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REVIEW PAPER

Zinc, its sources, functions and threats to the environment and biological life: A review*

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Abstract

Zinc is one of the most widespread elements on our planet. Zinc can be found in the environment in many forms, including different isotopic forms, organic and inorganic forms. In soil and water, zinc can be of both natural and anthropogenic origin. In soils, both the content and availability of zinc depend on many variables, and its presence is a multifaceted issue. Due to its unique structure and properties, zinc is an extremely valuable element for physiological processes. Zinc occurs in more than 200 enzymes, involved in fundamental processes such as the synthesis of proteins, nucleic acids and hormones. Zinc-dependent reactions include energy transfer reactions, protein synthesis or nitrogen metabolism. International trends indicate an insufficient content/availability of this micronutrient on more than 40% of agriculturally used land. This translates into the reduced efficiency of agricultural production and sub-optimal zinc levels in plant tissues, which in turn results in an insufficient zinc content in plant-derived food. Optimal zinc content in plant nutrition is crucial for both plant physiology and plant production efficiency. Both under- and over-nutrition of zinc will have a negative effect on the plant growth, development and performance. A possible solution to the problem of zinc deficiency in plant tissues is the use of biofortification. Ensuring optimal nutrition with this micronutrient is crucial for human health or animal production efficiency. Inadequate zinc nutrition results in the disruption of essential metabolic processes, reduced immunity and impaired reproduction as well as progeny development. The purpose of this article is to review the literature and provide a comprehensive overview of the knowledge concerning the sources and functions of zinc and risks of zinc deficiency or excess in the environment.

Keywords: zinc, metabolic reactions, malnourishment, micronutient

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INTRODUCTION

Zinc, the twenty-third most widespread element on the globe, is a blue-white metallic element that makes up about 0.02% of the Earth's crust. Zinc has five stable isotopes: 64Zn (48.63%), 66Zn (27.90%), 67Zn (4.90%), 68Zn (18.75%) and 70Zn (0.62%). In the atomic mass range from 54 to 83, there are about 30 short-lived radioisotopes of zinc, the longest-lived isotope (65Zn, t1/2 = 244.26 d) is regularly used as a zinc tracer in plant (Barak and Helmke 1993). Zinc, due to its properties resulting from the transitional nature of this element, has chemical properties that make it particularly important in biological systems. One of the most important characteristics of zinc is its ability to form strong, yet flexible and easily exchangeable complexes with organic molecules. As a result, it has an effect on modifying the structure of nucleic acids, specific proteins, and cell membranes. Its presence influences the catalytic properties of a large number of enzyme systems and intracellular signalling. Zinc is a component different metallo-enzymes responsible for a variety of functions including the synthesis of nucleic acids, specific proteins or hormones (Ziegler, Filer 1996). Thanks to these properties, zinc plays a central role in processes related to cell growth, differentiation and metabolism of cells.

In solution, Zn exists in the $^{2+}$ oxidation state and, unlike Fe^{2+} and Cu^{2+}, is redox-stable under physiological conditions as a result of a complete *d*-shell of electrons (Auld 2001), which translates into its free transport in biological systems without causing oxidative damage, unlike the transport of different trace elements. Zinc occurs in a wide variety of compounds, both in the form of soluble salts, which include halides, sulphates, nitrates, formates, acetates, thiocyanates, perchlorates, fluosilicates, cyanides, alkali metal zincates and Zn-ammonia salts, and sparingly soluble compounds, including Zn-ammonium phosphate, Zn hydroxide and Zn carbonate; and a range of soluble and insoluble organic complexes (Lindsay 1979, Barak, Helmke 1993).

