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The Nutrient Zinc in Soil and Plant: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Zinc is an element found in low amounts in the soil, which may limit the development of agricultural crops. In addition, the absorption of this nutrient by plants is directly influenced by several factors such as: high pH, amount of organic matter, high humidity associated with low temperatures and soil microbiota. Zinc is important for enzymatic activity, being a constituent part of the enzymes alcohol dehydrogenase, carbonic anhydrase, superoxide dismutase enzyme and polymer RNA, in addition to participating in the synthesis of precursor tryptophan in the metabolism of indoleacetic

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acid, which is a plant hormone directly related to the development of plants. In plants, the symptoms of zinc deficiency appear with the shortening of the internodes, reduction of the leaf area, reduction of its size, appearance of rosettes, chlorosis and necrosis. Thus, the objective of this review is to present the main aspects of the zinc nutrient in the soil and the functions performed in plants.

Keywords: Enzymes; Zn^{2+} cation; tryptophan.

1. INTRODUCTION

Zinc (Zn) is found in the earth's crust at a level of approximately 70 mg kg^{-1} and on average in the lithosphere at 8 mg kg^{-1}. In igneous rocks, the content of this element varies between 40 (granite) and 130 mg kg^{-1} (basalt), whereas in sedimentary rocks this variation is from 16 (sandstone) to 96 mg kg^{-1} (shale) [1]. The Zn content in these soils ranges from 10 to 300 mg kg^{-1}, with no correlation with its availability for plants [2]. In rocks and soil, Zn is in the divalent form (Zn^{2+}). In the mineral fraction that makes up the soil, this element is found in ferromagnetic minerals, such as biotite, magnetite, hornblende, and Zn sulfide, when they undergo weathering, these minerals release Zn, which can form complexes with organic matter or can be absorbed by soil colloids in the form of a Zn^{2+} cation [3].

Due to its low concentration in the soil, Zn is a limiting nutrient for most crops [4], this is since this mineral is often adsorbed to clays and linked to organic matter. In addition to the low availability in soils, Zn uptake is highly influenced by several factors. The pH values are the most important factor, and the higher they are, the lower the availability of Zn in the soil solution, in addition, high organic matter contents, in addition to high humidity, are associated with low temperatures and the microbiota in the soil can temporarily immobilize Zn [5].

The Zn requirement is very important for the activity of several enzymes [6-8]. This nutrient is a fundamental part of the enzymes alcohol dehydrogenase, carbonic anhydrase, enzyme superoxide dismutase (Cu-Zn-SD), and RNA polymer, in addition to being part of the synthesis of tryptophan, which is a precursor in the metabolism of indoleacetic acid (IAA), a hormone that acts directly on plant development [9,10]. Due to its importance in the metabolism of carbohydrates and plant hormones, the symptoms of Zn deficiency are characterized by the limitation of the growth of entrains, giving the plant a rosette growth habit, the leaves are small, twisted, and with wrinkled margins, in addition to being able to present an aspect of chlorosis that can evolve into necrotic spots [11].

2. ORIGIN OF ZINC

The element Zinc, represented in the periodic table by the symbology Zn, is a transition metal belonging to family 12 (2B), with an atomic mass of 65.38, a boiling point of 908ºC, a melting point of 419.5ºC, which has an atomic number 30 being the 23rd most abundant element on planet Earth. The entry of Zn into the soil can occur naturally, whose primary entry is due to the chemical and physical weathering of the parent rocks and the second entry can occur through the atmosphere through volcanic activities and forest fires, in addition to biotic processes such as decomposition. Another route of entry of Zn into the soil is through anthropic activities, that is, the influence of man through mining, smelting, and combustion of fossil fuels [12]. In Brazil, Hemimorphite, Willemite, and Sphalerite are the main minerals consisting of Zn, having 54, 58.5, and 67% of Zn, respectively.

3. ZINC IN SOIL AND PLANT

Zinc in the soil is usually found in the most superficial layers since plant residues are deposited in these layers, in which, through the process of decomposition, this nutrient is released, another fact that contributes to this is the low mobility of zinc. Zn in the soil profile due to the ability of this nutrient to fix the organic matter, silicate clays, and Fe oxides and hydroxides. Zn in rocks and soil is in the divalent form (Zn^{2+}), in the mineral fraction this nutrient is released into the soil solution through the weathering process and can be absorbed by plants, immobilized by soil microorganisms, or absorbed by colloids in the form of a Zn^{2+} cation [3,13].

Soil pH values directly affect the availability of Zn. In more acidic soils this nutrient is more available and may reach minimum availability with a soil pH value above 7, thus, excessive liming management, a practice that increases soil pH, can lead plants to Zn deficiency [3,8,14].

