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REVIEW PAPER

Effect of cadmium and lead on living organisms – transport, accumulation, metabolism

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Abstract

Heavy metals are metals and non-metals with molecular weights exceeding 20 and specific gravity above 5. The heavy metal cycle in the environment is linked to the food chain: soil – plant – animal – human. The transfer of metals to the higher link results in a cumulative increase in their content. Pollution with heavy metals has become a severe threat to the environment and food safety due to the rapid development of agriculture and industry and disturbances in the natural ecosystem induced by the enormous growth of the global population. Major sources of heavy metals in soil are bedrock, industrial and transport emissions, municipal management, and agriculture. Three main reasons for the toxicity of metals were found to be: participation of metals in enhancing the production of ROS (Reactive Oxygen Species) and modification of the activity of the antioxidant system, ability to react directly with proteins, resulting from the affinity between metals and thiol, histidine and carboxyl groups and leading to the attachment of metal ions to active sites of enzymes, structural elements of cells and proteins involved in cell transport, and replacement of elements necessary for metabolism, e.g. calcium in bones or iron in erythrocytes with metals, which leads to damage and changes in their structure and metabolism. The key solution towards decreasing the content of Cd and Pb in food is to limit or prevent their initial absorption by plants used for food or animal feed. However, due to the complexity of interactions between soil chemistry, varieties and species of plants and agronomic practices, additional research is needed.

Keywords: cadmium, lead, toxic effect on plant and human and animals, mechanism of toxicity

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INTRODUCTION

Heavy metals are harmful substances, the presence of which in the environment is difficult to prevent. The contamination of soil with heavy metals is particularly grave due to their migration and accumulation, also in forage crops grown in permanent cropland alongside transport routes, which increases with the growth in the number of diesel vehicles (Kuziemska et al. 2017). Toxic metals are taken in from soil by plants, which are then consumed by animals, acting as intermediaries in their transfer to the human body, which is associated with their ability to accumulate (Rybarska 2022). The content of heavy metals in soil depends on its chemical composition and the quantity of pollutants emitted into the air. Metal compounds occurring in the environment have a different degree of solubility and phytotoxicity. Compounds that are easily soluble in water can penetrate deeper into the soil. Soil acidity promotes the formation of phytotoxic components. The bioavailability of metals to plants depends on plant species, environmental conditions and the soil content of such metals (Rajmund, Bożym 2014).

The heavy metal cycle in the environment is linked to the food chain: soil – plant – animal – human. The transfer of metals to the higher link results in a cumulative increase in their content. The distribution of heavy metals mostly depends on their permeation through biological membranes and, to some extent, the degree of affinity with the specific structure of the body (Hegazy et al. 2010). Studies involving rats showed that the accumulation of Cd and Pb in organs is higher when these metals are supplied with water than with food (Winiarska-Mieczan, Kwiecień 2016). Heavy metals reach body cells through transport proteins and can bind enzymes and nucleic acids, which disturbs their function (Hegazy et al. 2010). Analyzing UNICEF data, it can be observed that in as many as nine countries worldwide, more than 1 child out of 20 is poisoned with Pb, meaning that their blood Pb level is at least 5 μg dL^{-1} (www.unicef-irc.org). These countries are: Mexico (31.1%), Costa Rica (13.4%), Romania (10.1%), Belgium (7.8%), and Malta (7.6%), as well as Lithuania, Hungary, Portugal, and Bulgaria, where this level is around 5 μg dL^{-1}. In Poland, this level was found in 3.6% of children.

Description of heavy metals

From the chemical point of view, heavy metals are metals and non-metals with molecular weights exceeding 20 and specific gravity above 5, and include cadmium (Cd), mercury (Hg), copper (Cu), arsenic (As), lead (Pb), chromium (Cr), nickel (Ni), iron (Fe) and zinc (Zn). From the biological point of view, ‘heavy’ describes several metals, including some metalloids, which, even at low concentrations, can be toxic to plants and animals (Rascio, Navariizzo 2011). The group of heavy metals also encompasses elements that are essential to living organisms as well as those with an unknown physiological role. Their shared feature is that at levels exceeding the admissible dose, even elements that are essential in small or trace quantities have a toxic effect on plant organisms, and animal and human bodies (Ahmadi et al. 2016). The most toxic ones triggering numerous diseases are Cd and Pb – metals that are redundant to living organisms. In animal or human bodies, heavy metals mostly alter the synthesis of proteins and disturb ATP production, which may lead to the development of severe pathological lesions, including tumours. The toxic effect largely depends on the amount of the element received by the body. It should be emphasised that the level of toxicity is also determined by the chemical form of metals, their solubility in body fluids and lipids, duration of exposure, and resistance of the specific body (Egorova, Ananikov 2017).