SOURCES OF ZINC IN THE ENVIRONMENT

Zinc content of soil

The zinc content of uncontaminated soil depends mainly on the chemical properties of the parent rock and weathering processes (Chesworth 1991). In magmatic rocks, the zinc content typically reaches between 40 and 120 mg kg^{-1}, while in sedimentary rocks the content of this micronutrient ranges from 10-25 mg kg^{-1} (Kabata-Pendias, Pendias 2001). Due to the mainly geological origin of zinc in soils, the key minerals that are sources of zinc in soils are sphalerite (ZnS) and smithsonite ($ZnCO_3$), zinc and iron oxide – franklinite ($ZnO \cdot Fe_2O_3$) and zinc hydrosilicate – hemimorphite ($Zn_4Si_2O_7(OH)_2 \cdot H_2O$) – Zyrin and Sadovnikova (1975), Greenwood, Earnshaw (1997). Simple compounds like ZnO_2 or $ZnCO_3$, which form with anions commonly found in soil, are too soluble to persist in the soil. Lindsay (1972) suggests that zinc is probably retained in the soil by crystal lattices through isomorphic substitution and as an ion occlusion. Because zinc is a trace element, it is usually surrounded by many other solid phases. Commensurately, the soil matrix formed by iron, aluminium, manganese and other oxides, in addition to carbonates and silicates, imposes some control over the solubility ratios of zinc in the soil.

The zinc content in agricultural soils ranges from 10-300 mg/kg and is distributed unevenly (Malle 1992, Barber 1995). According to some researchers, the range of zinc content in unpolluted soils is narrower at 10 to 100 mg kg^{-1} (Mertens, Smolders 2013). The global average soil Zn content is considered to be 64 mg kg^{-1}. However, total soil zinc content is not an adequate indicator to express the ability of the soil to provide Zn availability to plants, only a small fraction of zinc is in the soil solution from which it can be taken up by plants (Kabata-Pendias, Pendias 1999, 2001).

The abundance and availability of zinc in the soil is a complex issue. On the one hand, sandy soils formed on naturally zinc-poor quartz are considered zinc-deficient soils. However, these soils often show high levels of soluble zinc, which is usually characteristic of the finer soil types. Nonetheless, the lack of stable zinc deposits in those soil's results in severe depletion of this micronutrient in the root zone (Lindsay 1972). Other examples of zinc-poor soil types are mucks (histosols) and peat, where the topsoil in which underground plant organs develop is isolated from the deeper mineral soil layers with higher zinc content. Acidic soils are also usually identified as low zinc content soils, this is particularly noticeable in areas with heavy rainfall. As a result of chemical weathering of the minerals, significant amounts of zinc are released, but these are rapidly leached into the deeper soil profile, resulting in an insufficient amount of this micronutrient in the arable layer. Acidic soils may often have a high total zinc content, but insufficient amount of available zinc in the cultivated stratum (Schroo 1959, Jackson et al. 1967, Lucas, Davis 1961).

The main determinant of Zn availability in soil is pH, which affects the solubility of Zn in soil solution. An increase in the pH of the soil solution stimulates zinc adsorption on cation exchange sites in the soil, which contributes to a decrease in the availability of zinc in the soil solution. The availability of soluble zinc in soil solution decreases by 30 to 45 times for each unit increase in soil pH between 5.5 and 7.0 pH, which is one of the most increasing risks of zinc deficiency in plants production (Marschner 1993).

According to Lindsday (1957), there is a significant correlation between soil organic matter density and soil zinc content. This is due to the general lower content of heavy metals, including zinc, in soils with a decreased content of organic matter as well as to the fact that such soils usually have a higher pH and a higher content of carbohydrates, which further favours lower availability of zinc in soil solution.

Calcareous soils, whose pH usually exceeds 7.4, despite their relatively high total zinc content but because of their alkalinity, have a reduced zinc content in the soil solution. Some researchers have indicated that the low availability of zinc in calcareous soils, despite the high total content of this micronutrient, may be due to zinc absoption by carbonates (Jurinak, Bauer 1956, Thorne 1957).

Zinc deficiencies in agriculturally used soils are among the most geographically widespread soil micronutrient deficiencies, result in reduced crop productivity and can affect up to 40% of the world's arable land. Soil zinc content is strongly linked to soil organic matter content. Some researchers have shown a significant correlation between a decrease in soil organic matter content and soil zinc content (Follett, Lindsay 1970). Mechanical land levelling during which reach organic topsoil is often lost, especially on calcareous soils, contributes to a drastic reduction in soil zinc content. (Lindsay 1972, Singh et al. 2005, Çelik et al. 2017).

