



# Essential Key Points for Zinc Biofortification - Uptake, Translocation and Accumulation in Higher Plants



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## Abstract

Owing to continuous development of knowledge, to understand the mechanisms underlying the bio fortification with Zn in plants, a synoptical overview of this metal uptake, translocation and accumulation in plant organs are assessed. In this context, the mechanisms of bio fortification of plants with zinc are additionally correlated with soil interacting factors, namely pH and moisture.

**Keywords:** Zn bio fortification; Zn accumulation; Zn deposition within organs; Zn translocation; Zn uptake

## Zinc Accumulation

The amounts of Zn in unpolluted soils typically are below 125ppm [1-3] with the bioavailability of this metal in soil solution increasing at low pH and the organic ligands and hardness cations such as Ca<sup>2+</sup> decreasing its availability [4]. In this context, plant species differ in both their Zn requirements and tolerance [5,6]. Most plants require leaf Zn concentrations greater than 0.02-0.04mg g<sup>-1</sup><sub>dw</sub>, whereas their growth is inhibited at leaf Zn concentrations greater than 0.1-0.77 mg g<sup>-1</sup><sub>dw</sub> [6-8].

The threshold of toxicity is mostly determined by environmental pollution following industrial and agricultural activities, such as smelter and incinerator emissions, dispersal from mine wastes, excessive applications of Zn-containing fertilizers or pesticides and use of Zn-contaminated sewage sludges, manures or industrial wastes as fertilizers [4,9]. Nevertheless, in this case about 15-20 species (mostly belonging to the Brassicaceae) can hyper accumulate about 3000 mg Zn kg<sup>-1</sup><sub>dw</sub> [5,10-13], since can tolerate more Zn in their tissues and even require greater leaf Zn concentrations for optimal growth [5,13,14].

In the roots, Zn prevails in the elongation zone, being concentrated in endo dermal cells of dicotyledonous species

and in the pericycle of monocotyledonous species [15]. In Zn-hyper accumulator plants more than 30% of this metal is usually associated with cell walls, and much of the remainder is complexed with histidine [16,17].

Zn accumulation within shoots, although varying between plant species, accumulates in the leaf epidermal cells, with the exception of guard cells, particularly in older leaves [15,18-22], and trichomes [22-24]. In Zn-hyperaccumulator plants, 20-50% of Zn<sup>2+</sup> is chelated with vacuolar carboxylic acids, such as citrate, malate, and oxalate, whereas up to 45% can also be associated with histidine, and the remainder is largely bound to phosphate-groups and cell-wall components [16,17,20,25,26]. In the cereal grains, Zn accumulates in the aleurone and scutellum of the embryo, and, at a lower level in the endosperm [27-39].

## Zinc Uptake and Translocation

Metals availability for plant uptake is driven by complex interactions between the chemical properties of cations, the composition and physicochemical properties of the soil, microbial activity and plant roots [40]. In this context, Zn uptake, although depending of the composition in the growth media, follows a

linear pattern with its concentration in the nutrient solution or in the soils [41-43], occurring its mobilization to the roots xylem through the symplast and apoplast in regions of the root lacking a Casparian Band, to the stele where it enters the xylem [5,8]. Nevertheless, inconsistent studies about kinetics uptake of Zn report the occurrence of active and passive mechanism [44-47], although being recognized that its mobility in the xylem fluids is highly due to its bind to light organic compounds [48].

Transport of bio available Zn<sup>2+</sup> across the plasma membrane is the initial step of the uptake and accumulation kinetics, but cellular transition metal uptake systems seem to operate as uni porters or secondary carriers driven by protons, further implicating channel proteins. Some channels might let the passage of ions based solely on their positive or negative charge, whereas groupings of ion channels regulate the passage through the pore and can open or close by chemical or electrical signals and temperature. Additionally, non selective cation channels further have the capacity to catalyze passive fluxes of cations, namely Zn<sup>2+</sup>, through plant membranes [49]. Long-distance transport of Zn to the shoot, involves symplastic diffusion between interconnected root cells towards the stele and active loading across the plasma membrane of the xylem parenchyma into the apoplastic xylem [50]. Paralleling this xylem loading, the translocation rate of Zn from roots further depends of Zn accessibility and mobilization from vacuoles of the roots and a subsequent passage across the endodermis, where nicotinamine acts as a Zn ligand [51]. Within xylem sap, long-distance transport further implicates chelation by mobile low-molecular-weight ligands present in the xylem sap [52-54]. Zn<sup>2+</sup> destined for the developing seed leave the xylem, follows an active loading kinetics into the phloem [55,56] and, therefore, this metal ions are likely to form complexes with YSL proteins transport metal-nicotinamine complexes [57]. Through symplastic efflux from the phloem and plasma membrane influx Zn reaches the embryo and the endosperm of the seed [55].

### Bio Fortification with Zinc

The bio fortification of plants with Zn is dependent on the size of plant-available Zn pools in soil. Additionally, transport of Zn to root surface in soils occurs predominantly via diffusion [58], being this process is highly sensitive to soil pH and moisture. Among the soil chemical factors, soil pH plays the most important role in Zn solubility in soil solution. In a pH range between 5.5 and 7.0, Zn concentration in soil solution is decreased by 30 to 45-fold for each unit increase in soil pH, thus increasing a risk for development of Zn deficiency in plants [59]. Increasing soil pH stimulates adsorption of Zn to soil constituents and reduces the desorption of the adsorbed Zn. At pH 5.0 the concentration of Zn<sup>2+</sup> in soil solution is sufficiently high, about 6.5mg kg<sup>-1</sup>. When soil pH increased from 5 to 8, concentration of soil solution Zn<sup>2+</sup> is reduced 1,000 times and becomes approx. 0.007mg kg<sup>-1</sup>. Thus, an increase in soil pH is associated with strong decreases in the concentrations of Zn in plant tissues [60,61].

The role of soil moisture is very critical for an adequate Zn diffusion to plant roots in soils with low Zn availability [61,62], whereas the soil organic matter plays a critical role in solubility and transport of Zn to plant roots [61,63-65]. Accordingly, the pool of readily available Zn to plant roots may be extremely low in soils with high pH and reduced levels of organic matter and soil moisture.

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