HEAVY METALS IN MEDICINAL AND SPICE PLANTS

Milenko Smiljanić[1], Vesna Gojković Cvjetković*[1], Željka Marjanović-Balaban[2], Vesna Antunović[3], Milomirka Obrenović[1], Jelena Vuković[1], Kristina Đerić[1]

[1]University of East Sarajevo, Faculty of Technology Zvornik, Republic of Srpska, Bosnia and Herzegovina
[2]University of Banja Luka, Faculty of Forestry, Banja Luka, Republic of Srpska, Bosnia and Herzegovina
[3]University of Banja Luka, Faculty of Medicine, Banja Luka, Department of Pharmacy, Republic of Srpska, Bosnia and Herzegovina

(REVIEW PAPER)
UDC:633.88:632.122 , 635.7:632.122
DOI: 10.5937/savteh2502022S

The use of spices and medicinal plants in human nutrition has been increasing recently. They have numerous benefits due to their antioxidant and antimicrobial properties, and they are particularly important in the prevention of microbial transmission. Nevertheless, they may also contain environmental pollutants that are introduced during manufacturing, processing, and storage. Spices and medicinal herbs can become contaminated throughout the manufacturing and packaging process, as well as during the cultivation of plant species. The greatest danger comes from heavy metals, which enter plants through soil, air, and water. The operation of various industrial facilities results in contamination. This paper will discuss heavy metals, both essential and non-essential, and their effects on human health. Copper, zinc, manganese, iron, molybdenum, chromium, and selenium are essential, whereas lead, mercury, cadmium, arsenic, aluminum, tin, cobalt, and platinum are non-essential.

Keywords: medicinal plants, spice plants, essential and non-essential heavy metals

Introduction

People all over the world use herbs and medicinal plants on a daily basis every day. Spices are dried parts of plants processed into specific forms. They have antioxidant and antimicrobial properties [1, 2]. Apart from the fact that spices have many benefits, they may also contain various toxic substances from the environment, which may be introduced during production and processing, as well as due to storage conditions. Heavy metal contamination of spices occurs during crop cultivation (as a result of soil composition, current nutrients, and the use of mineral fertilizers), as well as during manufacture and packing [3-5].

For a long time, people have utilized herbs for therapeutic purposes, and information about their application has been transmitted from one generation to the next [6]. In ancient times, medicinal plants were chosen for the treatment of certain diseases and ailments according to their morphological properties, i.e. color or shape of leaves, flowers that resembled individual human organs or disease symptoms, so plants with heart-shaped leaves were used to treat heart diseases, for example [7, 8].

The use of medicinal plants in the food, pharmaceutical, and cosmetic industries has increased as a result of historical and technological advancements that have made it feasible to identify the chemical make-up of different plant species and, consequently, their therapeutic properties.

Medicinal plants are significant in traditional medicine in addition to these sectors [9, 10]. An advantage of natural medicines over synthetic alternatives is the fact that they are widely available through retail channels, including physical stores and online platforms.

However, as herbal products are gaining popularity and expanding throughout the world, they are becoming a public health concern [11, 12]. Most frequently, the reduced quality of herbal products can be attributed to using products tainted with potentially dangerous materials, such as radioactive particles, heavy metals, agrochemicals (pesticides), microbial metabolites (mycotoxins), as well as to the misidentification of toxic plant species as medicinal herbs, or improper dosage and interactions with conventional medications [13, 14]. The greatest danger is posed by heavy metals, which may enter the plant through soil, air, and water. Most often, land is contaminated by air pollution resulting from the operation of various industrial plants. Plant species, production and processing methods, harvest time, amount and length of exposure to contaminants, geography, place of origin, and storage all affect the possibility of contamination of spices and medicinal plants [15-17].

The aim of this review paper is to present the most important essential and non-essential heavy metals that can be found in spices and medicinal plants (yarrow, rosehip, rosemary, and laurel), the pathways of their entry into plant material, as well as the maximum permis-

***Author address**:Vesna Gojković Cvjetković, University of East Sarajevo, Faculty of Tecnology Zvornik, 75 400 Zvornik, Karakaj 34a, Bosnia and Herzegovina
E-mail: vesna.gojkovic@yahoo.com
The manuscript received: May 27, 2025
Paper accepted: October 12, 2025

sible values that can be found in these herbs according to the national and international regulations.

HEAVY METALS IN PLANT MATERIAL

Any metal with relatively high density and high toxicity, even at low concentrations, is referred to as a heavy metal. Because of their persistence and propensity to accumulate in the environment, heavy metals pose a threat to living things. They have a major impact on ecosystems and are regarded as one of the primary causes of environmental contamination. The causes of their occurrence can be anthropogenic and natural [18, 19]. The cause of environmental pollution with heavy metals can be mining, exhaust gases from industries, the use of artificial fertilizers, wastewater from sewage, fossil oil processing, battery production, exhaust fumes from cars, additives for motor fuels based on organic compounds with lead (which have been banned for some time), cadmium in batteries and carburetors, as well as other human activities. Natural sources of pollution include the presence of parent materials and the influence of topography [20, 21].

Heavy-metal-contaminated soil alters physiological and biochemical processes, which restricts the growth of plants cultivated in such soil. Food output declines as a result of this lower annual crop yield. When heavy metals enter the body, they can weaken the immune system, cause cardiovascular problems, lead to prenatal abnormalities, affect neurological and psychosocial behavior, induce gastrointestinal cancer, and more. Even at low quantities, the heavy metals cadmium, lead, arsenic, and mercury are mutagenic and poisonous [22, 23]. They enter the human body as a result of eating tainted food and vegetables, but breathing in contaminated air is also a major contributing factor. Heavy metals may induce many carcinogenic and non-carcinogenic effects in the human body. Some can be eliminated by treating the underlying cause of the disorder, while others persist in the body as a lifelong condition [24, 25].

There are two categories of heavy metals: essential and non-essential. The essential ones include copper, zinc, manganese, iron, molybdenum, chromium, and selenium, and the non-essential ones include lead, mercury, cadmium, arsenic, aluminum, tin, cobalt, platinum, and palladium. Essential heavy metals are necessary for carrying out biological processes in the body, and their absence, reduction, or excessive amounts can lead to disorders in the body [26, 27]. Toxicity depends on the concentration in the body. Non-essential ones are found in the Earth's biosphere and circulate in nature in various oxidation and chemical forms [28]. People can contribute to the increase in the concentration of these elements in nature through their lifestyle.

Copper (Cu)

Copper is a metal that is utilized extensively in many different industries and is crucial to many facets of our everyday lives. Because of its excellent electrical conductivity, it is most commonly utilized in the electrical industry for the manufacture of wires and cables [29, 30]. The human body needs copper as an essential mineral in order to function properly. It is crucial for the production of red blood cells, bone health maintenance, iron metabolism, and antioxidant defense, among other functions. The body needs regular copper levels to function properly [31]. Since copper is required for the proper functioning of numerous enzymes, it is categorized as an essential element. In plants, copper plays an important role in the photosynthetic and respiratory electron transport chains, in ethylene detection, cell wall metabolism, and protection against oxidative stress. Copper deficiency can alter essential functions in plant metabolism. It is used in agriculture as an antifungal agent, and it also enters the environment through human activities that often cause pollution. Excess copper is present in certain regions and environments, and exposure to such an element can be potentially toxic to plants, causing phytotoxicity by generating reactive oxygen radicals that damage cells, or by interacting with proteins that impair key cellular processes, inactivating enzymes, and disrupting protein structure. Plants have a complex network of metal transport pathways to appropriately regulate copper homeostasis in response to variations in environmental copper levels. Such strategies prevent the accumulation of the metal in a free reactive form and ensure proper delivery of this element to target metalloproteins [32, 33].