There are cases in which, despite international trends indicating a low zinc content or availability in the soil. We encounter areas where, for both natural and atropogenic reasons, the content of zinc in the soil is very high, often resulting in toxic effects of this micronutrient on plants (Singh et al. 2005, Sadeghzadeh 2013). In earlier times, the main anthropogenic source of zinc contamination in the soil was metal smelters that used outdated pyrometallurgical equipment. This resulted in dust emissions with a high zinc content causing the soil to be contaminated with this element (Zyrin, Sadovnikova 1985, Greenwood, Earnshaw 1997). During a research study in Canada, the zinc content extracted with 1 N HNO_3 in soils in the area near a smelter was found to reach 1390 mg kg^{-1}, compared to an average soil zinc content of 50-75 mg/kg in neighbouring uncontaminated areas (Ladonin 2002).

The availability and abundance of zinc in soils is a multifaceted issue. Due to the considerable number of processes and factors involved, researchers are not clear on these issues. Because of the high variability and irregular distribution of zinc in the soil, soil chemical analyses are necessary to determine the actual zinc level in the soil, as well as taking into account the mechanical composition and organic matter content of the soil.

Zinc content of water

An extremely important factor in the geochemical cycling of trace elements is their contamination of water. The trace element hydrocycle plays a key function in both aquatic and terrestrial ecosystems. A particular role is attributed to the circulation of trace metals in assessments, where their extremely important function in photosynthetic carbon fixation by phytoplankton is crucial (Kabat-Pendias, Mukherjee 2007).

Zinc enters water and soil both through natural processes and through human activities. A significant proportion of zinc is delivered to water artificially and can have multiple sources. The most important anthropogenic sources of zinc are mine site drainage, industrial and municipal activities, waste incineration, fossil fuel power plant operations, etc. However, most zinc is supplied by the erosion of Zn-containing soil particles (EPA 1980 *a*,*b*). In the EU, the largest source of zinc in the aquatic environment is discharges from chemical plants. Zinc also enters groundwater through leaching of some mineral fertilisers or through damage, including corrosion, to the coatings of zinc-plated steel components either used in the construction of buildings or in the pipes supplying drinking water (Sorlini et al. 2014).

Zinc content of running water in rivers based on studies of nine river basins in Germany, France and Belgium was established on levels from 1.3 to 14.6 μg Zn L^{-1} (Van Sprang et al. 2009). Zinc also occurs in drinking water, both as salts and as organic complexes. In unpolluted surface water and groundwater, zinc contents should not exceed 0.01 and 0.05 mg L^{-1}, correspondingly (FAO 1982).

In certain circumstances, significant quantities of trace elements are released into the water, causing acceptable levels to be exceeded. The scale of the ecological consequences caused by trace element pollution of water is difficult to estimate. The value of trace elements supplied by watercourses to the seas and oceans takes different values in the literaturę, and ranges from 20 kilotonnes per year (Gaillardet et al. 2003) to 200 kilotonnes per annum (Kitano 1992).

The role of zinc in plant growth and development

Zinc is a key micronutrient for normal plant growth and development. It is an integral part of the enzymes responsible for regulating DNA translation and transcription, repairing important photosystems, and regulating the function of chloroplasts and hydrolytic enzymes (White, Broadley 2011, Padash et al. 2016, Buturi et al. 2021). In addition, zinc is a crucial micronutrient for enzymatic, metabolic and redox reactions. In biochemical reactions, zinc-dependent enzymes are involved in many processes, including carbohydrate metabolism or the conversion of sugar into starch. Energy transfer reactions, protein synthesis or nitrogen metabolism are also zinc-dependent (Graham et al. 2001, Cakmak 2002). Zn is also involved in protein and auxin metabolism, pollen formation or maintenance of biological membranes and enzymes responsible for plant resistance to pathogen infection (Alloway 2008). Zinc nutrition of plants has a positive effect on the content of protein, vitamin C and starch (Breś et al. 2012).

The plant root system takes up zinc mainly as Zn^{2+} via ZIP transporters or as chelated low molecular weight compounds (Broadley et al. 2007). Within the plant, it is transported through the xylem apoplastically or symplastically, bound by organic acids or in ionic form (White, Broadley 2009).