Pollution with heavy metals has become a severe threat to the environment and food safety due to the rapid development of agriculture and industry, and because of disturbances in natural ecosystems caused by the enormous growth of the global population (Sarwar et al. 2016). Major sources of heavy metals in soil are bedrock, industrial and transport emissions, municipal management, and agriculture. The most significant anthropogenic sources of heavy metal pollution of the environment include non-ferrous metal mining and metallurgical processing, metallurgical industry, chemical industry, waste storage, use of contaminated mineral (mainly phosphate) fertilisers at high doses, use of lime waste for soil deacidification, plant protection products, fertilisation with sediments, and surface run-offs from roads with heavy traffic (Gouder de Beauregard, Mahy 2002, Vasquez--Murrieta et al. 2006, Ociepa et al. 2008, Sas-Nowosielska 2009). The heavy metal pollution of soil has been a global environmental concern. All over the world, 500 million ha of land are contaminated with heavy metals, which has a significant impact on the global economy (He et al. 2015). In contrast to organic pollution, pollution by heavy metals is latent, permanent and irreversible. Not only do they deteriorate the quality of water reservoirs, the air and food crops but, since they accumulate in the food chain, they are also a huge hazard to the health and welfare of organisms (Kankia, Abdulhamid 2014).

Effect of Cd and Pb on plants

Cadmium, among other effects, disturbs photosynthesis and the conversion of nitrogen compounds. It also alters the permeability of cell membranes and modifies the structure of DNA. Because it mainly occurs in an ionic form in the soil environment, plants can take it up relatively intensely and their root system easily transports the element to all the organs. Research has shown that the most significant factors affecting Cd uptake are its content and soil reaction (Kabata-Pendias, Mukherjee 2007). Factors that can affect the intensity of Cd uptake by plants include the soil content of micro- and macro-elements, in particular nitrogen, and weather conditions.

The presence of Zn in the soil solution can have a material impact on Cd uptake by plants, but this is not explicitly reported. In addition, the choice of plant species and variety has a considerable influence on Cd uptake. Generally, cadmium tends to be toxic to plants at soil levels ranging from 5 to 30 mg kg^{-1}. The main symptoms of its toxicity are chlorotic and brown spots on leaf blades, red veins, twisted leaves, and shortened roots (Kabata-Pendias, Pendias 2001, Kabata-Pendias, Mukherjee 2007).

Lead occurs naturally in plant organisms but its metabolic function has not been confirmed. Its excess amounts adversely affect the basic life processes of plants. It disturbs photosynthesis, cell division, nitrogen metabolism and water/fluid balance. The toxic impact reduces crop yield and causes leaves to grow smaller and become dark green or red, in extreme cases developing necrotic spots, and shorter roots with less dense root hair (Gruca-Królikowska, Wacławek 2006). They result from incorrect mitosis, photosynthesis or water/fluid balance of the plant. The mobility of Pb in plants is very limited. Research shows that generally more than 90% of this element accumulates in roots. The uptake of Pb from the soil by plant roots is insignificant. The overall content of Pb in the soil above 500 mg kg^{-1} is deemed toxic to plants (Ociepa-Kubicka, Ociepa 2012). It should be highlighted that the bioavailability of Pb to plants can change due to a change in the reaction, content of organic compounds, iron oxides, and phosphorus content. A significant factor determining the bioavailability of Pb to plants is also the exchange capacity of the soil. Elements such as Ca, S and P act as antagonists to Pb uptake by plants, precipitating poorly soluble lead (Kabata-Pendias, Pendias 2001).

