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Study on the Effect of Excess of Lead, Cadmium and Nickel on Plants and Humans

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Abstract: The contamination of the soil by the disposal of toxic substances has acquired, in recent years, a greater attention of the scientific community that has alerted the population of the countries, in general, to the consequences, especially, the pathologies that can occur when these substances enter our food chain. The aim of this study was to present the sources of contamination and toxicity of cadmium, lead and nickel, when these are at high levels in plants, especially when cultivation is carried out in previously contaminated soil. The high dosage of these metals can cause in humans different types of cancer, lesions in the stomach and lungs, as well as important changes in the immune and central nervous systems. On the other hand, in the attempt to decontaminate the soils bearing these metals, the researchers try to develop several remediation methodologies, even using plants with recognized absorption power.

Key words: potential toxic metals, food chain, pathologies

1. Introduction

One of the methods used to assess the nutritional status of plants is quantitative chemical analysis. The results are directly related to soil nutrient availability, as it is from this that plants absorb nutrients. Thus, the nutrient content in plant tissues reflects their actual availability in the soil, because there is a direct relationship between the supply of a nutrient by the soil or a fertilizer and its concentration in leaves and fruits [1]. This method can also be used for the detection and quantification of potentially toxic metals present in soil and/or agricultural inputs. With the metal presence in soil, it is necessary to know in what state it is, whether it is available to vegetables or not. Next, it is necessary to know the capacity of the plant to absorb metals and, if absorbed, in which part of the plant it will accumulate, in order to predict the possible toxic effects of the metal on the plants, and their consumption by animals [2].

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Metal mobility in plants is governed by various factors such as pH, oxidation state, cation competition, hydrolysis, polymerization and formation of insoluble salts such as phosphates and oxalates [3]. The accumulation and distribution of metallic contaminants varies considerably for each element, plant species and growth phase. Generally, the main organ, both for absorption and accumulation, is the root [4].

Among the metals needed for animal and plant metabolism are the so-called micronutrients, which include metals such as nickel. However, when these are present in foods in high concentrations, they can be absorbed and accumulate in tissues, being harmful to health. Cadmium metal is not essential to the metabolic process and is recognized as toxic.

Currently, nickel can already be considered an essential element for plants in adequate doses, since it participates in urease activity [5]. Ureases (urea starch hydrolases) are nickel-dependent enzymes that catalyze the reaction of urea hydrolysis yielding two molecules of ammonia and one of carbon dioxide. The main function of urease in plants seems to be related to nitrogen recycling from externally or internally generated urea [6, 7].

Contamination of the soil by potentially toxic metals is a major environmental problem. These metals can be toxic to plants, microorganisms, animals and humans if the amounts absorbed or ingested are above of certain limits. They may also enter the food chain and, upon reaching high concentrations, cause toxicity problems, decrease productivity in the case of plants and animals, and cause disease in humans [2].

The bioavailability of these metals for plants and, from these, for humans is a concern for humans. Cadmium is a toxic element. The contents found in soils usually do not pose risks. However, the concentration of it and other metals in the soil may increase by anthropic action. Increasing the concentration of these metals in agricultural soils may be due to the application of pesticides, fertilizers, correctives, organic and inorganic residues, irrigation with contaminated water and atmospheric deposition [8].

Fertilizers and other agricultural inputs may contain elements from its original rock or even from the industrialization process. Phosphate rocks contain a high concentration of cadmium, and after decades, the effect of this indirect addition of the metal, can still be observed. Phosphate is vital to the development of living things. In plants, for example, phosphorus is required for photosynthesis, respiration and reproduction. However, when phosphate fertilizers are applied to crops, only 10% of that application is absorbed by vegetables. Thus, there is a concern with the use of these fertilizers [9].