Differences in zinc accumulation in edible plant parts depend on the species and the mode of absorption of this micronutrient (Meneghelli et al. 2021). In most plants, optimal zinc content reaches the level of 15-30 mg kg^{-1} dry weight of green parts in order for the plant to function properly and to sustain vital or metabolic functions. Below these values, a disturbance of basic metabolic processes such as respiration or photosynthesis as well as yield reduction are observed. There is also an increase in the level of reactive oxygen species (ROS), indicating that plants enter a state of stress (White and Broadley 2011, Buturi et al. 2021, Praharaj et al. 2021). However, there are species, in limited numbers, that are capable of accumulating higher zinc contents in green parts. These primarily include species from the families *Brassicaceae*, *Caryophyllaceae*, *Polygonaceae* and *Dichapetalaceae*, and have the capacity to bioaccumulate even above 3000 mg kg^{-1} dry matter (Broadley et al. 2007). Examples of species in the *Brassicaceae* family capable of hyper-accumulation are *Arabidopsis halleri* and *Noccaea caerulescens*, in which zinc contents of 53 900 and 43 000 mg kg^{-1} dry weight have been determined in leaves of plants growing in the wild. For the remaining species, zinc contents in dry matter at levels of 100-700 mg kg^{-1} are considered toxic (White et al. 2018).

The zinc content in edible parts of vegetables is a species-specific feature and ranges from 1.0 to 64.6 mg kg^{-1} d.m (Table 1).

Table 1

Content of Zn in edible part of selected vegetable species according to other authors (mg kg^{-1} d.m.)

Species	Zn	Source
Onion	16.9-27.3	Kleiber et al. 2010
Red paprica	1.0-2.3	Rubio et al. 2002
Common red cabbage	33.2-39.5	Smoleń and Sady 2008
Carrot	23.0	Kunachowicz et al. 1997
Cocktail tomatoes	18.0	Dobromilska et al. 2008
Celery	12.9-64.6	Bosiacki, Tyksiński 2009

Toxic zinc concentrations in plants translate into impaired root and shoot development resulting in reduced growth and yield. The effect of high zinc concentrations on germination and vegetation of plants is a species--specific feature. An example of the inhibitory effect of increasing zinc concentrations (40, 80, 160, 240, 320, and 640 mg L^{-1}) on germination and seedling growth is presented by *Cucumis sativus L.*, where zinc at concentrations of 80 mg L^{-1} and above showed an inhibitory effect on root length (Aydin et al. 2012). An example of the positive effect of zinc application on plants is observed in the case of *Medicago sativa L.*, in which, at concentrations below 1.5 mM, a significant effect on increasing seed germination is observed. However, for the same species, an inhibitory effect of zinc is observed above a concentration of 1,5 mM (Yahaghi et al. 2019). Nonetheless, there are species such as *Coriandrum sativum L.* which, regardless of the concentration used, do not show any positive effect on zinc application. Plants treated with 0.1 mM zinc showed no significant differences in either germination or other morphological factors. Whereas plants grown at elevated zinc concentrations of 1 and 2 mM showed a lower overall plant height, a reduction in the number of second-order branches and a reduction in the dry and fresh weight of both aerial and root parts. The reproductive parts of the plants were also affected, particularly in the number of flowers per plant, the number of seeds per plant and the weight of 1,000 seeds (Marichali et al. 2014).These studies highlight the diversity of responses to zinc applications to plants, depending on the concentrations and species studied.

Zinc fertilizers increase both the yield and quality of crops: wheat (Cakmak 2008), rice (Liu et al. 2003), and peas (Fawzi et al. 1993). According to Anitha et al. (2016), the zinc levels were found to be increased after supplementation of Spirulina in different combinations and application methods. The effect in zinc nutrient status, which was evident in the cultivars of *Amaranthus gangeticus*, *Phaseolus aureus* and *Solanum lycopersicum*, can be attributed due to the biofortification of *Spirulina platensis*. Effect of foliar Zn applicaction on wheat yield occurred irrespective of the soil and environmental conditions, management practices applied and cultivars used in 23 site-years (Zou et al. 2012). In hydroponic cultivation, the zinc content in lettuce heads is influenced by the composition of the nutrient solution (Kleiber, Markiewicz 2010). Like concentrations of all heavy metals, the amount of this microelement in lettuce leaves depends on the plant growth, phase, fertilization doses, as well as the mutual relationships between the proportions of available mineral components (Sady, Domagała 1994, Kırpık et al. 2017). In ornamental plants, the foliar spray of Zn have promoting effects on photosynthesis rate and total phenolics, total flavonoids, flavanols and anthocyanins content in *Vitis vinifera* (Song et al. 2015). The flower yield, essential oil content and essential oil yield were markedly increased by the soil and foliar applications of Fe + Zn in chamomile (Nasiri, Najafi 2015). Khalifa et al. (2011) showed a positive response of iris plant growth, yield and yield components due to Zn foliar spray may be attributed to its deficiency in the studied soil. Similar results also were obtained on the gladiolus (Hassanien 1997, Prabhat, Arora 2000). The foliar spraying *Antholyza aethiopica* with Zn have an effect on increasing the leaf number per plant (El-Khayat 1999). The content of Zn in the shoots and roots of *Phalaenopsis* were determined to be dependent on the negative interaction of P × Zn, as shown by the significant decrease in Zn levels with the increase in the P application dose. The increase in the P application dose led to a higher accumulation of Zn in the roots, indicating lower translocation of this nutrient to the shoots of the plant (Novais et al. 2016).