Effect of Cd and Pb on humans and animals

The anti-oxidative effect of Cd and Pb may contribute to morphological changes and disturbances in the function of the heart and lungs as well as cause brain damage (Nazima et al. 2014, Winiarska-Mieczan 2013, Winiarska-Mieczan et al. 2020,). Reactive oxygen species (ROS) have a destructive effect on any biomolecules present in the body, leading to damage at the molecular and cell organelle levels. Cytotoxicity of heavy metals is limited by antioxidant enzymes such as: superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPX), which convert oxygen species into molecular oxygen and water and by non-enzymatic antioxidants occurring in cells, and in particular glutathione (GSH) – Winiarska-Mieczan (2018).

The toxic effect of Cd is mainly connected with its occurrence as free ions in the body. They bind to the atoms of sulphur, hydrogen and oxygen, which disturbs many metabolic cycles. Cadmium disturbs protein metabolism, and interferes with vitamin B_1 conversion (Genchi et al. 2020). Chronic poisoning affects the metabolism of calcium and phosphorus compounds and impairs bone mineralisation, hence increasing bone brittleness. Cadmium is classified as a carcinogenic element with a confirmed embryotoxic and teratogenic effect (Kumar, Sharma 2019). Cadmium in the bodies of humans and animals has a toxic effect, mostly on (1) the urinary system – the presence of proteins with high molecular weight, the inhibited reabsorption in renal tubules, and the development of renal stones; (2) respiratory system – pulmonary oedema and emphysema, inflammation of the mucous membrane of the nose and throat, respiratory distress, loss of smell; (3) cardiovascular system – impaired blood flow; and (4) embryotoxic effect – hyperchromatic anaemia, myocardial degeneration and hypertension, premature deliveries, low birth weight and embryopathies (Sharma et al. 2015).

The main target organs accumulating Cd are the liver and kidneys as well as the pancreas, intestines and lungs (Satarug 2018). This element can be detected in urine only after a kidney injury. If the renal cortex accumulates 200 µg Cd g^{-1}, acute symptoms of the disease will occur. The half-life of Cd in soft tissue is from 25 to 30 years (Genchi et al. 2020). On average, humans take in from 0.2 to 0.4 mg Cd a week with food, which falls into acceptable limits set by WHO, that is, 0.4-0.5 mg (Ociepa-Kubicka, Ociepa 2012). The tolerable weekly intake (TWI) of Cd with diet is estimated at 2.5 µg kg^{-1} body weight/week (EFSA 2012*b*), and human exposure to Cd under conditions of exposure is from 7 mg kg^{-1} body weight/week (Kaczmarek-Wdowiak et al. 2004). Research results indicate that smoking 20 cigarettes a day corresponds to taking in 40 µg Cd with food, which means that the intake of Cd is doubled in this case. According to the applied mathematical models, taking the Cd absorption rate into account, it is estimated that by consuming 10 µg of cadmium a day we can reach its critical concentration in the renal cortex, which WHO experts claim to be 200 mg kg^{-1}, within 50 years (WHO 2002). The International Agency for Research on Cancer put cadmium on the list of carcinogenic substances giving rise to prostate and testicular cancer, and blood cancer (Ociepa-Kubicka, Ociepa 2012). Researchers demonstrated that Cd can disturb the transport and metabolism of many essential metals, such as iron, zinc and copper (Piontek et al. 2014).

The body's main ways of lead absorption are the respiratory tract and skin, and – to a lower extent – the digestive system. Initially, the distribution of Pb in the body is mainly determined by the rate of the blood flow through tissues – during the first few minutes the largest amount of Pb reaches the organs with high blood flow (lungs, heart, kidneys, liver, and brain) – Celbis (2011). Reabsorption depends on the form of Pb, the metabolic activity of the body, age and physiology (Ismail et al. 2019, Mattisson et al. 2020, Balali-Mood et al. 2021). Human exposure to Pb under conditions of exposure is approximately 35mg/kg of body weight/week (Kaczmarek--Wdowiak et al. 2004). Based on the standards of WHO (2000), the Provisional Tolerable Weekly Intake (PTWI) for Pb was determined as 25 µg kg^{-1} body weight/week (3.6 µg kg^{-1} body weight/day). In turn, the European Food

Safety Authority (EFSA) set the Benchmark Dose Lower Confidence Limit (BMDL) for Pb as:

– BMDL01 1.5 μg,

– BMDL10 0.63 μg kg^{-1} body weight/day for adults,

– BMDL10 0.5 μg kg^{-1} body weight/day for children (EFSA 2012*a*).