Zinc (Zn)

Zinc is a silvery-white metal that is often used in various industrial and everyday applications. The best-known application is in electroplating, where it is used to protect other metals from corrosion. It is also used in the production of batteries, alloys (such as brass), in the construction industry, as a fertilizer additive, and as a food additive [34]. Both humans and animals need zinc as a trace element. It is essential for numerous enzymatic processes in the body, it supports healthy growth and development, moreover, it is involved in the regulation of the immune system, keeps skin and hair healthy, and contributes to the production of proteins and DNA. Zinc is essential for good health, and a lack of it can cause a number of issues, including poor immunity, sluggish growth, hair loss, skin issues, and vision impairment. However, consuming too much zinc can also be harmful to your health [35, 36]. Since zinc is required for the activity of over 300 enzymes, it is categorized as an essential element. Zinc participates in the catalytic, regulatory, and structural stability maintenance processes of these metalloenzymes. Zinc plays a role in both cell division and DNA and RNA synthesis [37, 38]. Zinc is considered a micronutrient for plants. It plays an important role in plant biochemistry and metabolism. It contributes to cellular and physiological activities of plants and promotes plant growth, development, and yield [38].

Manganese (Mn)

The grayish-white metal manganese is found in nature as a mineral. There are many allotropic forms of it, such as gamma-, beta-, and alpha- manganese. There are numerous industrial uses for it. When used as an alloy in steelmaking, manganese increases the steel's strength and hardness. Additionally, it is utilized as a catalyst in chemical reactions, in the manufacturing of fertilizers, paints, varnishes, and batteries [39, 40]. As an essential nutrient, manganese is needed for regular bodily functions. It has a significant impact on how fats, carbohydrates, and amino acids are metabolized. It is also necessary for the healthy growth of connective tissues and bones. Long-term excessive manganese exposure is harmful and can result in neurological issues like Parkinson's disease [41]. Despite being found in urban areas' air and water, manganese is mostly consumed through food (fruits, vegetables, and tea), with less than 5% of the total quantity consumed being absorbed. Manganese is an important micronutrient for plant growth and development, and it maintains metabolic roles within plant cells. Mn deficiency leads to serious disturbances of plant nutrition in dry and calcareous soils, as well as in soils containing large amounts of organic matter, where the bioavailability of Mn can fall below the level required for normal plant growth. Mn toxicity occurs in acidic soils where large amounts of Mn are available. However, plants develop mechanisms for strict regulation of Mn uptake, transport, and storage [42].

Iron (Fe)

Iron is a metal that is often used in various industrial and everyday applications. The best-known application is in the production of steel, an alloy of iron and carbon. Steel is used in the construction of bridges, buildings, vehicles, tools, and numerous other industrial and structural materials. Iron is also used in the production of electromagnets, electrodes, and many other products [43]. It is an essential nutrient for the human body. Iron plays a role in the transport of oxygen in the blood as a component of hemoglobin. It is also needed for the normal functioning of enzymes and metabolism. Its deficiency leads to anemia, which results in fatigue, weak immunity, and other symptoms. Excessive iron intake can also be harmful to health and is associated with oxidative stress [44]. Iron is the most prevalent transition metal found on our planet and is crucial for nearly all living organisms. As an essential metal, it plays a vital role in all cellular processes, including respiration, redox reactions, energy metabolism, DNA synthesis, and gene regulation. Additionally, iron and its compounds can be found as pollutants in the air, posing risks to health [45]. Iron plays an important role in biochemistry and is an essential micronutrient for plants and humans. Although abundant in the Earth's crust, it is not usually found in a form that is readily available to plants. The processes of iron absorption and metabolism are regulated by strict regulatory mechanisms, at the transcriptional and post-transcriptional levels, to avoid the accumulation of iron concentrations to toxic excess [46].

Molybdenum (Mo)

Molybdenum is a silvery-white metal that is highly soluble and has high hardness. It is used in various industries. The most significant application is in the production of alloys, especially steel and superalloys, where it improves the hardness and strength of the material. It is also used in electronics, catalysts, and other industrial applications [47]. Molybdenum is a vital nutrient for plants, animals, and humans. It is crucial for the body's metabolism, particularly in amino acid synthesis. Typically, it is regarded as safe for humans and seldom leads to toxicity. In minimal quantities, molybdenum is necessary for proper bodily functions. Nevertheless, exposure to excessive amounts of molybdenum can result in negative health consequences [48]. Next to Cu, Mo is the least abundant micronutrient found in most plant tissues. Molybdenum is used by selected enzymes to carry out redox reactions [49].

Chromium (Cr)

Chromium is a hard, brittle metal with a silvery-white appearance. It is a chemically stable element that remains non-reactive with water or air at ambient temperatures. Nonetheless, when exposed to oxygen, it develops a thin oxide layer on its surface that safeguards it against additional corrosion. This metal is applied across multiple industrial sectors. The most famous application is in steel production, where chromium is added to improve the strength and corrosion resistance of the material. It is also used in the production of alloys, catalysts, paints, pigments, electroplating, and the decorative materials industry [50].

Chromium is an essential element for organisms, but only in very small quantities. Its main function in the body is to participate in carbohydrate metabolism as a cofactor of enzymes that regulate the amount of sugar in the blood [51]. High levels of exposure to chromium (VI) can be toxic and carcinogenic. Chromium (VI) compounds are particularly harmful to the lungs and cause respiratory problems such as asthma and lung cancer. Chromium (III) compounds are less toxic and are less easily absorbed into the body. The most significant sources of chromium in the environment are emissions of chromium and its compounds from industrial processes, such as the production of iron-chromium master alloys (chromium ferroalloys), chromium-alloyed steels to which nickel and molybdenum are usually added, chromium-cobalt alloys, electroplating processes for chromium plating of metal surfaces, the production of chromium chromate salts, and the production of chromium pigments [52-54]. Plants growing in soils contaminated with Cr (VI) exhibit reduced growth and development, resulting in lower agricultural production and quality. Exposure to Cr (VI) causes oxidative stress due to the production of free radicals that modify morphophysiological and biochemical processes at the tissue and cellular levels. However, plants can develop extensive cellular and physiological defense mechanisms in response to Cr (VI) toxicity to ensure their survival [54].

Selenium (Se)

Selenium is a crucial micronutrient for humans, animals, and certain microorganisms. It serves as a cofactor for key enzymes that help neutralize free radicals and safeguard cells against oxidative stress. It is vital for the synthesis of selenoproteins, unique proteins that carry out various roles in the body, such as regulating immune responses and supporting cardiovascular health. Additionally, it is instrumental in converting thyroid hormones into their active forms and upholding proper thyroid function [55].

Selenium provides a protective benefit against specific cancer types. It can be found in numerous food sources, including nuts, seafood, meats, grains, and vegetables. It is important to consume selenium in moderation, as high levels can lead to toxicity. The main source of Se in food is plants, but the essentiality of Se for plants is controversial. The presence of Se at low doses protects plants from various abiotic stresses, such as cold, drought, desiccation, and metal stress. Selenium-induced oxidative stress and distorted protein structure and function are the main causes of Se toxicity in plants at high doses [56].

Lead (Pb)

Lead (Pb) is a silvery-gray metal. It occurs in many forms throughout the world, making it the most abundant trace metal element. Lead is acutely toxic to humans when present in large quantities. It accumulates in the top 20 cm of soil and is immobile [57]. Lead pollution is long-term, and without a systematic approach to soil remediation, high concentrations of lead in the soil will never return to normal levels. The most common source of lead pollution is motor vehicles. In the past, various fuel additives containing large amounts of lead were used. The form of lead determines how much of it accumulates in plants. The inorganic form of lead is difficult to accumulate and transport from the soil to above-ground plant organs. Organic lead compounds, unlike inorganic ones, accumulate and are transported very quickly in plant tissues. Lead in higher concentrations inhibits the growth of roots and leaves and the process of photosynthesis. It is a highly toxic metal that has serious negative effects on human health. Exposure to lead causes damage to the nervous system, decreased cognitive function, reproductive problems, kidney damage, anemia, and other health problems. Children are particularly sensitive to lead [58, 59]. Lead pollutes the environment through industrial exhaust gases, waste, lead battery landfills, and other sources. Its pollution negatively affects soil, water, flora, and fauna. It is a very dangerous metal due to its toxicity, as well as its compounds, especially due to the cumulative effect. Although lead also forms tetravalent compounds, which are not very stable, its divalent compounds are the most important. Lead and its compounds cause one of the most common occupational poisonings, called saturnism or plumbism [60, 61]. The uptake of Pb by plants affects their metabolic functions, growth, and photosynthetic activity. Excessive lead accumulation causes reduced root growth.