There is a great concern also with sludge from biological treatment station. The chemical composition of the sewage sludge varies depending on the place of origin, that is, whether it is a typically residential or typically industrial area, the time of year and the social level of the community [2]. Most of the time, these inputs are used in food crops. Therefore, knowledge of the concentrations of potentially toxic metals in all those matrices is of fundamental importance. Once the metal is absorbed by the plant, it is very important to know in which part of it the metal will concentrate, so it is possible to assess the risk of its entry into the animal and human trophic chain. Of great importance are the biological and health effects of humans and animals caused by metal pollution of plants.

In this work it was collected data on the consequences of the excess of the potentially toxic metals cadmium, lead, and nickel in plants and the damage they can cause to human health.

2. Analysis Method

The study involved searching for topics related to the subject in literature, including electronic media, printed publications and eventual published studies. Based on this search, it was possible to present some discussions and considerations about the growing concern regarding the risks generated by the consumption of vegetables with excessive content of these potentially toxic metals.

3. Results

3.1 Potentially Toxic Metals

According to Belluta et al. [10] the main sources of potentially toxic metals, such as Cd, Cu, Ni, Pb, Zn, are fertilizers and pesticides used in agriculture, as well as the burning of fossil fuels that emit particles which disperse into the atmosphere, precipitate into the soil and contaminate the bodies of water. These metals are also leached from waste batteries, pigments and inks, medical uses and additives in fuels and lubricants.

Potentially toxic metals are non-degradable and toxic to humans. In their free elemental form they are not particularly toxic. They are dangerous in their cationic forms and when attached to short carbon chains. With its accumulation in organisms, it can accumulate (bioaccumulate) until it reaches the entire trophic chain (biomagnification). Biochemically, the mechanism of toxic action derives from the strong affinity for the sulfhydryl group (-SH) in enzymes. The

–SH group occurs in enzymes that control the speed of important metabolic reactions and quickly bind to ingested metal cations. The metal-enzyme bond inhibits the enzyme and it ceases its normal function, affecting human health and that is sometimes fatal [11].

Bioaccumulation is the sum of xenobiotic uptake by ingestion or contamination. This process is more frequent in aquatic organisms. Biomagnification is the transfer of a xenobiotic through the food chain, which can cause serious problems for living organisms, as levels increase progressively along the trophic chain, reaching high levels in the top predatory organisms, also promoting persistence in the environment, which ensures that the effects continue over time even after their emissions have ceased. Bioaccumulation and biomagnification processes are responsible for transforming concentrations considered normal into toxic concentrations for different species of biota and for the human species [12]. Table 1 presents some of these metals, major sources and toxicity.

Table 1 Toxic metals, source and toxicity [13].

Heavy Metals	Organism Damage	Source
Bariun (Ba)	cardiovascular and nervous system damage, constriction of blood vessels, increased blood pressure and death	ceramic, rubber and textile industries
Cadmium (Cd)	carcinogenesis and kidney damage	coal burning, steel industries, pigments, fertilizers and pesticides
Chrome (Cr)	carcinogenesis	fertilizers, pigment and paint industries
Copper (Cu)	poisoning and liver damage	pipe, valve, alloy and algaecide industries
Mercury (Hg)	poisoning, kidney damage, central nervous system damage and fetal problems	fuel burning, waste incineration, mining and agriculture
Manganese (Mn)	considered low toxic	varnish, glass, battery and fertilizer industries
Nickel (Ni)	gastric irritation	battery, coin, pigment, soft drink and mining industries
Lead (Pb)	poisoning, nervous system disorder, anemia, cardiovascular disease, damage to the kidneys and interference with the bone and reproductive system	ceramics, plastics, fertilizers industries and mining
Zinc (Zn)	bioaccumulative	rubber, sunscreen, vitamins industries and sewage

3.2 Lead

Lead is an element of Group 14 (IV A) of the periodic table. Natural lead is a mixture of four stable isotopes, ^{208}Pb (51-53%), ^{206}Pb (23.5-27%), ^{207}Pb (20.5-23%) and ^{204}Pb (1.35-1.5%) [14], and its largest natural sources are volcanic emissions and geochemical weathering. The largest geological sources are igneous and metamorphic rocks. Naturally it is found combined with a variety of ores, the most important primary sources of lead, and the main commercial source being galena (PbS), anglesite ($PbSO_4$), and cerussite ($PbCO_3$) [15].

