta were 0.361 ± 0.064 and 0.003 ± 0.001 ppm, respectively. The values in samples of liver were 0.310 ± 0.057 and 0.02 ± 0.007 ppm, respectively. Arafa (2008) found that the mean values of Pb and Cd were 0.024 and 0.223 ppm, respectively in the examined samples of liver collected from slaughtered animals in Alexandria, and these levels were within the "EOS" permissible limits. Abedi *et al*. (2011) estimated Pb and Cd residues in five major brands of six types of cooked beef sausages consumed in Iran. The metal content in the samples varied from 24.0 to 158.7 μg/kg with an average of 53.5 for Pb and from 2.2 to 13.5 with an average of 5.7 for Cd. The highest Pb and Cd concentrations were obtained from a German sausage (158.7 μg/kg) and a hot dog (13.5 μg/kg) respectively. Al-Naemi (2011) estimated Pb and Cd levels in 150 samples of muscles and liver samples of slaughtered cattle in Mosul city. The mean concentrations of Pb in muscles and liver were 0.071 and 0.472 mg/kg, respectively, and Cd results showed that the mean values in muscles and liver were 0.009 and 0.059 mg/kg, respectively.

Darwish *et al*. (2015) estimated the toxic metals (Pb and Cd) residues in meat and animal byproducts of cattle and sheep. They observed that the residual concentrations of these metals exceeded MPL in the livers and kidneys of both cattle and sheep samples. Khalafalla *et al*. (2015) determined the residual levels of heavy metals (Pb, and Cd) in the meat and liver of cattle and sheep. The mean levels of Pb in the muscles of cattle and sheep were 3.135±0.35 and 0.94±0.81 ppm, respectively. The Cd residual levels in muscles were 0.2±0.01 and 0.7±0.03 ppm, respectively. The level of heavy metals residues in the liver of cattle, and sheep were 3.99±0.1 and 1.8±0.85 ppm for Pb; 0.25±0.043 and 0.35±0.02 ppm for Cd, respectively. Nasser (2015) found that four out of 13 canned meat samples marketed in Saudi Arabia had cadmium levels above the maximum permissible level. All samples had levels of Pb above the maximum permissible levels. Adejumo *et al*. (2016) evaluated thirteen samples of cured meat products of diverse origin marketed in South-west Nigeria for their Pb and Cd contents. Cd content ranged between 0.35 and 1.20 ppm; levels considered higher than acceptable limits in consumable products.

