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Review paper

Levels and accumulation of selected heavy metals in the One Health approach

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A B S T R A C T

Meat and meat products are main sources of human nutrients, including protein, minerals, vitamins, and fats**.** One of the main potential risks of meat consumption, to public health, is the accumulation of heavy metals. Their concentrations in the environment are increasing with the rapid development of human civilization as well as the exploitation of geological resources. Because they are so prevalent in the environment, heavy metals can infiltrate the food chain. Food contamination consequently has the potential to negatively impact consumer health. Heavy metals, including lead (Pb), cadmium (Cd), and mercury (Hg), that are frequently present in food have toxicological reference values, and their primary dietary sources are known. Their levels in all kinds of food, including meat, are assessed by comparing them with the maximum permissible limits set by the European Union. European Commission Regulation EC 2023/915 sets maximum levels (MLs) of heavy metals allowed in traded meats from domesticated bovine animals, sheep, pigs, and poultry, but also from less frequently eaten meats from wild animals, including cephalopods and bivalve mollusks.

1. Introduction

Meat is a rich source of nutrients important for human diet and provides the well-known proteins, minerals, vitamins and trace element contents. In recent years, much attention has been focused on the risk of heavy metal contamination in meat, because of the toxic nature of these metals even at relatively small levels (*Lukáčová et al*., 2013). Metals are a large group of elements that are classified as essential trace elements, macroelements (sodium, calcium, and magnesium) and toxic or heavy metals. While some elements (iron, copper, manganese, cobalt, and zinc) are essential for human health and play a specific role in body metabolism, others (lead, cadmium, chrome, mercury, and arsenic) are recognized as dangerous, and their presence can cause biochemical and neurological problems in humans. Heavy metals can be involved in different signaling pathways in carcinogenesis, interfere with ATP synthesis, and change protein synthesis (*Rudy et al*., 2007).

Metals are found in all living organisms and in the environment, where they are formed by burning fossil fuels, and are in pesticides and herbicides, waste disposal sites, and municipal sewage. They have a long life in the environment and can move up the food chain. Heavy metal contamination of meat and livestock products does not occur during processing; rather, the main contributing factors include giving contaminated feed to livestock and poultry

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or keeping them in close proximity to contaminated areas (*Singh et al.*, 2011). The target tissues, like muscle, the kidneys, and the liver, are the primary sites for the precipitation of heavy metals in the animal body (*Emami et al.*, 2023). There is a greater probability of toxic metal traces being found in higher levels in food from animals that are from areas with mining and anthropogenic activities.

The diet, particularly the consumption of meat and other animal products, is usually the main source of human exposure to heavy metals. Although acute ingestion of these elements through food can infrequently result in poisoning, the accumulation of them in the body has a negative impact on human health (*Ahmad et al.,* 2018). The WHO has concluded, after extensive evaluation studies on food additives and their toxicity, that even low amounts of particular metals, such as lead and cadmium, can result in disease in humans (*WHO*, 2001). Lead, cadmium, arsenic, mercury, and chromium are the heavy metals in meat and animal products that should primarily be controlled. Therefore, the EU Scientific Committee on Food has established a maximum limit for these specific pollutants in products, which is periodically monitored by the European Food Safety Authority (EFSA) (*Reg EC 2023/915*), with adjustments and additions for cadmium (*Reg EC 2021/1323*) and lead (*Reg EC 2021/1317*) in recent years. In accordance with these regulations, the Republic of Serbia published a currently valid regulation on maximum levels for certain contaminants in food *(Official Gazette of the RS, No. 127 of November 18*, 2022).

Lead (Pb) is a dangerous heavy metal that occurs naturally in the environment, in rocks, soil, vegetation, and the hydrosphere. Bipolar lead forms interfere with the normal function of enzymes and inhibit their action. If the bonding capacity for blood protein is exceeded, lead passes into the bone marrow, liver, and kidneys (*Levin et al.*, 2020). Table 1 shows the maximum permitted values of lead in the meat of different animal species according to *Regulation EC 2021/1317*. Cadmium (Cd) is a heavy metal found as an environmental contaminant, both through natural occurrence and from industrial and agricultural sources. Foodstuffs like cereals, vegetables, and meat and meat products are the main

Table 1. Maximum lead (Pb) levels (mg/kg wet weight) in meat of different animal species (Reg EC 2021/1317; Official Gazette of the RS, No. 127/2022)

Foodstuffs	Maximum level of Pb (mg/kg wet weight)
Meat (excluding offal) of bovine animals, sheep, pig and poultry	0.10
Offal of bovine animals and sheep	0.20
Offal of pig	0.15
Offal of poultry	0.10
Muscle meat of fish	0.30
Bivalve mollusks	1.50

Table 2. Maximum cadmium (Cd) levels (mg/kg wet weight) in meat of different animal species (Reg EC 2021/1323; Official Gazette of the RS, No. 127/2022)