Plants growing in lead contaminated soils have physiological, biochemical and structural effects, such as modifications in enzymatic activities, inhibition or reduction of seed germination, inhibition of photosynthesis, and modification of anatomical features. It also affects the structure and permeability of the membrane, induces an increase in the number of stomata and may alter the fluid and hormonal balance [16].

One of the most sensitive factors to the toxic level of lead is photosynthesis, as it causes a reduction in the photosynthetic rate and chloroplast organization, and causes changes in various enzymes and antioxidants that have protective function in plants. In addition to the aforementioned effects, lead can promote reduction in germination development, decreases in germination speed and seedling growth retardation, alteration of cell membrane permeability and disturbance in plant mineral nutrition [16].

Lead is extraordinarily harmful to the brain and nervous system. It affects the blood, kidneys, digestive and reproductive system, it promotes hypertension and it is also a teratogenic agent [17].

Its harmful effects can affect virtually every organ and system in the human body. Lead enters the body mainly by inhalation or ingestion, being directly absorbed, distributed and excreted. The gastrointestinal and respiratory tract are the main sites of absorption of lead that, once absorbed, is found in the blood, soft tissue and also mineralized. About 90% of lead in the body is stored in bones, the main deposit of this metal. Approximately 5% of the concentration of the metal in the blood is found in the plasma, representing its labile and biologically active fraction, capable of crossing the cell membranes and causing their toxic effects [18].

Its effects are mainly produced on the neurological and reproductive system. In men it can cause sperm dysfunction and in women it can cause miscarriage. In the nervous system, lead can cause the following effects: (i) breakdown of cell-to-cell bonds due to temporal change in their programming, interference in molecules responsible for adhesion of nerve cell, and change in migration time of nerve cell; (ii) interference with neurotransmitter function; and (iii) calcium metabolism dysregulation: calcium channels membrane blockage, which are voltage-dependent; calcium replacement at the calcium/sodium pump; competition to enter into mitochondria. Some neuronal morphological changes can be found in lead poisoning such as demyelination, axonal degeneration, presynaptic block with Schawnn cell degeneration, brain vessel disorders and glial cell proliferation in the gray and white masses. The effects of intoxication are dizziness, irritability, headaches and memory loss. Acute intoxication is characterized by intense thirst, metallic taste in the mouth, gastrointestinal inflammation, vomiting and diarrhea. The main risk in children is interference with normal brain development, which causes detrimental effects on behavior, attention span and IQ. Of all the toxic changes produced by lead poisoning, encephalopathy is the most severe in both adults and children, as it can lead to death [11].

3.3 Cadmium

Cadmium (Cd) is in Group 12 (II B) of the periodic classification of elements. It is a relatively rare element and does not occur in nature in its pure form, being associated with sulfides in zinc, lead and copper ores. Cadmium is emitted into soil, water and air by non-ferrous metal mining, refining, manufacture and application of phosphate fertilizers, combustion of fossil fuels and incineration and waste disposal, which can accumulate in agricultural crops. Its mobility depends on several factors, such as pH and amount of organic matter, which will vary depending on the environment. Cadmium generally binds strongly to organic matter, becoming immobile in the soil and absorbed by vegetation, eventually entering the food chain. The most important valence state of Cd in the natural environment is Cd(II). This ion can form a series of ionic species and complex with organic matter [2].

In plants, one of the typical visible symptoms of cadmium toxicity is the chlorosis in leaves (Fig. 1), which occurs in greater proportion in young leaves, which are more vulnerable to toxicity. When poisoned by cadmium, the photosynthetic activity is inhibited, affecting the absorption, transport and utilization of elements such as calcium, phosphorus, potassium and sulfur, as well as water by plants [19].