Mercury (Hg)

Mercury (Hg) is a metal that is naturally present in various forms. It can react with sulfur, chlorine, and oxygen to form inorganic mercury compounds or salt. It also occurs in organic compounds when combined with carbon. It is an important material in the chemical industry [62]. Mercury is an environmental pollutant that can accumulate in fish, animals, and humans, where it persists. The toxicity of mercury salts and organometallic mercury compounds is influenced by the type of compound, and they can be some of the most toxic compounds in nature. Its presence in the environment can be the result of industrial activities and the use of fungicides, but also some of household waste, such as bleach, battery acid, thermometers, barometers, dental fillings (amalgam), pesticides, pharmaceutical products (cosmetics, contact lens products, nasal sprays), and detergents [63, 64]. Mercury builds up in roots twenty times more than in tissues above ground. In plants, mercury affects photosynthesis and oxidative metabolism by interfering with electron transport in chloroplasts and mitochondria. It also inhibits the activity of aquaporins and reduces water uptake in plants [65].

Cadmium (Cd)

Cadmium is a soft, silvery-white metal that conducts electricity well. It is used in numerous industrial applications. Batteries, coatings, alloys, solar cells, electronics, paints, and other products used to rely extensively on cadmium. However, cadmium's use has been increasingly limited because of its high toxicity. Cadmium is an extremely hazardous metal that has detrimental effects on human health. Kidneys, lungs, bones, and other organs are harmed by cadmium exposure. It is linked to a higher risk of cancer, particularly prostate and lung cancer [66].

Landfills, exhaust gases, industrial waste, and other sources are some of the ways that cadmium contaminates the environment. It builds up in plants, animals, water, and soil. It enters the body primarily through the gastrointestinal and respiratory systems. Its entry into the body is largely prevented by the digestive tract's mucous membrane. Cadmium excretion from the human body is comparatively low. Cadmium has a toxic effect on a number of key processes of plant growth and development, particularly affecting seed germination rate, transpiration rate, chlorophyll content, and biomass [67].

Arsenic (As)

The gray, silvery element arsenic (As) can be found in a variety of inorganic and organic substances. It can be found in nature as an inorganic compound with sulfur, and combined with oxygen and chlorine. While organic compounds are used as pesticides, usually for cotton plants, inorganic arsenic compounds are most frequently used to preserve wood. Three categories of arsenic species can be distinguished from a biological and toxicological perspective: gaseous arsenic, organic arsenic, and inorganic arsenic. In partially reducing environments, trivalent arsenic predominates [68]. Humans and other living things are extremely susceptible to poisoning by arsenic. The form in which it is found determines its toxicity. The form (inorganic and organic) and oxidation state of arsenic are influenced by pH, redox conditions, mineral content, and microbial activity. In general, trivalent arsenic compounds are more toxic than pentavalent ones, and inorganic compounds are more toxic than organic ones. Generally speaking, plants have a significantly lower arsenic content than soil. Accumulation is higher in acidic soils, particularly if pH<5. Additionally, the type of soil determines its presence; sandy soils have a higher concentration than heavier soils. Plant species differ in their arsenic sensitivity and absorption characteristics [69, 70]. Arsenic poisoning can be peracute, acute, and chronic. It can be local, and entry into the body can occur through inhalation and ingestion. The development and appearance of symptoms of arsenic poisoning depend on the amount ingested, the extent of absorption, metabolism, and the method of excretion. Exposure of plants to arsenic, even at very low concentrations, causes many morphological, physiological, and biochemical changes. Different plant species have different absorption, toxicity, and detoxification mechanisms [68].

Aluminum (Al)

Aluminum is a silvery-white metal that is light, soft, yet strong, and extremely resistant to corrosion. It is used in many industrial and everyday applications. Its lightness, strength, and resistance to corrosion make it an ideal material for making aircraft, automobiles, structures, packaging, electronics, and many other products.

Aluminum is a relatively safe metal for humans, and most people ingest it through food, water, and other sources. On the other hand, neurological conditions like Alzheimer's disease have been connected to exposure to elevated levels of aluminum. It is usually found in nature in the form of compounds. Industrial production of aluminum results in waste materials that pollute the environment [71, 72]. However, aluminum is recyclable, which reduces the need for new raw materials and the negative impact on the environment. The organs primarily affected by aluminum poisoning include the lungs, nervous system, and bones. In plants, Al has both beneficial and toxic effects, depending on factors such as metal concentration, chemical form of Al, growth conditions, and plant species [72].

Tin (Sn)

Tin is a silvery-white metal that is soft and malleable. It is used for various industrial and technical purposes. The most well-known application of tin is in the production of sheet metal, pipes, and other tin-steel products. It is also used in the electronics industry for soldering electronic components, making solder wire, and molds. Tin is a relatively safe metal for humans. Under normal exposure conditions, it does not exhibit significant toxic effects on human health [73]. However, long-term exposure to high concentrations of tin has a detrimental effect can have detrimental effects on fertility and fetal development. It naturally occurs in ores, such as tin oxide. Air, water, and soil pollution are among the environmental issues caused by the mining and processing of tin. Nonetheless, the environmental impact is deemed to be minimal due to the comparatively low usage of tin in comparison to other metals.

Tin plays a crucial role in the healthy growth and development of bone tissue. It contributes to bone growth and maintenance and influences muscle contraction. It helps keep the heart and blood vessels functioning properly, and it is found in traces in the body. It is essential for healthy hormone production and thyroid function. Tin takes part in enzymatic processes necessary for the body's hormone synthesis and regulation. It is crucial for preserving the body's normal immune response [74, 75]. It participates in the function of immune cells and processes that are crucial for the body's defense against infections and diseases. It is present in nerve cells and participates in the normal functioning of the nervous system. Tin enters the environment through industrial processes, mining, weathering, and erosion, and can then be absorbed by plants. It accumulates in green vegetables, but it can also enter the edible parts of plants [75].

Cobalt (Co)

Cobalt is a hard, silvery-white metal with magnetic properties. It is stable under normal conditions but susceptible to oxidation in the presence of air. It is used in a variety of industries. The most well-known use of cobalt is in the production of superalloys used in the aerospace and turbine industries. Cobalt is also used in the production of lithium-ion batteries, magnets, paints, ceramics, catalysts, and medical implants [76].

The human body requires cobalt as an essential trace element in order to function properly. High levels of cobalt exposure, however, are harmful and can result in major health issues, such as skin reactions, lung diseases, and possibly even cancer. It is found in the air, water, and soil naturally. Cobalt levels in the environment are raised by human activities like mining and industrial production. Additionally, cobalt salts and compounds are also harmful to both plants and animals. Animals exposed to CO^{2+} have shown signs of developing cancer. Cobalt's toxicity and carcinogenicity are exacerbated by the production of cobalt-mediated free radicals [77]. Plants accumulate Co mainly in roots due to lower mobility, only in small amounts, while the mobility, distribution, and accumulation capacity of cobalt depend on the target species. The absorption and transport of Co ions in plant organs are controlled by different mechanisms in different plants and by different transporters. Lower Co concentrations improve plant growth and yield, improving nitrogen fixation capacity, nutritional quality, nutrient uptake, antioxidant defense systems, and plant tolerance by improving and alleviating phytohormone synthesis and abiotic stress [76, 77].

Platinum (Pt)

Platinum is a lustrous, silvery-white metal. It is one of the heaviest metals and one of the rarest elements on Earth. It is used in a variety of industries. The most well-known application of platinum is in the automotive industry, where it is used in emission control catalysts. It is also used in jewelry, electronics, chemicals, medical devices, thermoelectric converters, and many other areas [78].