Due to the wide spectrum of zinc fertilisation forms and the multiplicity of both species and varieties of cultivated plants, it is necessary to carry out studies to determine their response to zinc nutrition.

According to several researchers (Foy et al. 1978, Larbi et al. 2002, Fodor et al. 2005), zinc toxicity includes symptoms similar to those of cadmium (Cd) or lead (Pb) toxicity. High Zn concentrations (100 and 300 μM Zn) in the nutrient solution reduced whole-plant DW and leaf area in sugar beet plants grown in a greenhouse (Sagardoy et al. 2010).

The findings presented by Egli et al. (2010) and Jiang et al. (2010) suggest that zinc and other heavy metals have the potential to disturb the microbial balance in soil. The various effects these heavy metals have on different microbial groups are influenced by the unique physiological, morphological, and genetic traits of the microbes.

The effect of toxic zinc concentrations in plants in addition to other symptoms is a reduction in the relative water content of plant tissues (RWC) or destabilisation of plant water relations (Garg, Singh 2018), resulting in severe plant dehydration and loss of cell turgor (Ghnaya et al. 2010). Such a phenomenon is probably due to zinc accumulation in the aerial tissues of plants. The decrease in water potential under exposure to high zinc content is mainly due to increased osmotic potential in the adjacent medium and reduced water absorption (Mir et al. 2015). The reduction in the relative water content of the tissues may also be caused by a reduction in the absorptive surface area of the roots, but also through zinc blocking the xylem vessels and thus limiting the transport of plant juices (Koleva et al. 2010). A reduction in RWC combined with a loss of cell turgor leads to a reduction in plant cell expansion, resulting in the inhibition of growth and biomass production. In addition, changes in chlorophyll structure, reduced stomatal conductance, reduced net carbon dioxide fixation, altered membrane permeability, and oxidative stress occurring in the plant are observed (Tsonev, Cebola Lidon 2012, Marichali et al. 2014).

Due to the immobility of zinc in plant tissues, zinc deficiencies initially manifest themselves on young plant leaves. The surface area of the leaves decreases, the leaves become crescent-shaped and interveinal chlorosis and necrotic spots develop on the upper side of the leaves. As chlorosis and necrosis progress, dry, brown necrotic lesions form on the leaves. The occurrence of necrosis is particularly evident in cases of highly advanced zinc deficiency symptoms as the symptoms progress to older leaves eventually leading to their withering and rejection by the plant (Brennan et al. 1993). Zinc deficiency symptoms in plants, even in large-scale crops, are often manifested heterogeneously in the crop, and are often highly dependent on other plant stressors (Kubota, Allaway 1972).

Low zinc contents in plant food are a result of the insufficient content of this micronutrient in the soil (Thorne 1957). In addition, its low bioavailability and the occurrence of abiotic stresses contribute to low zinc contents in plants, leading to disorders in plant growth and development. Biofortification is the simplest and also the most promising method to increase the zinc content in plant tissues without adversely affecting plant yield (Szerement et al. 2021). Biofortification is the term given to a series of processes aimed at increasing the micronutrient content of the edible parts of plants. For this purpose, traditional breeding and biotechnological methods are used. Biofortification also includes other approaches, such as the use of micronutrient fertilisers (agronomic biofortification) or increasing the availability of micronutrients to plants by manipulating the levels of nutrients and anti-nutrients in plant nutrition (Nestel et al. 2006, Graham et al. 2007, Mayer et al. 2007).