The half-life of Pb in soft tissue is about 30 days (EFSA 2010). At high doses, lead reveals a toxic effect, but it is long-term exposure to Pb that is particularly dangerous to humans.

All Pb compounds are toxic. The most frequent disease resulting from Pb exposure is saturnism (lead poisoning). This is chronic poisoning with Pb and its salts developed by workers of: printing houses, battery factories, lead paint factories (Ociepa-Kubicka, Ociepa 2012).

Acute poisoning is rare. Chronic poisoning primarily affects the digestive and nervous systems. Its main symptoms include tiredness, fatigue, muscle paralysis, Burton line, memory loss, and neurological and mental issues (Dobrakowski et al. 2013). It is especially toxic to the nervous system of young people, who have not yet well developed the blood-brain barrier (Winiarska-Mieczan 2013, Winiarska-Mieczan et al. 2022). Already at 0.2 mg kg^{-1} in blood, Pb damages the central and peripheral nervous systems. In addition, Pb poisoning can affect the blood circulation and cardiovascular systems, respiratory system, as well as kidneys and liver. It disturbs the reproductive functions and the metabolism of calcium, which excessively builds up in the body and causes bone deformation (Ara, Usmani 2015). Lead has a wide range of toxic effects on humans and animals (Assi et al. 2016), including:

(1) embryotoxic effect – decreasing foetal count and size, increasing neonatal mortality;

(2) carcinogenic effect – benign and malignant tumours of kidneys, endocrine gland tumours, pulmonary adenoma;

(3) mutagenic effect – DNA damage.

The permissible concentration of lead in biological material is 50 μg Pb 100 ml^{-1} of blood, while for cadmium it is 2 μg Cd g^{-1} creatinine in urine and 2 μg l^{-1} blood (Regulation of the Minister of Health, 30 December 2004 r.)

Mechanism of Cd and Pb toxicity

Three main reasons for the toxicity of metals were found: (1) participation of metals in enhancing the production of ROS and modification of the activity of the antioxidant system; (2) ability to react directly with proteins, which results from an affinity between metals and thiol, histidine and carboxyl groups and leads to attachment of metal ions to active sites of enzymes, structural elements of cells and proteins involved in cell transport; (3) replacement of elements necessary for metabolism, e.g. calcium in bones or iron in erythrocytes with metals, which leads to damage and changes in their structure and metabolism (Winiarska-Mieczan 2018).

Cadmium and lead do not participate directly in producing reactive oxygen species but they indirectly contribute to oxidative stress, leading to increased peroxidation of lipids, damage to nucleic acids, alterations in the expressions of genes and apoptosis processes, inhibiting the activity of antioxidant proteins by binding them to sulfhydryl groups and inhibiting calcium homeostasis (Czeczot et al. 2009, Winiarska-Mieczan 2018). Their participation in producing ROS comprises disturbance to the flow of electrons in the electron transport chain and releasing transition metals involved in the Fenton and Haber-Weiss reactions from cells (Valko et al. 2006, Winiarska-Mieczan 2018), as well as impairment of the body's endogenous antioxidant mechanisms due to displacing Mn, Cu and/or Zn ions from the centre of active SOD, Fe ions from the CAT heme system or Se ions from GPX (Nemmiche 2017, Winiarska-Mieczan 2018). Experiments on laboratory animals proved that Cd and Pb adversely affected the body's antioxidative status. Reactive oxygen species react with polyunsaturated fatty acids in cell membranes, which initiates the process of lipid peroxidation resulting in the modification of proteins, and changes in the electrochemical gradient, which in turn gives rise to a loss of their integrity and irreversible damage (Winiarska-Mieczan 2018). Cadmium and lead are classified as EDCs. They are characterized by high lipophilicity, so they can penetrate the placental barrier and the blood-brain barrier (Peivasteh-Roudsari et al. 2023).