Platinum is considered a very inert metal and has low toxicity. In general, platinum is not considered harmful to human health. However, some people develop allergic reactions to platinum compounds. It occurs naturally in sediments, rivers, and soil. Platinum is released into the environment as a result of human activities such as mining and industrial production. Nonetheless, platinum is thought to have a minimal environmental impact due to its high value and limited usage [79]. Platinum has a broad range of biological effects and affects different parts of the body. It treats a variety of cancers by acting as an antitumor medication in chemotherapy. Cell death is the result of its inhibition of cell division. It has an impact on bone marrow cell differentiation and proliferation. It is mostly eliminated by the kidneys. However, kidney damage results from prolonged exposure to platinum. The nervous system is poisoned by platinum. It results in neurotoxicity, neuropathy, and peripheral neuropathy. It has an impact on the synthesis of platelets, white blood cells, and red blood cells [79, 80]. Platinum occurs in very low concentrations in soil in uncontaminated areas. However, the concentration of this element in urban areas is constantly increasing and represents a threat to human health, especially when it is present in particles in the air.

Discussion

As previously mentioned in this paper, heavy metals are among the major environmental pollutants, therefore, they end up in spice and medicinal plants. Several methods are used to clean the environment from these types of pollutants, but most of them are expensive and it is difficult to achieve optimal results. Phytoremediation is an effective and affordable solution used to extract and remove inactive metals and metal pollutants from contaminated soil and water. This technology is environmentally friendly and potentially cost-effective [81]. Heavy metals also have the potential to accumulate in the human body through bioaccumulation. The pollution of terrestrial and aquatic ecosystems with toxic heavy metals causes major environmental problems with significant consequences for public health. Heavy metals can become highly toxic when mixed with various environmental elements, such as water, soil, and air. Humans and other living organisms can be exposed to them through the food chain. Many experimental studies have been conducted to evaluate promising treatment options from natural sources. Nanotechnology-based treatment options are constantly being developed. The use of nanotechnology for the analysis and removal of heavy metals from food and water resources offers many advantages over traditional methods. These advantages include a wide linear range, low limits of detection and quantification, high sensitivity and selectivity [82].

Heavy metals also enter aquatic habitats from various sources, including household waste, industrial waste, atmospheric sources, and electronic waste. Heavy metal pollution is responsible for the degeneration of aquatic species, the creation of physical abnormalities in organisms, and the contamination of the aquatic environment. Heavy metal contamination in water bodies and ecosystems has a significant impact on the food chain. Heavy metals also have an impact on the environment, as they persist for a long time and have bioaccumulative properties, leading to deterioration of water quality [81, 82].

Considering that heavy metals can end up in plant material, national and international standards have prescribed the maximum permissible concentrations of metals in these plants. According to the World Health Organization [83], the permissible value of Cu in plants is 10 mg/kg. The permissible value of Zn in plants is 0.60 mg/kg. Average daily dietary intake for Mn is 2-5 mg/kg, for Fe is 10-28 mg/kg, and for Cr is 0.05-0.2 mg/kg [84]. The World Health Organization [83] has recommended 50–55 μg/day Se in the human diet all over the world. Permissible Pb level in food is 0.01-3 mg/kg, permissible Hg level in food is 0.5-1 mg/kg according to the international standards, the permissible limit of Cd in food is 0.05-2 mg/kg [85]. The permissible limit of As in food is 0.1-0.2 mg/kg. The normal range for Al in plants is 200-1000 mg/kg. The normal range of Co in plants is 0.1-10 mg/kg [85].

According to the Regulation on Maximum Permitted Quantities of Certain Contaminants in Food [86], the maximum permitted amount of Pb in spice samples is from 0.60 mg/kg to 2 mg/kg. According to this Regulation from Bosnia and Herzegovina, the maximum permitted amount of Cd in spices is 0.050 mg/kg, for Hg the maximum permitted amount is 0.10 mg/kg, and for As it is 0.15-0.30 mg/kg. Based on the regulations in national standards that prescribe the maximum permitted amounts of Pb, Cd, Hg, and As in plant materials, it can be seen that they are within the permitted amounts prescribed by international standards. For those metals for which the maximum permitted amount is not prescribed in national standards, the regulations prescribed by international standards are used.

Alhusban et al. [87] assessed the levels of contamination with toxic metals (Pb, Al, Ni, Cd, and As) in 25 pharmaceutical herbal products for infants, 15 traditional herbs in Jordan, and herbal products and herbs prescribed by pediatricians. Lead, aluminum, and nickel were detected in some of the analyzed samples of pharmaceutical herbal products and in some samples of traditional herbs. Neither Cd nor As was detected in any of the analyzed samples. The results, when compared with the acceptable limits of toxic heavy metals according to the World Health Organization standards, generally showed acceptable levels of toxic metals in the finished pharmaceutical products and traditional herbal medicines for infants. It was found that the daily intake of the detected metals via pharmaceutical herbal products was lower than the maximum acceptable daily intake set by regulatory authorities. Only 8% of the products exceeded the maximum daily intake limit for lead set by the US FDA. The obtained results showed that excessive use of medicinal herbs as an alternative medicine requires caution, taking into account the safety factor in infants.

Kowalska [88] assessed the safety of heavy metals in commonly used herbs, spices, and coffee in Poland. They determined the levels of heavy metals (Cd, Pb, As, and Hg) in 240 samples of plant materials. They also assessed the risks (non-carcinogenic and carcinogenic risks) using models including the target hazard quotient (THQ) and cancer risk (CR). Based on the obtained results, the element with the highest level of accumulation in the analyzed samples was lead (from 0.010 to 5.680 mg/kg). Among the analyzed heavy metals, the lowest concentration was recorded for mercury (from 0.005 to 0.030 mg/kg). The analyzed samples of herbs and spices contained a significantly higher level of heavy metal contamination compared to tea and coffee samples. Compared to World Health Organization (WHO) recommendations on permissible limits for the contamination of plant raw materials with heavy metals, lead levels exceeding the limits were recorded in only 24 plant samples. In all analyzed samples of spices, tea, and coffee, no cases of exceeding the limit were recorded for any of the analyzed heavy metals. Given that the THQ values are ≤1, there is no likelihood of adverse effects associated with the consumption of the analyzed group of raw materials and products of plant origin. The CR value for As was lower than the maximum acceptable level proposed by the United States Environmental Protection Agency (USEPA).

Hasan Al-Keriawy et al. [89] conducted an environmental risk assessment of heavy metals in selected medicinal herbs and spices. They determined the total concentration of heavy metals and performed a risk assessment for ten species of culinary herbs, spices, and medicinal herbs available in the local market of Iraq. The average concentrations of Cu, Ni, Zn, Pb, Co, As, Cd, Cr, and Hg were within the limits permitted by the World Health Organization. Culinary herbs and spices contained significant amounts of Cu>Ni>Zn>Pb>Co>As>Cd>Cr>Hg. The concentrations of copper, zinc, and nickel were higher in all herb samples. The highest total elemental concentrations were recorded in the aerial parts of the plants, particularly in the leaves of *Thymus vulgaris* and the bark of *Cinnamomum verum*. The non-carcinogenic risks and estimated daily consumption of these herbs were calculated based on the Target Hazard Quotient (THQ) and Hazard Index (HI). THQ values for individual minerals were above one, indicating a health risk for nickel for *Mentha verticillata* leaves, for *Matricaria chamomilla*, as well as for other metals Cu, Co, Pb, and Zn, which are considered unsafe for human consumption. The average hazard index (HI) for the nine metals was >1 for all plants except *Zingiber officinale,* indicating that there are non-carcinogenic risks from exposure to these nine elements.

Oladeji et al. [90] assessed heavy metals and their risks to human health in selected spices from South Africa. Food safety concerns are growing in developing countries such as South Africa due to heavy metal contamination. Heavy metal analysis was performed on 20 spice samples purchased from different registered stores. Based on the obtained results, the following concentrations were measured: Fe (32.22±1.22-131.1±3.26 mg/kg), As (ND to 0.12±0.04 mg/kg), Cr (0.08±0.01-3.2±0.09 mg/kg), Pb (ND-0.21±0.02 mg/kg), and Cd (ND to 0.14±0.08 mg/kg). The results showed that the concentrations of Cr in all tested spice samples were significantly higher than the maximum permissible values. All spices in this study had THQ and HI values below one, indicating that consumers will not experience potential health risks from consuming certain metals through spices. However, continuous monitoring is required.