Foodstuffs	Maximum level of Cd (mg/kg wet weight)
Meat (excluding offal) of bovine animals, sheep, pig and poultry	0.050
Horsemeat (excluding offal)	0.20
Liver of bovine animals, sheep, pig poultry and horse	0.50
Kidney of bovine animals, sheep, pig poultry and horse	1.0
Muscle meat of fish	0.050
Bivalve mollusks	1.0

source of cadmium exposure. The specified maximum cadmium values for meat products according to *Regulation EC 2021/1323* are shown in Table 2. Arsenic (As) is found in high concentrations in nature as a result of anthropogenic pollution (use of herbicides, fungicides, pesticides, glass and smelter manufacturing). There is no need to restrict or avoid eating meat and animal products in order to lower exposure to arsenic because they contain little to no arsenic (*Nachman et al.*, 2017). Mercury (Hg) is global toxic heavy metal, even in trace amounts, and its presence in food must be monitored at all times. Mercury can be present in contaminated air, soil, and water, and it can also be converted by microorganisms into more accessible organic forms that are then ingested at higher levels of the food chain (*Rodríguez-Estival et al.*, 2020).

2. The presence of heavy metals in meat of different animal species

Different animal species have various bio-accumulation capacities for heavy metals. The level of heavy metals in animals and meat thereof also depends on environmental conditions and industrialization development in the environment where the animals are raised (*Badis et al.,* 2014). For example, mutton accumulates lower levels of these metals than do other meat animals, which may be caused by the specific feeding of sheep with grass and less mineral supplement (*Han et al.*, 2022). Accumulation of cadmium and lead in kidney, liver, and spleen of horse was found to be relatively higher than in tissues of other animal species (*Mor et al.*, 2005). Generally, liver was found to have the highest significant level of metals, and the meat and blood has the lowest levels. Due to frequent the high concentrations of metals in the sea, we can find high levels of arsenic, cadmium, lead, and mercury in marine fish above the regulatory limits. Seafood is the main dietary source of arsenic in humans, because these foods contain several times the amount of this metal than other foods (*Bosch et al.*, 2016). Besides this, mercury levels found in some seafood products are of great concern, exceeding the limits set for fishery products by the European Regulation (1.0 mg/kg) (*Regulation EC 2022/617*). Because lead ammunition is used in hunting, it is common knowledge that game meat occasionally contains high quantities of lead, especially around the bullet entry and exit points on the carcasses. While non-lead alternatives to lead shotgun and rifle ammunition have been developed, there is no European rule requiring their usage for game shooting (*Mateo & Kanstrup*, 2019). Some other heavy metals can also appear in somewhat higher levels in wildlife than in meat from domesticated animals.

3. General health effects of heavy metals

The high exposure to heavy metals is a serious problem in the food chain because of their toxicity and bioaccumulation. The competence of the body to exude toxic metals is generally slower than the intake, thus leading to their accumulation in organs and to long-term health impacts. Carcinogenic effects, central and peripheral nervous system damage, and blood circulatory effects are some of health effects that can be expected (*Durkalec et.*, 2015).

For example, excessive intake of lead in the human body can lead to developmental disabilities in children, nervous system dysfunction of the fetus and infants, kidney and blood problems, reproductive dysfunction, and cardiovascular disease. Cadmium manifests in several pathological processes, especially being toxic to the kidneys, and particularly to proximal tubular cells, where it accumulates over time and can cause kidney dysfunction. Besides this, chronic exposure of cadmium can cause liver harm and bone and blood damage. One consequence of mercury poisoning is damage to the nervous system of newborn children (*Han et al*., 2022). According to the EFSA Panel on Contaminants in the Food Chain (CONTAM Panel), the tolerable weekly intake (TWI) of cadmium is 2.5 µg/kg b.w. (body weight of the person) per week, which is equivalent to 2.5/7 = ~0.36 µg/kg b.w. per day (*EFSA*, 2011). For lead, the benchmark dose level (BMDL10) of 0.63 µg/kg b.w. per day is considered as health-based guidance value (HBGV), since EFSA concluded that the current provisional tolerable weekly intake (PTWI) of 25 µg/kg b.w. is no longer appropriate, as there is no evidence for a threshold for critical lead-induced effects (*EFSA*, 2010).

Metallic mercury poisoning often results from mercury vapor, which enters the alveoli through the respiratory tract and is transported throughout the body through the blood circulation, causing movement disorders, headache, dizziness, etc. The persistent occurrence and accumulation of heavy metals from numerous sources resulted in them being ranked by the Agency of Toxic Substances and Disease Registry (ATSDR) as the most hazardous and toxic substances in the environment (*ATSDR*, 2011).

4. Conclusion

In the human diet, meat has an important function and is a rich source of nutrients. In addition to its useful components, meat contains some hazardous components such as heavy metals, whose levels must be periodically monitored to ensure the safety of public health. Preventive and regulatory measures for controlling contamination sources are the best way to reduce contamination in meat and meat products. Implementation of good agricultural practices, farm management systems, water testing, feed protection from contamination, and the selection of uncontaminated areas to keep animals can help identify and control the risks of heavy metals occurring in meats. Developed and some developing countries have responded to the potential menace of the over-intake of these metals by regulating the amounts of toxic metals permissible in different types of meat and meat products. The promotion of the One Health concept in meat production from farm to fork is one strategy that can be used to prevent the contamination of meat by heavy metals.

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