An important aspect of how toxic metals affect the human body is the interaction between the metal and protein. Heavy metals reach body cells through transport proteins and can bind enzymes and nucleic acids, which disturbs their function. These metals interfere with native proteins by binding to free thiols or other functional groups, catalysing the oxidation of side chains of amino acids, impeding protein folding and/or displacing essential metal ions in enzymes (Witkowska et al. 2021). In the complexation of heavy metals with thiol-containing proteins, the ligands are amino acids which contain the –SH (sulfhydryl) functional group (Balali-Mood et al. 2021). The mechanisms maintaining the homeostasis of metals in cells mainly depend on cysteine-rich peptides capable of binding metals, such as GSH and metallothionein (Witkowska et al. 2021). Therefore, metallothioneins protect against the toxic effect of toxic metals (Jakimska et al. 2011). At first, Cd binds to albumins and blood cells, and then forms complexes with metallothionein in liver and kidney tissues, which facilitates the deposition of Cd in the liver, reduces the production of GSH and causes mitochondrial damage through binding Cd ions to the sulfhydryl groups in the critical particles of mitochondria (Teschke 2022). Inactivated thiol groups trigger mitochondrial oxidative stress, and increase mitochondrial permeability and mitochondrial dysfunction (Teschke 2022). Liver damage can also be induced by Kupffer cells activated by inflammatory and cytotoxic mediators, such as cytokines and chemokines (Rikans, Yamano 2000). Lead (Pb) binds to sulfhydryl groups of structural proteins or other cytosolic proteins (e.g. GSH, CAT, GPX, and SOD), hence diminishing the antioxidative protection properties and increasing the toxicity of Pb through cell membrane peroxidation, for instance, in the mitochondria or the endoplasmic reticulum (Firoozichahak et al. 2022, Teschke 2022). In addition, it inhibits heme biosynthesis by blocking ALAD (aminolaevulinic acid dehydratase) and ferrochelatase – enzymes responsible for the biosynthesis of this compound (Ihmed 2016, Balali-Mood et al. 2021).

Due to their bio-physicochemical affinity with the ions of calcium, magnesium, zinc and other divalent metals, Cd and Pb are capable of imitating the primary metals and/or replacing them in specific locations (Witkowska et al. 2021). These ions replace magnesium, zinc and calcium, for instance, in calmodulin, protein kinase C, troponin C and synaptic proteins (Witkowska et al. 2021). Cadmium and lead are the so-called 'heavy metals' and form the most stable complexes with the donor atom N-S, which makes Cd(II) complexes more stable than Mg(II) and Ca(II) ones (Jacobson, Turner 1980). Exposure to Cd or Pb is known to

– decrease the mineral density of bones by displacing calcium,
– manifest in osteoporosis or osteomalacia,
– increase the risk of bone fracture,
– affect general bone growth.

It also changes bone geometry and diminishes its mechanical properties, as demonstrated by tests involving rats (Tomaszewska et al. 2017*a*,*b*). This effect can be explained by the fact that heavy metals can displace calcium from hydroxyapatite. They can also impair the synthesis of bone-building collagen fibres (Tomaszewska et al. 2017a). Some authors also reported late mineralisation of enamel in the incisor teeth of rats exposed to Pb due to displacement of calcium and inhibition of enamel matrix proteases in the process of tooth enamel formation (Gerlach et al. 2002). Cadmium and lead participate in creating ROS and their derivatives by disturbing the flow of electrons in the respiratory chain, and by releasing transition metals involved in the Fenton and Haber-Weiss reactions – mainly Fe(II) and Cu(I) – from the sites in which they occur in cells, for example, ferritin, ceruloplasmin, proteins containing iron-sulphur clusters in the respiratory chain, heme proteins and other (Winiarska-Mieczan 2018). Diagnostics of human exposure to cadmium and lead involves determining these substances in biological material, most often blood and urine. Urine is the most frequently used material for testing due to the possibility of obtaining large volumes in a non-invasive way. Blood is not as widely used as urine, mainly due to the invasive nature of the collection method. Blood tests are most often performed during periodic tests in the event of exposure to substances that are slowly eliminated from the body (Jones et al. 2017).