Ezez et al. [91] conducted an assessment of the bioaccumulation of heavy metals (Cd, Cr, Cu, Fe, Mn, Pb and Zn), assessing the carcinogenic and non-carcinogenic risks to human health in various spices in Ethiopia. The average levels of metals in white cumin, fenugreek, black cumin, turmeric, basil, cardamom and coriander seeds varied in the range of 0.35-1.70; 1.20-11.96, 1.69-32.19, 20.74-38.98, 7.38-26.01, 2.96-9.57 and 5.38-44.63 mg/kg for Cd, Cr, Cu, Fe, Mn, Pb and Zn. The target hazard quotient (THQ) and hazard index (except for cumin and fenugreek) for heavy metals in different spices were lower than the acceptable limit (THQ and HI < 1). The carcinogenic risk values were within the acceptable limits, indicating that consumption of different spices in the study area does not pose a potential health risk to human health.

Table 1 shows the maximum allowed values of heavy metals in spices and medicinal plants in Bosnia and Herzegovina and the European Union.

Table 1. The maximum allowed values of heavy metals in spices and medicinal plants

Name	Maximum allowed values in Bosnia and Herzegovina (mg/kg) [86]	Maximum allowed values in EU (mg/kg) [92]
	Pb	**Pb**
Dried spices	0.60	-
Fruit spices	0.60	0.60
Spices from roots and rhizomes	1.50	1.50
Spices from bark	2.0	-
Spices from the buds and spices from the pistil	1.0	1.00
Spices from seeds	0.90	0.90
Herbs	-	2.00
Fresh ginger and fresh turmeric	0.80	-
"Turovac"(white root/salsify)	0.30	-
	Cd	**Cd**
Fresh herbs	-	0.20
food	-	0.05-2.00 [85]
spices	0.050	-
	Hg	**Hg**
food	-	0.50-1.00 [85]
spices	0.10	-
	As	**As**
food	**-**	0.10-0.20 [85]
spices	0.15-0.30	-

Conclusion

Considering that the use of spices in human nutrition has been increasing in recent years, as well as the use of medicinal plants for the treatment of various diseases in humans, it is necessary to take into account the area (land) from which these plants are taken. Depending on the area where they grow, the mentioned plants may be contaminated with heavy metals. Special attention should be paid if the plants grow near industrial facilities, as a result, excessive amounts of heavy metals may enter the environment. Taking into account where herbs and medicinal plants grow, as well as determining the level of heavy metals after sampling, and then comparing the obtained values with the maximum permissible values prescribed by national and international standards, is important for the food and pharmaceutical industries, as well as for consumers. Considering all that has been stated in this review paper, it is necessary to emphasize the need for global vigilance in food safety practices, especially in countries with less stringent regulations regarding the presence of heavy metals in spices and medicinal plants. The measures that are recommended include improving agricultural practices, improving soil management, and implementing strict post-harvest procedures to mitigate contamination.

Funding.
This work is a part of the research project titled "Analysis of the presence of heavy metals in spices and medicinal herbs from the area of Herzegovina," financed by the Ministry of Science and Technology Development and Higher Education of the Republic of Srpska.

References

[1] Rizvi SA, Einstein GP, Tulp OL, Sainvil F, Branly R. Introduction to Traditional Medicine and Their Role in Prevention and Treatment of Emerging and Re-Emerging Diseases. *Biomolecules.* 2022, 12(10), 1442. https://doi.org/10.3390/biom12101442.

[2] Chaachouay N, Zidane L. Plant-Derived Natural Products: A Source for Drug Discovery and Development. *Drugs Drug Candidates.* 2024, 3(1), 184-207. https://doi.org/10.3390/ddc3010011.

[3] Chaachouay N, Azeroual A, Ansari MKA, Zidane L Use of Plants as Medicines and Aromatics by Indigenous Communities of Morocco: Pharmacognosy, Ecology and Conservation. *In Plants as Medicine and Aromatics;* CRC Press: Boca Raton, FL, USA, 2023, 33–44.

[4] Ansari MKA, Iqbal M, Chaachouay N, Ansari AA, Owens G. The Concept and Status of Medicinal and Aromatic Plants:

History, Pharmacognosy, Ecology, and Conservation. *In Plants as Medicine and Aromatics;* CRC Press: Boca Raton, FL, USA, 2023, 129–144.

[5] Orch H, Chaachouay N, Douiri EM, Faiz N, Zidane L, Douira A. Use of medicinal plants in dermato-cosmetology: An ethnobotanical study among the population of Izarène. *Jordan Journal of Pharmaceutical Sciences*, 2021, 14, 323–340.

[6] Benkhnigue O, Chaachouay N, Khamar H, El Azzouzi F, Douira A, Zidane L. Ethnobotanical and ethnopharmacological study of medicinal plants used in the treatment of anemia in the region of Haouz-Rehamna (Morocco). *Journal of Pharmacy & Pharmacognosy Research*. 2022, 10, 279–302. https://doi.org/10.56499/jppres21.1196_10.2.279.

[7] Brook K, Bennett J, Desai SP. The chemical history of morphine: An 8000-year journey, from resin to de-novo synthesis. *Journal of Anesthesia History.* 2017, 3, 50–55. https://doi.org/10.1016/j.janh.2017.02.001.

[8] Kurhekar JV. Ancient and modern practices in phytomedicine. In: *Preparation of Phytopharmaceuticals for the Management of Disorder.* 2021, 55-75. https://doi.org/10.1016/B978-0-12-820284-5.00019-8.

[9] Atanasov A, Zotchev SB, Dirsch VM, Supuran CT. Natural products in drug discovery: Advances and opportunities. *Nature Reviews Drug Discovery.* 2021, 20, 200–216. https://doi.org/10.1038/s41573-020-00114-z.

[10] Boakye YD, Osafo N, Danquah CA, Adu F, Agyare C. Antimicrobial agents: Antibacterial agents, anti-biofilm agents, antibacterial natural compounds, and antibacterial chemicals. Antimicrobials Antibiotic Resistance Antibiofilm *Strategies and Activity Methods.* 2019, 13, 75. https//doi.org/10.5772/intechopen.82560.

[11] Altemimi A, Lakhssassi N, Baharlouei A, Watson DG, Lightfoot DA. Phytochemicals: Extraction, isolation, and identification of bioactive compounds from plant extracts. *Plants.* 2017, 6, 42. https//doi.org/10.3390/plants6040042.

[12] Usmani Z, Sharma M, Tripathi M, Lukk T, Karpichev Y, Gathergood N, Singh BN, Thakur VK, Tabatabaei M, Gupta VK. Biobased natural deep eutectic system as versatile solvents: Structure, interaction and advanced applications. *Science of the Total Environment.* 2023, 881, 163002. https://doi.org/10.1016/j.scitotenv.2023.163002.

[13] Majolo F, Delwing LK, Marmitt DJ, Bustamante-Filho IC, Goettert MI. Medicinal plants and bioactive natural compounds for cancer treatment: Important advances for drug discovery. *Phytochemistry Letters.* 2019, 31, 196–207. https://doi.org/10.1016/j.phytol.2019.04.003.

[14] Chaachouay N, Azeroual A, Bencharki B, Douira A, Zidane L. Cannabis sativa L.: A Review on Traditional Uses, Botany, Phytochemistry, and Pharmacological Aspects. *Traditional and Integrative Medicine.* 2023, 8, 97–116. https//doi.org/10.18502/tim.v8i1.12407.

[15] Sandeep G, Vijayalatha KR, Anitha T. Heavy Metals and Its Impact in Vegetable Crops. *International Journal of Chemical Studies.* 2019, 7, 1612–1621.

[16] Hadia-e-Fatima AA. Heavy Metal Pollution–A Mini Review. *Journal of Bacteriology and Mycology.* 2018, 6, 179–181.

[17] Kapoor D, Singh MP. Heavy Metal Contamination in Water and Its Possible Sources. *In Heavy Metals in the Environment;* Elsevier: Amsterdam, The Netherlands, 2021, 179–189. https://doi.org/10.1016/B978-0-12-821656-9.00010-9.

[18] Ke B, Nguyen H, Bui XN, Bui HB, Choi Y, Zhou J, Moayedi H, Costache R, Nguyen-Trang T. Predicting the Sorption Efficiency of Heavy Metal Based on the Biochar Characteristics, Metal Sources, and Environmental Conditions Using Various Novel Hybrid Machine Learning Models. *Chemosphere.* 2021, 276, 130204. https//doi.org/10.1016/j.chemosphere.2021.130204.