The success of biofortification depends mainly on the correct choice of plant species in which the process is used. The use of biofortification in brassicaceous plants, particularly in the form of microgreens, allows the zinc content of the plant tissue to be increased by 75 to 281%, making it extremely suitable for the process. In favour of the use of microgreens is the ability to deliver an extremely micronutrient-rich food quickly just in 7-21 days. This makes them particularly suitable for supplementing zinc deficiencies in situations where continuous and significant amount of nutrient-rich food is needed (Di Giogia et al. 2019).

Effects of zinc on animals

In the case of animals, zinc is considered to be a key element in more than 200 enzymes. For this reason, zinc is essential for the metabolism and synthesis of proteins and nucleic acids. It is also involved in cell division and repair processes, and is responsible for the integrity of epithelial tissues, transport and use of vitamins A and E in the animal body, synthesis of reproductive steroids, intracellular detoxification of free radicals or carbohydrate metabolism (Bindari et al. 2013). Zinc plays important role in the endocrine system, particularly in the reproductive field (Capuco et al. 1990). Its influence on sexual maturity and, in particular, entry into oestrus, its effect on the maintenance and regeneration of the uterine lining and the return to normal reproductive function in cattle are also not negligible. Both deficiency and excess are detrimental as they can impair spermatogenesis or affect fertility, embryonic development and postpartum recovery of animals (Smith, Akinbamijo 2000).

Zn deficiencies in animals can quickly take the form of symptoms such as changes in taste sensation, limb growth restriction, eye infections, ending with disorders of keratin synthesis (Prasad 2013). Animals show a fairly high resistance to high levels of zinc in the diet (Fosmire 1990).

In cattle, zinc deficiencies affect both cows and bulls. During intensive milk production, cows have an increased need for protein and energy, which translates into an elevated demand for dietary zinc, making them susceptible to deficiencies of this micronutrient in the case of an unbalanced diet

(Strusinska et al. 2003). Zinc deficiency in bulls manifests itself in the form of diminished libido, lower semen quality and reduced testicle size (Daniel 1983).

In poultry, zinc deficiency causes moulting problems, reduced egg quality and decreased laying performance. Moreover, zinc deficiency results in reduced hatchability and slower growth of the chicks. In addition to improving production factors, an adequate supply of zinc in the poultry diet increases resistance to pathogens and reduces the mortality rate of chicks due to disease by up to 10% (Huang et al. 2019). Although an inadequate amount of zinc in fodder can cause gastrointestinal and pancreatic damage in the laying hens, reduced growth rates and high mortality in offspring (Dewar et al. 1983, Blalock, Hill 1988).

Zinc toxicity manifests itself exceptionally in pigs. In their case, zinc toxicity is manifested by haemorrhage in the intestines and clear signs of inflammatory bowel disease. Clear signs of haemorrhage are seen in many internal organs including the spleen, brain and lymph nodes. The animals' joints show significant swelling and an arthritic condition. In most cases, animals experiencing zinc toxicity show weight loss and characteristic yellow faeces with large amounts of mucus (Brink et al. 1959).

The role of zinc in the human body

While deficiencies of micronutrients such as iron are widely known, a global problem sometimes referred to as ‚hidden hunger' is zinc deficiency in the human diet (Graham et al. 2012, Praharaj et al. 2021). According to Wessells and Brown (2012), 17.1% of the world's population is at risk of dietary zinc insufficiency.

Zinc was recognised by science as an essential nutrient around 125 years ago. On the basis of studies in the first half of the 20th century, its significant effects on the growth and development of higher plants, rodents, pigs or poultry were recognised. Despite the promising results of these studies, the occurrence of deficiencies in humans was considered doubtful, due to the prevalence of this element in the environment. However, with the population growth, cases of clinical zinc deficiency in the human diet became widespread. In the 1960s, numerous cases of dwarfism and delayed puberty in adolescents were reported in Egypt. Since then, research on people with Brandt syndrome, an inborn defect in zinc metabolism resulting in zinc malabsorption and consequent zinc deficiency, has confirmed the crucial role of zinc in normal growth and the functioning of the human organism (Moynahan 1974).