Fig. 1 Leaf chlorosis (creative commons).

Although not an essential element in plant nutrition, Cadmium is absorbed by the roots and also leaves. pH of soil is the factor that controls the total and relative absorption of Cd. Soluble species are always readily available to plants [2]. The presence of cadmium in plants decreases the potential of nutrient absorption [9]. In bean plants, Cd accumulated mainly in the roots (Fig. 2). Table 2 shows the maximum limits for Cd and Ni concentration in plants.

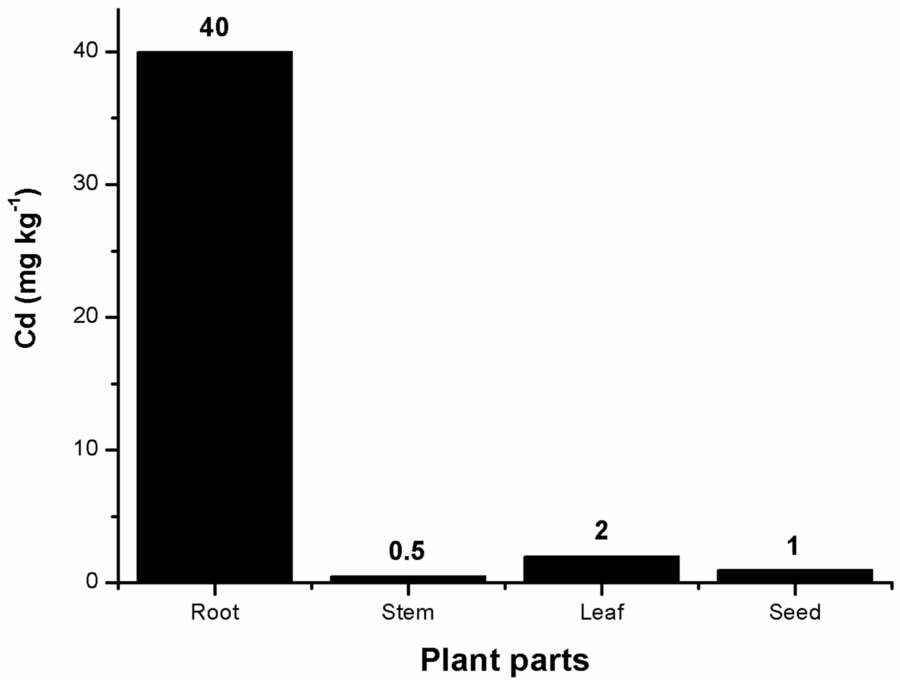

Fig. 2 Distribution of cadmium in common bean plants [2].

Table 2 Maximum permitted limits for cadmium and nickel concentration in plants [20, 21].

$[Cd^{2+}]$ mg kg^{-1}	$[Ni^{2+}]$ mg kg^{-1}
< 0.0571	0.02-5.00

Cadmium is considered a carcinogenic element in the respiratory tract of humans. It can cause elevated blood pressure, heart swelling, decreased immunity, bone weakening, joint pain, anemia, pulmonary emphysema and osteoporosis, among others [9].

The acute effects of cadmium poisoning are cough, nausea, vomiting, among others. Chronic effects are persistent cough, chest pain, among others. Smokers ingest twice as much cadmium as non smokers, since they are exposed to soil-absorbed Cd and irrigation water from tobacco plants. In addition, cadmium easily replaces calcium in our body [11].

Chronically, the most significant effect of intoxication is renal overload, characterized by renal failure that leads to abnormal protein loss. Contamination may also lead to decreased of calcium absorption and increased excretion in the digestive tract, favoring osteoporosis and osteomalacia, lead to anemia due to competition with iron, also lung and prostate cancer, and inhalation may cause acute inflammatory reactions in the lungs, chronically favoring conditions such as bronchitis and emphysema [22].