[19] Oladoye PO, Olowe OM, Asemoloye MD. Phytoremediation Technology and Food Security Impacts of Heavy Metal Contaminated Soils: A Review of Literature. *Chemosphere*. 2022, 288, 132555. https//doi.org/ 10.1016/j.chemosphere.2021.132555.

[20] Ali H, Khan E. What Are Heavy Metals? Long-Standing Controversy over the Scientific Use of the Term 'Heavy Metals'–Proposal of a Comprehensive Definition. *Toxicological & Environment Chemistry.* 2018, 100, 6–19. https://doi.org/10.1080/02772248.2017.1413652.

[21] Ali H, Khan E, Ilahi I. Environmental Chemistry and Ecotoxicology of Hazardous Heavy Metals: Environmental Persistence, Toxicity, and Bioaccumulation. *Journal of Chemotherapy.* 2019, 2019, 6730305. https://doi.org/10.1155/2019/6730305.

[22] Li Q, Xing Y, Fu X, Ji L, Li T, Wang J, Chen G, Qi Z, Zhang Q. Biochemical Mechanisms of Rhizospheric Bacillus Subtilis-Facilitated Phytoextraction by Alfalfa under Cadmium Stress–Microbial Diversity and Metabolomics Analyses. *Ecotoxicology and Environmental Safety.* 2021, 212, 112016. https://doi.org/10.1016/j.ecoenv.2021.112016.

[23] Das U, Rahman MA, Ela EJ, Lee KW, Kabir AH. Sulfur Triggers Glutathione and Phytochelatin Accumulation Causing Excess Cd Bound to the Cell Wall of Roots in Alleviating Cd-Toxicity in Alfalfa. *Chemosphere*. 2021, 262, 128361. https//doi.org/10.1016/j.chemosphere.2020.128361.

[24] Kumar S, Prasad S, Yadav KK, Shrivastava M, Gupta N, Nagar S, Bach QV, Kamyab H, Khan SA, Yadav S. Hazardous Heavy Metals Contamination of Vegetables and Food Chain: Role of Sustainable Remediation Approaches—A Review. *Environmental Research.* 2019, 179, 108792. https//doi.org/10.1016/j.chemosphere.2020.128361.

[25] Rajendran S, Naushad M, Vo DV, Lichtfouse E. *Inorganic Materials for Energy, Medicine and Environmental Remediation*; Springer: Cham, Switzerland, 2022, ISBN 3030798992.

[26] Priya AK, Jalil AA, Vadivel S, Dutta K, Rajendran S, Fujii M, Soto-Moscoso M. Heavy Metal Remediation from Wastewater Using Microalgae: Recent Advances and Future Trends. *Chemosphere.* 2022, 305, 135375. https//doi.org/10.1016/j.chemosphere.2022.135375.

[27] Bhat SA, Bashir O, Ul Haq SA, Amin T, Rafiq A, Ali M, Américo-Pinheiro JHP, Sher F. Phytoremediation of Heavy Metals in Soil and Water: An Eco-Friendly, Sustainable and Multidisciplinary Approach. *Chemosphere*. 2022, 303, 134788. https//doi.org/10.1016/j.chemosphere.2022.134788.

[28] Tatu GLA, Vladut NV, Voicea I, Vanghele NA, Pruteanu MA. Removal of Heavy Metals from a Contaminated Soil Using Phytoremediation. *MATEC Web of Conferences*. 2020, 305, 00061. https//doi.org/10.1051/matecconf/202030500061.

[29] Pohanka M. Copper and Copper Nanoparticles Toxicity and Their Impact on Basic Functions in the Body. *Bratislava Medical Journal.* 2019, 120, 397–409. https//doi.org/10.4149/BLL_2019_065.

[30] Thandapani G, Arthi K, Pazhanisamy P, John JJ, Vinothini C, Rekha V, Santhanalakshmi V, Sekar V. Green Synthesis of Copper Oxide Nanoparticles Using Spinacia Oleracea Leaf Extract and Evaluation of Biological Applications: Antioxidant, Antibacterial, Larvicidal and Biosafety Assay, Materials. *Today Communication.* 2023, 34, 105248. https://doi.org/10.1016/j.mtcomm.2022.105248.

[31] Sandoval C, Ríos G, Sepúlveda N, Salvo J, Souza-Mello V, Farías J. Effectiveness of Copper Nanoparticles in Wound Healing Process Using In Vivo and In Vitro Studies: A Systematic Review. *Pharmaceutics.* 2022, 14, 1838. https//doi.org/10.3390/pharmaceutics14091838.

[32] Gondim E, Rondom JN. The Crucial Role of Photosynthesis in Sustaining Plant Life and Its Impact on the Global Ecosystem, Climate, And Human Survival. *Australian Herbal Insight.* 2020. https://doi.org/10.25163/ahi.319925.

[33] Mir AR, Pichtel J, Hayat S. Copper: uptake, toxicity and tolerance in plants and management of Cu – contaminated soil. *Biometals.* 2021, 34(4), 737-759. https//doi.org/10.1007/s10534-021-00306-z.

[34] Gammoh NZ, Rink L. Zinc in infection and inflammation. *Nutrients.* 2017, 9, 624. https//doi.org/ 10.3390/nu9060624.

[35] Maares M, Haase H. A guide to human zinc absorption: General overview and recent advances of in vitro intestinal models. *Nutrients.* 2020, 12, 762. https//doi.org/10.3390/nu12030762.

[36] Skalny AV, Aschner M, Lei XG, Gritsenko VA, Santamaria A, Alekseenko SI, Prakash NT, Chang JS, Sizova EA, Chao JCJ, et al. Gut microbiota as a mediator of essential and toxic effects of zinc in the intestines and other tissues. *International Journal of Molecular Sciences*. 2021, 22, 13074. https//doi.org/ 10.3390/ijms222313074.

[37] Wang W, Van Noten N, Degroote J, Romeo A, Vermeir P, Michiels J. Effect of zinc oxide sources and dosages on gut microbiota and integrity of weaned piglets. *Journal of Animal Physiology and Animal Nutrition.* 2019, 103, 231–241. https//doi.org/10.1111/jpn.12999.

[38] Jin L, Deng L, Bartlett M, Ren Y, Lu J, Chen Q, Pan Y, Wang H, Guo X, Liu C. A novel herbal extract blend product prevents particulate matters-induced inflammation by improving gut microbiota and maintaining the integrity of the intestinal barrier. *Nutrients.* 2022, 14, 2010. https//doi.org/ 10.3390/nu14102010.

[39] Dey S, Tripathy B, Kumar MS, Das AP. Ecotoxicological consequences of manganese mining pollutants and their biological remediation. *Environmental Chemistry and Ecotoxicology.* 2023, 5, 55–61. https://doi.org/10.1016/j.enceco.2023.01.001.

[40] Khoshru B, Mitra D, Nosratabad AF, Reyhanitabar A, Mandalm L, Farda B, Djebaili R, Pellegrini M, Guerra-Sierra BE, Senapati A, *et al.* Enhancing manganese availability for plants through microbial potential: A sustainable approach for improving soil health and food security. *Bacteria*. 2023, 2, 129–141. https//doi.org/10.3390/bacteria2030010.

[41] Obeng SK, Kulhaken M, Balik J, Černý J, Sedlář O. Manganese: From Soil to Human Health—A Comprehensive Overview of Its Biological and Environmental Significance. *Nutrients.* 2024, 16(20), 3455. https//doi.org/10.3390/nu16203455.

[42] Queiroz HM, Maki B, Ferreira AD, Boim AG, Ying SC, Nóbrega GN, Otero XL, Ferreira T. Manganese: The rise of an unnoticed environmental contaminant. In: *Inorganic Contaminants and Radionuclides*. 2024, 151-188. https://doi.org/10.1016/B978-0-323-90400-1.00002-1.

[43] Dghaim R, Al Khatib S, Rasool H, Ali Khan M. Determination of heavy metals concentration in traditional herbs commonly consumed in the United Arab Emirates. *Journal of Environmental and Public Health.* 2015, 2015, 973878. https//doi.org/10.1155/2015/973878.