The indispensability of zinc in the human body is due to its several functions, which include its role as a cofactor in the synthesis of enzymes, DNA and RNA (WHO 1996). According to the joint FAO/WHO committee on food additives, the approximate daily requirement for zinc in the human diet has been set at 0.3 mg kg^{-1} body weight. The maximum occasional intake of zinc is considered to be 1.0 mg kg^{-1} body weight (FAO 1982). Averaging globally, an adult's daily zinc requirement ranges from 15-22 mg Zn per day, while studies of dietary zinc yielded a range of 5 to 22 mg Zn per day, depending on the area studied (Sandstead 2015).

Children under 5 years of age and pregnant women are particularly vulnerable to zinc deficiency because of their increased need for this micronutrient. Among children, zinc deficiency contributes to the occurrence of infections and diarrhoea, which results in 800 000 deaths each year (Black et al. 2008, Krebs et al. 2014). In the case of pregnant women, it can contribute to complications during pregnancy, abnormal development and the occurrence of foetal malformations (Black 2001, Deshpande et al. 2012, Stevens et al. 2022). In the remaining cases, zinc deficiency can be manifested as loss of taste and smell, anaemia and atherosclerosis.

An insufficient amount of Zn in the body disrupts the body's homeostasis. Due to the fact that zync is a lymphocyte mitogen of natural origin, its deficiencies cause a decrease in the number of T cells, which are part of the immune system responsible for recognising pathogen antigens of bacterial and viral origin, in particular. They are also responsible for maintaining immunological memory and tolerance to pathogens (Keen, Gershwin 1990, Tapiero, Tew 2003, Kumar et al. 2018). Furthermore, zinc malnutrition contributes to a reduced response to phytoestrogens and the occurrence of defective platelet aggregation.

The toxic effects of zinc on the human body can be divided into two main types: chronic toxicity and acute toxicity. Acute zinc toxicity occurs when a large dose of zinc is taken in a short period of time, often caused by the consumption of a large amount of zinc-rich food or an overdose of zinc-containing dietary supplements. This type of toxicity usually manifests itself through nausea, vomiting, diarrhoea, headaches and abdominal pain; in some cases, neurological symptoms and metabolic imbalance also occur. Chronic zinc toxicity is caused by persistently elevated levels of zinc in the human body. This is often caused by uncontrolled intake of zinc supplements or prolonged exposure to zinc-containing dusts and fumes. Symptoms of chronic exposure to zinc toxicity, manifested by zinc-induced copper deficiency symptoms, include impaired immune function, decreased levels of high-density lipoprotein (HDL) and increased levels of low-density lipoprotein (LDL) – Kim et al. (2010), Schoofs et al. (2024).

Most zinc in the human body is accumulated in the bones and muscles, where up to 85% of the total zinc content of the human body is found, while other areas of the body with high volumes of this micronutrient are the skin and liver, where 11% of the body's zinc content is accumulated. The organs with the highest concentrations of zinc in the tissue are the eyeball and the prostate (Bhowmik et al. 2010, Prasad 2013).

As zoonotic products, and meat in particular, are the main dietary sources of zinc, people who are particularly vulnerable to zinc deficiency are those who, for either health, worldview or economic reasons, have given up these products in their diet (Dussiot et al. 2021). This micronutrient undernourishment most commonly occurs in areas where the diet is based on cereal crops, which are naturally deficient in micronutrients including zinc (Biesalski 2013).

CONCLUSIONS

Proper Zn nutrition is a key aspect from the perspective of both human health and the efficiency of plant and animal production. Due to the extremely diverse roles of zinc in metabolic processes, enzymatic processes, DNA synthesis, etc., it is essential for normal growth and development both at the cellular and whole organism level. Because of the non-specific symptoms of its deficiency, the scale of the problem is difficult to estimate. The low content of this element in the soil combined with its limited availability to plants and results in unsatisfactory Zn content in plant tissues. This translates into a small amount of Zn supplied in plant food. As a solution to this problem, one of the possible methods is to use a biofortification process to significantly increase the Zn content of plant tissues, thereby increasing the zinc intake from plant origin food. Due to the specific characteristic of the biofortification process, and depending on many factors for the success of this process. It is therefore necessary to pursue studies that will identify the most promising solutions.

Author contributions

Conceptualization –J.R., B.M., A.B investigation – J.R., B.M., data curation – J.R., B.M., A.B., writing – original draft preparation – J.R., B.M., writing – review and editing – J.R., B.M., A.B. All authors have read and agreed to the published version of the manuscript.

Conflicts of interest

The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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