There is a proportional relationship between the effects on the respiratory system and the time and level of cadmium exposure. Pulmonary obstruction results in chronic bronchitis, progressive fibrosis, and alveolar destruction. Pulmonary disease manifests as dyspnea, reduced vital capacity and decreased residual volume. Cadmium is responsible for irreversible damage to the membranes of the alveoli, including septa rupture, leading to interstitial fibrosis. The metal also crosses the placental barrier easily, inducing the synthesis of metallothionine (metal regulating protein), leading to the formation of cadmium-metallothionine complex, which progressively accumulates in the placenta during pregnancy, and acting as a protective element for cadmium transport to the fetus. In late pregnancy, the cadmium concentration in the placenta is approximately 10 times higher than in maternal blood and in the umbilical cord is two to three times lower than in maternal blood. In the newborn, blood cadmium is 30% to 50% lower than the mother's blood cadmium [17].

3.4 Nickel

Nickel (Ni) is in Group 10 (VIII B) of the Periodic Classification. It is dense metal that has properties that make it very desirable for combination with other metals to form alloys. Some of the metals to which nickel can bind are iron, copper, chromium and zinc. These alloys are used in the manufacture of coins and jewelry and in the industry to make items such as valves and heat exchangers. Most nickel is used to make stainless steel. There are also nickel compounds combined with other elements including chlorine, sulfur and oxygen. Waste application and certain phosphate fertilizers can also be important sources of Ni [23].

Vegetables are the foods that concentrate the metal the most. It acts on growth, metabolism, iron absorption and also helps in the resistance of plants to diseases. Excess in plants can cause chlorosis because it inhibits iron absorption (see Fig. 1), reduced root growth, and abnormal development of certain parts [19].

Nickel is considered an essential element for plants as it participates in urease activity [2, 5]. Ureases are widely distributed in plants, fungi and bacteria. The main function of urease in plants seems to be related to nitrogen recycling from externally or internally generated urea [6, 7]. Urease catalyzes the conversion of urea to ammonia, which is assimilated into the glutamine synthesis pathway. Urease also plays an important role in the recycling of exogenous urea applied as fertilizer [24]. However, in plants under Ni stress, nutrient uptake, root development and metabolism are strongly retarded. Before acute symptoms of Ni toxicity are evident, high concentrations of this metal in plant tissues inhibit photosynthesis and transpiration. There are also reports of low N_2 fixation by soybean plants caused by excess Ni [2].

Nickel is an essential element to the human organism as long as it is not in excess. It is involved in enzymatic and hormonal activity, structural stability of biological macromolecules and metabolism in general. In high concentrations it can be toxic, causing diseases such as contact dermatitis, ulcers, increased red blood cells and protein loss in the urine, chronic bronchitis [25].

Nickel is considered a carcinogenic element in human airways, and occupational exposure to metal can lead to the development of nasal, lung and laryngeal cancer [26].

The main source of exposure to nickel is through food. Foods with a high concentration of nickel are chocolate, soy, nuts and oats [23]. Nickel absorption increases when large amounts of vegetables from polluted soils are consumed. Plants are known to accumulate nickel. Smokers have a higher absorption of nickel through the lungs. Also, nickel can be found in detergents. Humans may be exposed to nickel through air (breathing), eating water and food, and smoking. Skin contact with soil or water containing nickel in high levels may also result in contamination. In small quantities, nickel is essential, but when absorption is very high it can be a danger to human health [27].

Absorption of high amounts of nickel increases the chances of lung, nose, larynx and prostate cancer. It can also cause pulmonary embolism, respiratory arrest, birth defects, asthma and chronic bronchitis, allergic reactions, and cardiac disorders. Nickel-containing fumes are respiratory irritants and may cause pneumonia. Exposure to nickel and its compounds may result in the development of allergic contact dermatitis in sensitized individuals. The first symptom is usually itching, which occurs up to 7 days before a rash occurs. The primary rash is erythematous or follicular, which may be followed by skin ulceration. Nickel sensitivity, once acquired, seems to persist indefinitely [27].