Khalafalla *et al*. (2016) determined the residual levels of Pb, Cd, Hg, and tin (Sn) in canned meat products marketed in Egypt, they examined random samples (40 each) of canned chicken luncheon (CCL), canned beef luncheon (CBL), canned frankfurter (CF) and canned corned beef (CCB) were randomly collected from different supermarkets in Egypt to be analyzed using atomic absorption spectrophotometry. The residual levels of Pb in examined CCL, CBL, CF, and CCB samples were 0.330, 0.224, 0.206 and 0.334 mg/ kg, respectively, while those of Cd was 0.057, 0.053, 0.039, and 0.042 mg/kg, those of Hg were 0.387, 0.450, 0.402 and 0.332 mg/kg, and finally those of Sn were 2.061, 2.308, 0.755 and 1.997 mg/kg. Di Bella *et al*. (2020) measured heavy metals in animal foodstuffs from the Augusta-Melilli-Priolo area in order to evaluate the potential human health risks associated with their consumption. All heavy metals were detected in seafood products while most of them were <LOD in beef, pork, and milk samples. Particularly, seafood products registered higher values of total arsenic, mercury, and lead than other food categories, while beef and pork showed higher content of zinc. Cadmium and Pb were below the tolerable limits reported by the European Union in foodstuffs while mercury exceeded the threshold value in seafood products. Kowalska *et al*. (2020) conducted a study to determine the content of tin, lead, mercury, cadmium, and arsenic in canned meat by means of an ICP-MS apparatus and mercury analyzer. Also, probabilistic risk assessment (non-carcinogenic) was estimated by models including target hazard quotient (THQ). The average contents of other elements were as follows respectively, for canned meat Pb 0.202 mg/kg, Hg 0.00003 mg/kg, Cd 0.00496 mg/kg, As 0.002 mg/kg. Besides, the calculation of HI for mixed contaminants revealed values lower than one for canned meat. Barone *et al*. (2021) estimated levels of various trace metals (Pb, Cd, Hg, Zn, Cu, Cr) in meat products (baked ham, raw ham, mortadella, cured sausage, würstel, salami) from South Italy and calculated potential health risk toxicity associated with their consumption for the total population and for children. In the samples studied metal concentrations are within the permissible legal limits (Cd: 0.01-0.03 μg g^{-1} w.w., Hg: 0.01-0.02 μg g^{-1} w.w., Zn: 5.71-7.32 μg g^{-1} w.w., Cu: 1.08-1.21 μg g^{-1} w.w., Cr: 0.15-0.23 μg g^{-1} w.w.), except for Pb (Pb: 0.22-0.38 μg g^{-1} w.w.). The estimated intake values were within the provisional tolerable daily intake limits for toxic metals and recommended daily intake values for essential metals in both tested groups. The noncarcinogenic risk values of the individual metals indicate that there was no health risk, but their combined effects might constitute a potential risk for children. Furthermore, the cumulative cancer risk of all samples studied exceeded the recommended threshold risk limit (> 10-4) in both the total population and children, indicating a risk of potential health problems for consumers, especially for children, who are more vulnerable to toxic metal exposure. Stojanović *et al*. (2021) aimed to examine the influence of the storage period on the content of toxic elements (As, Cd, Hg, and Pb) in five types of canned meat products regularly used in the Serbian Armed Forces. Cans of beef goulash (BG), pork ragout (PR), spam (SP), liver pate (LP), and meatballs in tomato sauce (MB), produced according to military standards and stored under regular conditions, were analyzed. Meat products were packed in tin cans made according to special requirements in terms of tin and varnish application and stored for up to 6 years. The content of toxic elements varied depending on the analyzed product. The highest average content of arsenic was in BG (10.00 μg/kg), cadmium in LP (35.91 μg/kg), and mercury and lead in PR (15.04 and 8.00 μg/kg, respectively). The average concentrations of As, Cd, Hg, and Pb in all types of canned meat products were significantly lower than the maximum permitted levels in food currently in force by local and EU legislation. The storage period did not significantly affect the level of toxic elements, although higher concentrations were found in samples stored for more than 2 years. Raeeszadeh *et al*. (2022) mentioned that heavy metals accumulation in food products as a result of industrialization is one of the main potential threats to public health. Their study aimed to evaluate the concentrations of heavy metals in the meat of some prevalent farm animal species including sheep, beef, turkeys, and ostriches in Sanandaj (one of the strategic cities in Kurdistan province, Iran). In this study, the contents of some heavy metals (selenium, lead, cadmium, arsenic, cobalt, zinc, nickel, copper, and chromium) were assessed in 170 meat samples collected from meat distribution centers in Sanandaj, Kurdistan province. The ICP-MS method was used to assess the levels of these elements in the meat of beef, sheep, turkey, and ostrich as the main consumed meats in this region. The results showed that there were no significant differences in the average contents of selenium, nickel, cobalt, and chromium among various meats ($P > 0.05$). However, the amounts of lead, cadmium, arsenic, zinc, copper, chromium, and nickel were meaningfully different to maximum permissible limits (MPL) ($P < 0.05$).