In the plant, Zn is absorbed by the roots mainly in the divalent form (Zn^{2+}), which may vary between different species in terms of absorption rate, adequate content in leaves (Table 1), transport to the shoot and compartmentalization in different types of organelles. Because it generally presents a greater demand to Zn^{2+} concentrations in the soil, since there is a low level of Zn^{2+} in the cytosol due to subcellular compartmentalization of this nutrient, the entry of Zn^{2+} ions into the root cells is facilitated, in this way, diffusion becomes the mechanism main source of Zn for plants [3].

Table 1. Suitable range of zinc (Zn) content in leaves of several species of commercial interest

Culture	Zn (mg kg^{-1})
Rice	10-50
Corn	15-100
Wheat	20-70
Cocoa	30-80
Coffee	10-20
Smoke	20-80
Cotton	25-200
Orange	25-100
Apple	20-100
Grape	30-35
Lettuce	30-100
Onion	30-100
Carrot	25-100
Strawberry	20-50
Pepper	30-100
Tomato	30-100
Bean	18-50
Soy	20-50
Chrysanthemum	20-250
Potato	20-60
Manioc	35-100
Cane	10-50
Eucalyptus	35-50
Pine	30-45

Source: Fernandes et al. [3]

One way to increase the efficiency of Zn uptake by plants is through the use of arbuscular mycorrhizae [7]. Absorbed Zn is transported through xylem pathways, where the mobility of its redistribution within the plant has no consensus, being described by some authors as immobile or with intermediate mobility. Xylem loading is considered a key step in the translocation of Zn^{2+} to the aerial part of plants since the hyperpolarization process generated by the H+ ATPase enzyme in the plasma membrane of xylem parenchyma cells causes restriction of Zn^{2+} output from cells [3].

3.1 Function of Zinc in the Plant

Carbohydrate metabolism: When there is a deficiency in Zn, the enzyme carbonic anhydrase (CA) significantly reduces its activities, this enzyme that can be located in the cytoplasm and the chloroplasts has the function of facilitating the transfer of CO2/HCO3 for the photosynthetic fixation of CO2. However, there is evidence that despite the decrease in CA activity, the photosynthetic rate is not affected and carbohydrates accumulate in Zn-deficient plants, thus, it is possible to conclude that the change in carbohydrate metabolism generated by Zn deficiency is not fundamentally responsible. by the limitation of growth, nor by the visual symptoms of the deficiency of this nutrient [15].

Synthesis of indoleacetic acid (IAA): Zn directly interferes with the synthesis of indoleacetic acid auxin (IAA) and may increase the activity of the IAA oxidase enzyme responsible for IAA degradation or reduce its synthesis. In the synthesis of IAA, Zn is required in the synthesis of the amino acid tryptophan which is a precursor of AIA biosynthesis, thus, the availability of Zn limits the synthesis of AIA [14].

However, the mode of action of Zn on auxin metabolism is still unclear. Malta et al. [11], studying the effect of foliar application of zinc on coffee seedlings, observed that in plants sprayed with 0.6% ZnSO4.7H2O, in the apical and basal parts and the leaves of the apical and basal regions and the plagiotropic branches, had a reduction in the concentration of tryptophan up to 72 h, regardless of the spraying position. Thus, the authors concluded that Zn is required in the metabolism of tryptophan via tryptamine, which is a biogenic amine formed from the decarboxylation of tryptophan.

Commonly, Zn deficiency promotes a decrease in cell volume and limits apical growth, due to changes in the metabolism of auxins such as AIA, thus Zn is important in maintaining the active state of auxin, therefore, in plants where there is Zn deficiency, there are drastic drops in auxin content before the appearance of visual symptoms [3].

Protein synthesis (RNA): Plants that are deficient in Zn may have their growth compromised due to the great reduction in RNA levels, having a direct consequence in lower protein synthesis and difficulty in cell division, this fact can be explained because Zn inhibits RNAase (the enzyme responsible for the disintegration of Zn). RNA), in addition, this nutrient is part of RNA polymerase (the enzyme responsible for RNA synthesis). Zn is also part of ribosomes (site of protein synthesis), in case of deficiency there is dehydration of ribosomes [14,16].

Removal of superoxide radicals: The enzyme superoxide dismutase (Cu-Zn-SD) which is made up of Zn and plays a key role in protecting plants by removing superoxide radicals (O_2), thus playing an important role in defending membranes and proteins against oxidation. Under conditions where there is a lack of Zn, O_2 production is significantly increased resulting in increased permeability of the plasma membrane while O_2 free radicals destroy the bonds of polyunsaturated fatty acids and phospholipids causing loss of sugars, amino acids, and potassium. With the constant increase in the oxidation of lipids in the leaves, there is the destruction of chlorophyll, necrosis, and stunted growth [14,17].