Transport and accumulation of Cd and Pb in plants

Heavy metals are present in the top layers of soil, from which plants take them up. Increased soil concentrations of metal ions, metallothionein, stress proteins, etc., contribute to the production of ROS, which ultimately leads to programmed cell death. To handle such stress, plants have developed certain defense mechanisms or adaptation strategies, including limited uptake of metal ions, export of metals from the plant, chelating and compartmentalisation etc. (Colangelo, Guerinot 2006). Foliar absorption of heavy metals is also possible after wet or dry atmospheric deposition (Shahid et al. 2016). In comparison with other organisms, plants have well-developed families of transporters involved in taking up and excreting metals. First of all, plants prevent or minimise heavy metal absorption by root cells by capturing metal ions in the apoplast, binding them to the cell wall or preventing their transfer into the cell. If the concentration of non-essential metals exceeds standard limits, then the active metabolic mechanism produces chelating compounds, such as genetically coded metallothionein and enzymatically produced phytochelatins (Balzano et al. 2020). Afterwards, the complexes are transferred into vacuoles via specific transporters.

Plants can grow and reproduce even at high levels of pollution with toxic metals. Therefore, we can distinguish: (1) excluders that is plants that, in addition to the reduced uptake of metals, immobilise and inactivate them in the root zone to prevent translocation into the most sensitive organs, and (2) hyperaccumulators that is plants with efficient systems for detoxication of metals and their translocation to the aerial parts due to binding metal ions (Konkolewska 2013). The absorption and transport of heavy metals can be modified by multiple factors, such as plant variety, and the time and place of plant growth (Sękara et al. 2005). Cadmium is a mobile element easily taken up by the roots and transported to shoots. It is evenly distributed in the plant's organs (Sękara et al. 2005). Cadmium is transported in plant cells via transporters specific to essential minerals: Ca, Zn, K and Mn (Tao, Lu 2022). Recent research has shown that transporters intermediating in the uptake, transport and accumulation of Cd in plants include mainly natural resistance-associated macrophage protein (Nramp), heavy metal-transporting ATPase (HMA), zinc and iron-regulated transporter protein (ZIP), ATP-binding cassette (ABC), and yellow stripe-like (YSL) families (Tao, Lu 2022). Lead is a low-mobility element and its level in particular parts of plants can be represented as follows: roots > shoots > leaves > fruits > seeds (Sękara et al. 2005). This is due to the mobilisation of protective mechanisms of plants inhibiting transport to further tissues and organs.

Transport and accumulation of Cd and Pb in human and animal bodies

Since toxic metals are not biodegradable, have a long half-life and living organisms cannot decompose them, the metals accumulate in body parts and the environment, posing a health risk (Mitra et al. 2022). The distribution of Cd and Pb in the organs is not even. It is mainly determined by the rate of blood flow through the particular organ because blood transports toxic metals, and by the permeability of cell membranes (Winiarska-Mieczan, Kwiecień 2016). The difference found in studies involving rats between the degree of accumulation of Cd and Pb in organs under separate and joint exposure can be a result of the antagonism between these metals, which can be a form of the body's defence against the accumulated effect of Cd and Pb supplied at low doses over a long time (Winiarska-Mieczan, Kwiecień 2016). Research shows that the bodies of animals subject to oral exposure to Cd and Pb in the form of salts absorb approximately 1-8% Cd and 10-50% Pb (Winiarska-Mieczan, Kwiecień 2016).

Most of the absorbed Cd is transported with gamma-globulin in the blood plasma, and part of it can be bound to haemoglobin or metallothionein in red blood cells (Saljooghi, Fatemi 2010). Cadmium taken up orally is transported to the liver via the portal vein, while Cd that is inhaled is transported mostly to the lungs (Satarug et al. 2022). The portion of Cd that has not been captured by hepatocytes reaches the greater circulatory system and is transported to all tissues in the body, including adipose tissue and major body organs (Satarug et al. 2022). Studies involving rats found that Cd accumulates in the liver > kidneys > brain > lungs > heart > spleen (Winiarska-Mieczan, Kwiecień 2016). It was also demonstrated that it accumulates in ovaries, where it causes hormonal imbalance by imitating oestrogen (Malmsten et al. 2021), and in bones, where it displaces calcium (Tomaszewska et al. 2017*a*).