Sources of heavy metals contamination in meat products

Saygideger and Dogan (2005) mentioned that heavy metal contamination occurs in nature from different natural sources such as weathering and soils and from man-made pollution sources like industrial effluents. Shaheen *et al.* (2005) reported high levels of air-born trace metals (Pb and Cd) from contaminated fumes and effluents of local industries and traffic emissions. Kirkham (2006) reported that Cd is recovered as a byproduct from the mining of sulfide ores of Pb and Cu. Other sources of Cd contamination include plating operations, disposal of Cd–Cd-containing wastes from paint pigments, alloy preparation, and batteries. Turhan (2006) determined that the fat content in foods in addition to the cooking process, affected the migration of aluminum from foil to food. ATSDR (2007) reported that Pb is one of the most ubiquitous metals known to humans. The main route of exposure for the general population is food and air. Lead is used to make lead shots, fishing weights, sheet lead, some brass and bronze products, pipes, paints, ceramic glazes, dyes in paints and pigments, and medical equipment. EFSA (2009) concluded that for a non-smoking person who is not occupationally exposed to cadmium; foodstuffs represent the source of up to 90% of his or her total intake of Cd. Ragan and Turner (2009) reviewed that Pb is a common environmental pollutant. Sources of lead contamination include industrial use of lead, such as lead–acid batteries, lead wire, pipes, metal recycling, and foundries. Zhuang *et al.* (2009) reported that the distribution of cadmium into the food was often through water, air, and soil. In humans and animals, cadmium contamination is usually caused by the food chain. Darwish *et al.* (2010) revealed that the pollution by heavy metals has increased because of increases in population, the number of agricultural projects, as well as industrial and other activities along the Nile Delta. Environment Canada (2010) reported that lead may enter the environment from natural processes, and human industrial activities such as metal smelters or refineries. Lead has been and continues to be used extensively, particularly in the making of lead–acid batteries. Johri *et al.* (2010) reported that environmental exposure through food is increasingly recognized as an important source of heavy metal exposure in developed countries. Heavy metal toxicity could be present in different ways depending on its route of ingestion, dose, tissue affinity, age, and sex, as well as whether exposure is acute or chronic. EFSA (2011) revealed that cadmium is a toxic metal occurring in the environment from natural sources and as a consequence of anthropogenic activities related to industry and agriculture. CDC (2012) mentioned that lead can be ingested from various sources, including lead paint and house dust contaminated by lead paint, as well as soil, drinking water, and food. Yazdi *et al.* (2012) reported that contamination of the environment by heavy metals is a worldwide issue due to their toxicity, accumulation in the food chain, and finally uptake of these metals by humans and other organisms. Elshewey *et al.* (2015) mentioned that there were many sources of heavy metals, often due to smaller mining activities. This has led to toxic metals in the environment that directly affect air, water, soil, and food. Zhang *et al.* (2016) conducted a study in which heavy metals concentration in sediments and water from the Lake Pontchartrain estuary along the I-10 Bridge were investigated in two seasons to evaluate the level of contamination and to assess the effect of vehicular traffic. Vehicular traffic has led to heavy metals such as As, Cd, Cr, Pb, Zn, Ni, and Cu accumulation in sediments along the bridge. The HMs content in water, especially in summer increased due to high temperatures which led to the release of heavy metals from the sediments. The level of pollution attributed to anthropogenic activities was evaluated using several pollution indicators. The overall heavy metals bioavailability was mostly high in summer and the concentration of the heavy metals in both sediments and water was highly influenced by the season and the distance from the highways. Dane and Şişman (2020) reported that heavy metal contamination is becoming a global issue. Heavy metals can enter fish through three routes: the gills, the body surface, and the digestive tract. Wang *et al.* (2021) mentioned that heavy metal contamination of water is one of the most serious environmental concerns affecting plants, animals, and humans.

Public Health importance of heavy metals

ATSDR (2006) classified lead and cadmium as potentially toxic to human health due to their known or suspected toxicity. CDC (2006) reported that lead exposure has interfered with bone formation, maturation, and reabsorption and may be a potential risk factor for osteoporosis. Signs and symptoms of acute lead poisoning in adults may include abdominal pain, anorexia, nausea, severe vomiting, intestinal cramps, epigastric colic, constipation, headache, joint and muscle pain, convulsions, and hemolytic anemia. Im *et al.* (2006) mentioned that cadmium is a heavy metal that accumulates in the body, and its accumulation in the brain damages both neurons and glial cells. They added that cadmium induced astroglial toxicity and astroglia death via glutathione depletion. ATSDR (2007) reported that lead could be transferred to infants via breast-feeding. After immediate exposure, humans are able to get rid of 50% of lead within 2 – 6 weeks, but it takes 25 – 30 years to get rid of 50% of lead that has accumulated in the body over time. CSC (2007) recorded that lead exposure has been linked to miscarriage, hormonal changes, and reduced fertility. Pearce (2007) reviewed that symptoms of lead toxicity may be headache, abdominal pain, memory loss, kidney failure, weakness, pain or tingling in extremities, and male reproductive problems. ATSDR (2008) reported that oral exposure to high levels of cadmium has led to severe stomach irritation, leading to vomiting and diarrhea, while exposure to lower levels over time has been found to cause kidney damage, bone deformity, and the ability of bones to break easily. Meanwhile, breathing cadmium has been associated with lung cancer in humans occupationally exposed. Flora *et al.* (2008) lead is stored in blood, bone, and soft tissues including the brain, spleen, kidneys, liver, and lungs. The presence of excess levels of lead leads to the production of free radicals, which subsequently cause oxidative damage to cellular components including DNA and cell membranes. Mañay *et al.* (2008) indicated that adverse health effects of cadmium exposure may occur primarily in the form of kidney damage, but possibly, bone effects and fractures may also occur. Edwards and Prozialeck (2009) indicated that cadmium is a severe pulmonary and gastrointestinal irritant, which can be fatal if inhaled or ingested. Furthermore, cadmium plays a role in hypertension, and diabetes mellitus in humans, through injury of the adrenal gland, adipose, hepatic, and pancreatic tissues, especially cells within islets of Langerhans, reducing insulin levels, altering glucose metabolism and glucose uptake that ultimately results in increased blood glucose. EFSA (2009) reported that cadmium is primarily toxic to the kidneys. Exposure to Cd is associated with many other effects such as nephrotoxic, neurotoxic, carcinogenic, genotoxic, and teratogenic effects, the development of osteoporosis or osteomalacia, and damage to the endocrine system and reproductive functions. Ohsawa (2009) reported that the lead provides adjuvant signals to promote lymphocyte proliferation and enhance adaptive immune responses to unrelated antigens, enhance allergic and hypersensitivity reactions to environmental antigens, and activate neo-antigen-specific T-cells. Health Canada (2010) reported that in the human body, lead accumulates in tissues, especially bone, but also in the liver, kidneys, pancreas, and lungs. Pregnant women and young children are particularly vulnerable because lead can cross the placenta easily and enter the fetal brain. Moreover, cadmium is absorbed into the body accumulating in the kidney and liver, although it can be found in almost all adult tissues. IARC (2010) mentioned that cadmium and cadmium compounds are considered carcinogenic to humans.