3.2 Symptoms of Zinc Deficiency in Plants

Zn is the micronutrient that is most often associated with a deficiency in tropical soil crops, so plants under these conditions suffer drastic effects on enzymatic activity, chloroplast development, protein, and nucleic acid content. Zn deficiency is less frequent in annual crops, being more felt in multiannual crops [3].

Due to its functions in protein synthesis, carbohydrate and auxin metabolism, factors that directly control plant growth, Zn deficiency has very characteristic symptoms. Plants lacking this nutrient have short internodes and a reduction in leaf area, leading to a reduction in their size and rosette appearance (Fig. 1A), there may also be chlorosis (Fig. 1B) which in more extreme cases evolves to necrosis (Fig. 1C) [10].

3.3 Symptoms of Zinc Toxidity in Plants

Zn toxicity is commonly observed in plants grown in soil where there are high pH values because in these cases there is intense immobilization of Zn. However, it is also possible to observe Zn toxicity in acidic soils or in soils where the parent material is rocked rich in this nutrient, in addition, there may be contamination with Zn from industrial sources or the application of organic waste. Plants with Zn toxicity have leaves with red pigmentation on the petiole and veins (Fig. 2), in addition to chlorosis due to low Fe concentration, since the excess of Zn prevents the reduction of Fe and its transport in the plant [3].

3.4 Plant Defense Mechanisms

Because Zn maintains the structure and integrity of the membrane, in addition to controlling its permeability by removing superoxide radicals (O_2), this nutrient protects plants against attack by various pathogens. In plants where there is Zn deficiency, due to membrane permeability, carbohydrates and amino acids are released, which ends up attracting pathogens and insects to the roots and shoots [15].

(A) (B) (C)

Fig. 1. Zinc (Zn) deficiency symptoms. A) Rosette appearance; B) Leaves with chlorosis; C) Leaves with necrosis

Source: Giracca; Nunes [18]

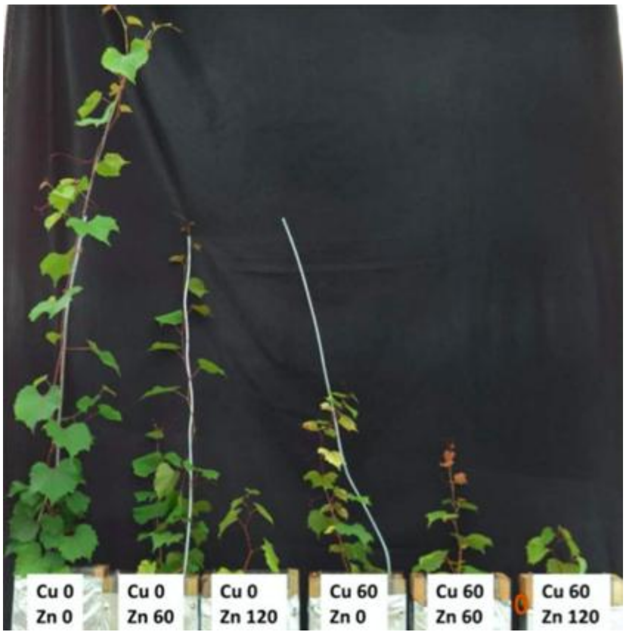

Fig. 2. Zinc (Zn) and Copper (Cu) toxicity symptoms in grape seedlings
Source: Ambrosini et al. [19]

4. CONCLUSION

Zinc (Zn) is an essential nutrient for plants. Concerning this nutrient, the following factors must be taken into account:

- Zn is absorbed by roots mainly in the divalent form (Zn^{2+}).
- The availability of Zn depends on the pH value of the soil, values above 7 can considerably reduce its availability.
- Diffusion is the main mechanism for supplying Zn to plants, as they generally have a greater demand for Zn^{2+} concentrations in the soil.
- Absorbed Zn is transported through xylem pathways, and its mobility and redistribution within the plant are defined as immobile or with intermediate mobility.
- The requirement of Zn is very important for the activity of several enzymes such as carbonic anhydrase, superoxide dismutase enzyme, and RNA polymer, in addition to being part of indoleacetic acid metabolism.
- Symptoms of Zn deficiency in plants promote short internodes, reduced leaf area, reduced size, rosette appearance, chlorosis, and necrosis.
- Plants with Zn toxicity have leaves with red pigmentation on the petiole and veins, in addition to chlorosis due to low concentration of iron (Fe).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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