Erythrocytes carry Pb distributing it to soft tissues (kidneys and liver), bones, teeth, and hair. The rates of absorption and distribution are largely dependent on the consumption of Pb and the availability of phosphates and calcium and iron ions to the body (Ihmed 2016). If the availability of phosphates and vitamin D is high, lead is stored in bones, while at low levels of phosphates and/or high levels of Ca ions, lead is transferred to soft tissue. More than 90% of Pb accumulates in bones, and the rest in soft tissue (Winiarska-Mieczan, Kwiecień 2016). The relationship between the percentage distribution of Pb in soft tissue can be represented as liver > kidneys > brain > spleen > heart > lungs, whereas ca. 70% of Pb accumulates in the liver, 26-29% in kidneys, and the remaining 1% is deposited in other organs (Winiarska-Mieczan 2014, Winiarska-Mieczan, Kwiecień 2016). The brain is one of the organs critical to the toxic effect of lead (Khalaf et al. 2012, Winiarska-Mieczan et al. 2022). The brain's particular ability to accumulate Pb can be a reason for irregularities in its development and functioning due to oxidative stress.

Limited absorption of Cd and Pb by humans and animals

The efficiency of Cd and Pb absorption depends on many factors, including the chemical form of the element or the physiological condition of the exposed individual. An effective way to reduce their toxic effect on the body is chelating these metals using nutrients (which reduces their absorption by tissues) or increasing the oxidative capacity of the body (which decreases the possibility of inducing oxidative damage to internal organs). The kind of diet or its components can affect Cd absorption or toxicity, irrespective of its chemical form. It was demonstrated that a diet rich in fibre, polyphenols, some minerals (e.g. iron, copper, zinc, and calcium) and vitamins (C, E, B1, and B6) significantly reduces Cd absorption (Klinck, Wood 2011, Winiarska-Mieczan 2013, 2015, Zhai et al. 2015, Winiarska-Mieczan 2018). In contrast, a diet supplying considerable amounts of copper, zinc, iron, and calcium has a favourable effect and limits Pb absorption, while fat-rich diets, high-protein diets, or diets containing considerable amounts of vitamin D and ascorbic acid increase Pb absorption (Ma et al. 1993). As it is impossible to eliminate Cd and Pb from food, research is conducted on methods to reduce the absorption of these elements by the body. The methods should be easily accessible and uncomplicated. Available literature reports positive effects, among other foods, for garlic and honey, tomatoes, herbs and spices, kombucha tea as well as green, red, white, and black tea (Figure 1).

Next to limiting Cd and Pb absorption, active ingredients present in certain foods mitigate the toxic effect of these metals on the body through their antioxidant and anti-inflammatory effect. Folic acid and vitamin B_{12} protect against Cd-induced oxidative stress due to liver cell damage in rats (Banerjee et al. 2019). Honey and other bee products effectively protect against oxidative stress caused by toxic metals (Azzaz et al. 2022). Drinking black, green, white, and red tea infusions reduced oxidative stress in the organs and blood of rats exposed to Cd and Pb (El-Shahat et al. 2009, Khalaf et al. 2012, Winiarska-Mieczan 2013, 2015, Winiarska-Mieczan et al. 2022). Similarly beneficial effects (reduced content of malondialdehyde (MDA) and nitrogen oxide and increased activity of superoxide dismutase (SOD) and catalase (CAT) and the content of reduced glutathione (GSH)) were observed in rats exposed to Cd having received a kombucha drink (Nashwa 2011). Furthermore, alpha lipoic acid and melatonin showed a protective effect against oxidative stress induced by Cd in the red blood cells of rats (Hussein et al. 2014). Results were also promising for spices with antioxidant properties used in laboratory animals exposed to Cd and/or Pb, such as turmeric (Enogieru, Inegbedion 2022), ginger (Gabr et al. 2019), garlic and onion (Obioha et al. 2009) and black caraway (Kanter et al. 2005, Azzaz et al. 2022).