Reddy *et al*. (2011) reported that lead absorption is increased considerably with fasting or in persons whose diet is deficient in calcium, iron, phosphorous, or zinc. Recent studies from Hyderabad also showed high blood lead levels in neonates and mothers in the general population and abnormal cognitive functions in children at levels above 10μg/dl as it is labeled as a poisoning amount. Hussain *et al*. (2012) concluded that the risk associated with the exposure of food products to heavy metals had aroused widespread concern in human health. Contamination of heavy metals is a serious threat because of their toxicity, bioaccumulation, and biomagnification in the food chain. There are reports in which Cd accumulates in the kidney and liver over a long time and interacts with a number of minerals mainly zinc (Zn), iron (Fe), copper (Cu), and selenium (Se) due to chemical similarities and competition for binding stage. Taha *et al*. (2013) revealed that exposure to lead toxicity leads to impairment of kidney and liver functions and causes immune depression. Darwish *et al*. (2015) concluded the exceeding of both cadmium and lead levels in the meat of Egyptian sheep and cattle than FAO and WHO permissible limits. This indicated that the consumption of such meat might pose a health risk. Elshewey *et al*. (2015) illustrated that heavy metals are chemical elements, which cannot be destroyed or broken down through heat treatment or environmental degradation, so pollution of the environment with it can be a serious problem. The presence of heavy metal residues particularly in fast foods is potentially hazardous to humans, especially children. Lin *et al*. (2016) recorded a significant decrease in the vaccine antibody titers of polio, Japanese encephalitis, measles, diphtheria, pertussis, tetanus, and hepatitis B virus following preschool children's exposure to lead and cadmium. Zeng *et al*. (2016) reported that lead and cadmium influence a number of diverse systems and organs, resulting in both acute and chronic effects on children's health, ranging from minor upper respiratory irritation to chronic respiratory, cardiovascular, nervous, urinary, and reproductive disease, as well as aggravation of pre-existing symptoms and disease. Sani *et al*. (2017) mentioned that Cu and Zn are one of the major hazardous heavy metals produced by industrial activities. They mainly infringe on the liver and kidney function and the central nervous system after being absorbed into bodies, and Cu gives rise to depression or even lung cancer. Zaynab *et al*. (2022) mentioned that heavy metal toxicity can deplete energy and affect the brain, lungs, kidneys, liver, blood, and other vital organs. Long-term exposure eventually results in degenerative physical, tissue, and neurological processes imitating diseases such as Alzheimer's, Parkinson's, muscle dystrophy, and multiple sclerosis. Acute lead exposure can induce appetite loss, headaches, hypertension, stomach discomfort, renal dysfunction, fatigue, insomnia, arthritis, hallucinations, and vertigo. Mercury toxicity results in acrodynia or pink disease. Increased mercury exposure may affect the brain's structure and cause shyness, tremors, cognitive loss, irritability, and visual or hearing.

Conclusion

This review confirmed the contamination of meat products with several toxic metals such as Pb, Cd, Hg, As, Therefore, continuous screening and monitoring of heavy metals in meat and meat products is of a particular importance for the sake of human health and food safety.

Conflict of interest

The authors declare no conflict of interest.

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