[44] Suchacz B, Wesolowski M. The analysis of heavy metals content in herbal infusions. *Central European Journal of Medicine.* 2012, 7, 457–464. https//doi.org/10.2478/s11536-012-0007-y.

[45] Zhang J, Yang R, Li YC, Peng Y, Wen X, Ni X. Distribution, accumulation, and potential risks of heavy metals in soil and tea leaves from geologically different plantations. *Ecotoxicology and Environmental Safety.* 2020, 195, 110475. https://doi.org/10.1016/j.ecoenv.2020.110475.

[46] Briguglio M, Hrelia S, Malaguti M, Lombardi G, Riso P, Porrini M, Perazzo P, Banfi G. The Central Role of Iron in Human Nutrition: From Folk to Contemporary Medicine. *Nutrients.* 2020, 12 (6), 1761. https//doi.org/10.3390/nu12061761.

[47] Alam F, Kim TY, Kim SY, Alam SS, Pramanik P, Kim PJ, Lee YB. Effect of molybdenum on nodulation, plant yield and nitrogen uptake in hairy vetch (Vicia villosa Roth). *Soil Science & Plant Nutrition.* 2015, 61, 664–675. https://doi.org/10.1080/00380768.2015.1030690.

[48] Zakynthinos G, Varzakas T. Carotenoids: From plants to food industry. *Current Research in Nutrition and Food Science Journal.* 2016, 4, 38. http//doi.org/10.12944/CRNFSJ.4.Special-Issue1.04.

[49] Han Z, Wei X, Wan D, He W, Wang X, Xiong Y. Effect of molybdenum on plant physiology and cadmium uptake and translocation in rape (Brassica napus l.) Under different levels of cadmium stress. *International Journal of Environmental Research and Public Health.* 2020, 17, 2355. https://doi.org/10.3390/ijerph17072355.

[50] Fitzgerald M, Heinrich M, Booker A. Medicinal plant analysis: A historical and regional discussion of emergent complex techniques. *Frontiers in Pharmacology.* 2020, 10, 1–14. https//doi.org/ 10.3389/fphar.2019.01480.

[51] Chen YG, Huang JH, Luo R, Ge HZ, Wołowicz A, Wawrzkiewicz M, Gładysz-Płaska A, Li B, Yu QX, Kołodyńska D, et al. Impacts of heavy metals and medicinal crops on ecological systems, environmental pollution, cultivation, and production processes in China. *Ecotoxicology and Environmental Safety.* 2021, 219, 17. https//doi.org/10.1016/j.ecoenv.2021.112336.

[52] Chaplygin V, Dudnikova T, Chernikova N, Fedorenko A, Mandzhieva S, Fedorenko G, Sushkova S, Nevidomskaya D, Minkina T, Sathishkumar P. Phragmites australis cav. As a bioindicator of hydromorphic soils pollution with heavy metals and polyaromatic hydrocarbons. *Chemosphere.* 2022, 308, 136409. https://doi.org/10.1016/j.chemosphere.2022.136409.

[53] Debnath M, Paul N, Bhattacharya S, Biswas M, Haldar PK. Formulation and assessment of microbial and heavy metal contents of Vidangadilouham: A classical Ayurvedic formulation. *International Journal of Herbal Medicine.* 2020, 8, 101–102.

[54] Parveen R, Abbasi AM, Shaheen N, Shah MH. Accumulation of selected metals in the fruits of medicinal plants grown in urban environment of Islamabad, Pakistan. *Arabian Journal of Chemistry.* 2017, 13, 308–317. https://doi.org/10.1016/j.arabjc.2017.04.010.

[55] Bhattacharjee A, Bastu A, Bhattacharya S. Selenium nanoparticles are less toxic than inorganic and organic selenium in mice *in vivo*. *Nucleus.* 2019, 62, 259–268. https://doi.org/10.1007/s13237-019-00303-1.
[56] Filipovic N, Usjak D, Milenkovic MT, Zheng K, Liverani L, Boccaccini AR, Stevanovic MM. Comparative study of the antimicrobial activity of selenium nanoparticles with different surface chemistry and structure. *Frontiers in Bioengineering and Biotechnology.* 2021, 8, 1591. https://doi.org/10.3389/fbioe.2020.624621.
[57] Obeng-Gyasi E, Roostaei J, MacDonald Gibson J. Lead distribution in urban soil in a medium-sized city: Household-scale analysis. *Environmental Science & Technology Journal.* 2021, 55, 3696–3705. https//doi.org/10.1021/acs.est.0c07317.
[58] Mehrandish R, Rahimian A, Shahriary A. Heavy metals detoxification: A review of herbal compounds for chelation therapy in heavy metals toxicity. *Journal of Herbmed Pharmacology.* 2019, 8, 69–77. https//doi.org/10.15171/jhp.2019.12.
[59] Rehman K, Fatima F, Waheed I, Akash MSH. Prevalence of exposure of heavy metals and their impact on health consequences. *Journal of Cellular Biochemistry.* 2018, 119, 157–184. https//doi.org/:10.15171/jhp.2019.12.
[60] Torres-Sánchez L, Vázquez-Salas RA, Vite A, Galván-Portillo M, Cebrián ME, Macías-Jiménez AP, Ríos C, Montes S. Blood cadmium determinants among males over forty living in Mexico City. *Science of the Total Environment.* 2018, 637-638, 686–694. https//doi.org/10.21149/12540.
[61] Mikulski MA, Wichman MD, Simmons DL, Pham AL, Clottey V, Fuortes LJ. Toxic metals in ayurvedic preparations from a public health lead poisoning cluster investigation. *International Journal of Occupational and Environmental Health.* 2017, 23, 187–192. https//doi.org/10.1080/10773525.2018.1447880.
[62] Vázquez-Fresno R, Rosana A, Sajed T, Onookome-Okome T, Wishart N, Wishart D. Herbs and spices–biomarkers of intake based on human intervention studies—A systematic review. *Genes & Nutrition.* 2019, 14, 18. https//doi.org/10.1186/s12263-019-0636-8.
[63] Jiang TA. Health benefits of culinary herbs and spices. *Journal of AOAC International.* 2019, 102, 395–411. https://doi.org/10.5740/jaoacint.18-0418.
[64] Brodziak-Dopierała B, Fischer A, Szczelina W, Stojko J. The content of mercury in herbal dietary supplements. *Biological Trace Element Research.* 2018, 185, 236–243. https//doi.org/10.1007/s12011-018-1240-2.
[65] DalCorso G, Fasani E, Manara A, Visioli G, Furini A. Heavy metal pollutions: State of the art and innovation in phytoremediation. *International Journal of Molecular Sciences.* 2019, 20, 3412. https//doi.org/ 10.3390/ijms20143412.
[66] Behnam A, Ghorbanpour M, Nikabadi S. Heavy metals in contaminated environment: destiny of secondary metabolite biosynthesis, oxidative status and phytoextraction in medicinal plants. *Ecotoxicology and Environmental Safety*. 2017, 145, 377–390. https//doi.org/10.1016/j.ecoenv.2017.07.035.
[67] Andrae-Marobela LMD, Das S, Silva EBD. Metal concentrations in traditional and herbal teas and their potential risks to human health. *Science of the Total Environment.* 2018, 633, 649–657. https://doi.org/10.1016/j.scitotenv.2018.03.215.
[68] Mishra S, Wellenreuther G, Mattusch G, Stark HJ, Kupper H. Speciation and distribution of arsenic in the nonhyperaccumulator macrophyte Ceratophyllum demersum. *Plant Physiology.* 2013, 163, 1396–1408. https//doi.org/10.1104/pp.113.224303.
[69] Mishra S, Stark HJ, Kupper H. A different sequence of events than previously reported leads to arsenic-induced damage in Ceratophyllum demersum L. *Metallomics*. 2014, 6, 444–454. https//doi.org/ 10.1039/c3mt00317e.
[70] Srivastava S, Sharma YK. Arsenic phytotoxicity in black gram (Vigna mungo L. Var. PU19) and its possible amelioration by phosphate application. *Journal of Plant Physiology & Pathology.* 2013, 1, 3. https//doi.org/10.4172/jppp.1000107.
[71] Sjogren CA, Bolaris SC, Larsen PB. Aluminum-dependent terminal differentiation of the Arabidopsis root tip is mediated through an ATR-, ALT2-, and SOG1-regulated transcriptional response. *Plant Cell.* 2015, 27, 2501–2515. https//doi.org/10.1105/tpc.15.00172.
[72] Wang Y, Li R, Li D, Jia X, Zhou D, Li J, Lyi SM, Hou S, Huang Y, Kochian LV, Liu J. NIP1;2 is a plasma membrane-localized transporter mediating aluminum uptake, translocation, and tolerance in Arabidopsis. *Proceedings pf the National Academy of the Sciences of the USA*. 2017, 114, 5047–5052. https//doi.org/10.1080/15592324.2021.1991686.
[73] Abou AAK, Abou Donia MA. Heavy metals in Egyptian spices and medicinal plants and the effect of processing on their levels. *Journal of Agricultural and Food Chemistry.* 2000, 48, 2300–2304. https//doi.org/ 10.1021/jf990508p.
[74] Gonzalez-Martin MI, Revilla L, Betances-Salcedo EV. Pesticide residues and heavy metals in commercially processed propolis. *Microchemical Journal.* 2018, 12, 49. https://doi.org/10.1016/j.microc.2018.08.040.
[75] Jin L, Zhao L, Yue X. Determination of heavy metal residues in Shiquan Dabu herb paste and its Chinese herbal pieces. *Practical Pharmacy and Clinical Remedies.* 2017, 20 (11), 1310–1313. https//doi.org/10.3389/fphar.2020.595335.
[76] Annan K, Kojo AI, Cindy A, Samuel AN, Tunkumgnen BM. Profile of heavy metals in some medicinal plants from Ghana commonly used as components of herbal formulations. *Pharmacognosy Research.* 2010, 2, 41–44. https//doi.org/10.4103/0974-8490.60579.
[77] Aasfar A, Bargaz A, Yaakoubi K, Hilali A, Bennis I, Zeroual Y, et al. Nitrogen fixing azotobacter species as potential soil biological enhancers for crop nutrition and yield Stability. *Frontiers in Microbiology.* 2021, 12. https://doi.org/10.3389/fmicb.2021.628379.
[78] Kumar R. Introduction and Importance of Medicinal Plants and Herbs. *International Journal of Multidisciplinary.* 2018, 3 (12), 1315-1316.
[79] Sam S. Importance and effectiveness of herbal medicines. *Journal of Pharmacognosy and Phytochemistry.* 2019, 8 (2), 354-357.
[80] Zhou Y, Zhuang W, Hu W, Liu GJ, Wu TX, Wu XT. Consumption of large amounts of Allium vegetables reduces risk for gastric cancer in a meta-analysis. *Gastroenterology*. 2011, 141 (1), 80–89. https//doi.org/10.1053/j.gastro.2011.03.057.
[81] Tandahu BV, Abdullah SZ, Basri H, Idris M, Anuar N, Mukhlisin M. A Review on Heavy Metals (As, Pb, and Hg) Uptake by Plants through Phytoremediation. *International Journal of Chemical Engineering*. https://doi.