Some studies correlate high Ni levels with increased IgG, IgA, and IgM immunoglobulin levels, and low IgE rates. Some studies correlate Ni with thyroid and adrenal changes. Cases of acute intoxication produce symptoms such as nausea, vomiting, palpitation, weakness, dizziness and headaches [28].

The use of pesticides, fertilizers, concealers, organic and inorganic residues, as well as irrigation using contaminated water is very common. Often these compounds contribute to soil contamination as they provide excessive concentrations of potentially toxic metals. Of course, these products influence the economic value of plant production, but they can also increase the risk to human health. Table 3 shows the concentration of cadmium, nickel and lead metals in some agricultural inputs and by-products.

Table 3 Concentration of cadmium, nickel and lead in some agricultural inputs and by-products [2].

Metal	SS	PF	Limestone	NF	Manure	Pesticides
	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	%
Cd	2-1500	0,1-170	0,04-0,1	0,05-8,5	0,3-0,8	-
Ni	16-5300	7-38	10-20	7-38	7,8-30	-
Pb	50-3000	7-225	20-1250	2-1450	6,6-3500	60

Metals have a long life span, so they remain in the soil for long periods and are readily available to locally grown plants. Excessive concentrations of these metals in the soil reduce microbial activities and thus slow down the process of recycling important nutrients, pest control and maintaining soil structure [29].

Consumption of vegetables grown on contaminated soil is an open pathway of metals potentially toxic to humans and animals, causing potential health risks. Therefore, prevention is required where it is possible to reduce the use of agrochemicals and to use unpolluted water source for irrigation. Good agricultural practices and regular monitoring of soil, crop and water quality are ways to mitigate these risks [29].

During plant development biochemical mechanisms occur that lead them to adapt and create tolerance to chemically unbalanced environments, so the reaction of plants under conditions of chemical stress caused by excess or deficiency of metallic contaminants does not follow a rule. Potentially toxic metals absorbed by plants may participate in metabolic processes, but may also be stored in cells as inactive compounds. They can also affect the chemical composition of plants without causing some visible damage. It is of great environmental interest, for example, the ability of some plants to absorb large amounts of Pb, as this fact allows the application of these plants in the practice of phytoremediation, an important tool in the task of soil pollution [2].

It is also crucial to know the risks involved in handling products containing potentially hazardous substances. Moreover, besides recognizing the existence of a certain substance in the workplace, its proper quantification is also required. This quantification will allow the establishment of better control over the environment [30].

4. Conclusions

Determining the total concentration of an element is known to be limited information, especially regarding its behavior in the environment and the damage it may cause to health. The physical, chemical and biological properties are dependent on the chemical form in which the element is present. To estimate the risk involved, variables such as variation in toxicity, transport and bioavailability need to be taken into account [11].

The fact that organic matter changes rapidly in tropical regions and their clay minerals have low CTC would lead to the assumption that potentially toxic metals would be readily available for absorption by plants and therefore through them into the trophic chain of animals and man. Despite this fact there is still a need for further research, especially on long-term and at the field conditions, to conclude on the behavior of potentially toxic metals in the soil-plant-atmosphere system and the real risks that their application in the soil represent for the environment, for animals and ultimately for man [2].

Recognizing that there is a relationship between occupational exposure to hazardous substances and the onset of disease is essential to avoid contact without proper care [30].

Recycling waste produced in most industrial production processes is the subject of more and more research for several reasons. Protection of health and the environment is of great importance. Similarly the economic benefits generated from this process cannot be overlooked. The impact on health and the environment caused by products containing potentially toxic metals must comply with national and international regulations [31].

It is concluded that all metals surveyed are widely used in everyday life, whether by industry, agriculture or in medicines and food. The problem lies in the disposal of waste materials, which has largely been done without any criteria for a long time. This situation is worrying, since it has the sequence soil → plant → man and there is always the possibility of excessive consumption of these metals, sometimes causing harm to human health.

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