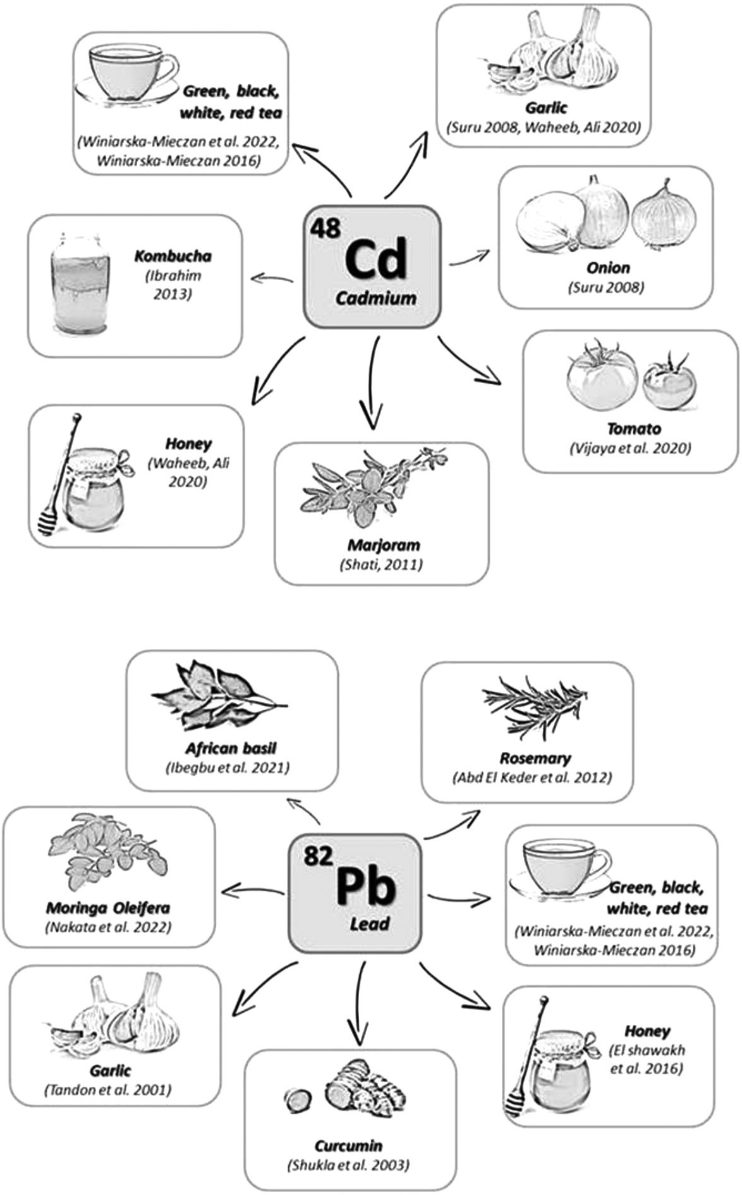

Fig. 1. Research on ways to reduce the uptake of Cd and Pb from food

Prospects

The presence of Cd and Pb in food is variable and dependent on the geographic situation, bioavailability of metals from soil, plant variety, agronomic practices, and post-harvest measures. Screening tests are carried out in Poland and around the world to monitor the exposure of adults, pregnant women and children to Pb and Cd (Osman et al. 1992, 1998, Ecsedi-Angyal et al. 2020, Garí et al. 2022, Bah et al. 2023) . Although the food supply system has many points where food can become contaminated, the key step towards decreasing the content of Cd and Pb in food is to limit or prevent their initial absorption by plants used for food or animal feed. However, due to the complexity of interactions between soil chemistry, varieties and species of plants and agronomic practices, additional research is needed. Another effective way of diminishing Cd and Pb absorption in the bodies of animals and humans may be using dietary components having a chelating effect and reducing the prooxidative effect of toxic metals. Such strategies are beneficial in preventing and mitigating the toxicity of Cd and Pb, as these components are inexpensive and can be easily added to the everyday diet with few side effects.

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