org/10.1155/2011/939161.
[82] Mitra S, Chakraborty J, Tareq AM, Bin Emran T, Nainu F, Khusro A, Idris AM, Khadaker MU, Osman H, Alhumaydhi FA, Simal-Gandara J. Impact of heavy metals on the environment and human health: novel therapeutic insights to counter the toxicity. *Journal of King Saud University – Science.* 2022, 34 (3), 101865.
[83] World Health Organisation. Permissible limits for heavy metals in plant and soil. 1996.
[84] National Institute of Health. Daily needs of the world's daily average uptake of elements by a person weighing 70 kg. 1996.
[85] Codex Alimentarius. Codex general standard for contaminants and toxins in food and feed - CODEX STAN 193-1995. Joint FAO/WHO. 2015, 59.
[86] Official Hazette of BiH. Regulation on Maximum Permitted Quatities of Certain Contaminants in Food. 2022.
[87] Alhusban AA, Ata SA, Shraim SA. The Safety Assessment of Toxic Metals in Commonly Used Pharmaceutical Herbal Products and Traditional Herbs for Infants in Jordanian Market. *Biological Trace Elem Research.* 2019, 187 (1), 307-315. https//doi.org/10.1007/s12011-018-1367-1.
[88] Kowalsa G. The Safety Assessment of Toxic Metals in Commonly Used Herbs, Spices, Tea, and Coffee in Poland. *International Journal of Environmental Research and Public Health.* 2021, 18(11), 5779. https//doi.org/10.3390/ijerph18115779.
[89] Hasan Al-keriawy HA, Nehaba SS, Alwan AW. Environmental risk assessment of heavy metals in selected medicinal herbs and spices. *Journal of Ecological Engineering.* 2023, 24(6), 376-384. https//doi.org/10.12911/22998993/162985.
[90] Oladeji OM, AASA OA, Adelusi OA, Mugivhisa LL. Assessment of heavy metals and their human health risks in selected spices from South Africa. *Toxicology Reports.* 2023, 11, 216-220.
[91] Ezez D, Birhanu H, Shamena S, Engidaw S. Bioaccumulation of heavy metals, assessment of carcinogenic and noncarcinogenic health risk in various spices. *Journal of Hazardous Materials Advances.* 2024, 15(21), 100441. https//doi.org/10.1016/j.hazard.2024.100441.
[92] ASTA. Guidance levels for heavy metals in spices. Industry Guidance levels for lead. 2025.

Izvod

TEŠKI METALI U LEKOVITIM I ZAČINSKIM BILJKAMA

Milenko Smiljanić[1], Vesna Gojković Cvjetković[1], Željka Marjanović-Balaban[2], Vesna Antunović[3], Milomirka Obrenović[1], Jelena Vuković[1], Kristina Đerić[1]

[1]Univerzitet u Istočnom Sarajevu, Tehnološki fakultet Zvornik, Republika Srpska, Bosna i Hercegovina
[2]Univerzitet u Banja Luci, Šumarski fakultet Banja Luka, Republika Srpska, Bosna i Hercegovina
[3]Univerzitet u Banja Luci, Medicinski fakultet Banja Luka, odsjek za farmaciju, Republika Srpska, Bosna i Hercegovina

(PREGLEDNI RAD)
UDK: 633.88:632.122 , 635.7:632.122
DOI: 10.5937/savteh2502022S

U poslednje vrijeme u porastu je upotreba začinskog i lekovitog bilja u ishrani ljudi. Ono ima brojne uloge, koje uključuju sprečavanje prenosa mikroorganizama, antioksidativna i antimikrobna svojstva. Međutim, osim što ima mnoge prednosti, onio takođe može da sadrži i toksične materije koje dospeva iz okoline tokom proizvodnje, prerade i uslova skladištenja. Kontaminacija začinskog i lekovitog bilja dešava se tokom uzgoja biljnih vrsta (utiče na sastav zemljišta, prisutne hranljive materije i mineralna đubriva), kao i tokom proizvodnje i pakovanja. U najvećoj meri opasnost predstavljaju teški metali, koji do biljaka dospijevaju putem zemljišta, vazduha i vode. Do kontaminacije dolazi kao posljedica rada različitih industrijskih postrojenja. U ovom radu predstavljeni su teški metali (esencijalni i neesencijalni). U esencijalne spadaju bakar, cink, mangan, gvožđe, molibden, hrom i selen, a u neesencijalne olovo, živa, kadmijum, arsen, aluminijum, kalaj, kobalt i platina.

Ključne reči: lekovite biljke, začinske biljke, esencijalni i neesencijalni teški metali

CRediT authorship contribution statement:
Milenko Smiljanić: Conceptualization, Writing – Original Draft, Reviewing and Editing
Vesna Gojković Cvjetković: Conceptualization, Writing – Original Draft
Željka Marjanović-Balaban: Conceptualization, Reviewing and Editing
Vesna Antunović: Resources
Milomirka Obrenović: Resources
Jelena Vuković: Resources
Kristina Đerić: Resources