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Bio-availability of Zinc in Crops for Ensuring Nutrition

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INTRODUCTION

About seventy per cent of the undernourished people at the global level live in Asia, predominantly in India and China. According to WHO Report published in 2002, Zn deficiency was the fifth most important risk factor responsible for illness and death in the developing world. The problem with Zn deficiency has been more intensified with the increased cultivation of high-yielding cultivars of the 'Green Revolution' cereals whose grains contain low concentrations of Zn. Antinutrient and some substances called promoter has a negative and positive effect for bio-accumulation of Zn in plant harvest. Agronomic strategies, viz. method and time of Zn application are more effective for enhancing grain Zn concentration. Under Zn-deficient soil, appreciable concentrations of Zn in harvest could be obtained by a combined soil and foliar application of Zn. So, identification of field crop deficiency of Zn and its right estimation for extent of deficiency in soils followed by proper agronomic intervention may ensure a sustainable nutrient management system for crop production, and necessary correction of Zn deficiency in soil-crop-human chain. Very low concentrations and poor bioavailability of Zn in the commonly consumed foods seem to be the main reason for widespread occurrence of Zn deficiency in human populations. Cereal-based foods are most commonly consumed foods and, contribute up to 75% of the daily calorie intake in the rural parts of the developing countries. Usual, breeding of new cereal genotypes with high genetic capacity for grain accumulation of Zn is widely accepted and most sustainable solution to the problem. There are impressive progresses in breeding new genotypes for high Zn density. However, the breeding approach is a long-term process and may be affected from very low chemical solubility of Zn in soils due to high pH and low organic matter. Agronomy-related approaches offer short-term and complementary solutions to the Zn deficiency for crop production.

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Soil amendments contributing to solubility of Zn in soil solution, and soil and foliar application of Zn-containing fertilizers are well-documented agronomic tools which contribute to root uptake, shoot and grain accumulation of Zn. So, fertilization strategy is a simple and effective agronomic practice to contribute grain concentrations of micronutrients such as Zn. Increasing number of evidence is available showing that soil and especially foliar application of Zn fertilizers results in impressive enhancements in grain Zn concentration. Recently published results indicate that foliar application of ZnSO4 at later growth stages seems to be more effective for enhancing grain Zn concentration. Agronomic practices mentioned are simple and easily applicable in many target countries with high incidence of Zn deficiency. Combination of agronomic practices with breeding approach will ensure the plants to maximize grain accumulation of Zn.

Zinc deficiencies are well-documented public health issue affecting nearly half of the world population. Developing countries are among the worst affected from Zn deficiencies which result in number of serious health complications, such as impairments in brain function and mental development. Recent reports indicate that Zn deficiency is responsible for death of nearly 450000 children annually under 5-years old. Animals also suffer from Zn malnutrition. Major health consequences of Zn deficiencies include retardation of growth, anaemia and impaired immune functions, diminished intellectual development and retarded sexual maturation.

Why Zn Biofortification

Zinc biofortification in the soil—plant system can be defined as increasing the density and its bioavailability in the edible parts of crop plants through both plant biotechnology and nutritional management of the soil—plant system with the aim of improving human nutrition and health. From an ecological point of view, such an approach is more sustainable as it involves an adjustment of the flow of micronutrients from soils to humans in order to secure better ecological cycling and environmental effects. The quality of the plant products is also critical for enhancing Zn balance in the soil—plant—animal—human food chain. Soil—plant system is instrumental to human nutrition based on the 'food chain', and improvements in this system resulting in better nutrient cycling will contribute towards a better ecological environment. Enhancements in concentration of micronutrients, especially Zn, also result in several positive consequences for crop production, such as improvements in seedling vigour, pathogen resistance, and competition against weeds and, finally, an enhanced yield.

Extent of Zn Deficiency

In modern agriculture all micronutrients are becoming deficient day by day due to follow of intensive cultivation with high yielding varieties of crops using high analysis fertilizers which not only reduces the crop productivity but also deteriorate the quality of produce. The problem further has been intensified with the heavy and monotonous consumption of cereal-based foods with low concentrations and reduced bioavailability of Zn to humans in developing countries. Recent reports indicated that nearly half of the world soils are deficient in available plant Zn. Rice and wheat are two major staple foods in India, contributing 73 and 62% of the daily calorie intake in the rural and urban regions of the country. Generally, the regions in the world with Zn-deficient soils are also characterized by its widespread deficiency in humans. Cereal crops which are inherently very low in grain Zn concentrations, particularly when grown on high pH calcareous soils become deficient in this micronutrient cation. Zn deficiency is widespread throughout the world particularly in lowland rice fields causing decreased crop yields and nutritional quality of the produce.

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Soil Properties Influencing Zn Availability in Soil and Crops

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. Increasing soil pH stimulates adsorption of Zn to soil constituents (e.g. metal oxides, clay minerals) and reduces the desorption of the adsorbed Zn: Soil organic matter plays a critical role in solubility and transport of Zn to plant roots. There is a strong inverse relationship between the contents of soil organic matter and soluble Zn concentrations in the rhizosphere. The extent of Zn deficiency is largely influenced by presence of calcareousness in soil.

Factors Affecting Zn Bioavailability in Crops for Human Nutrition

The bioavailability of Zn in grains, such as phytate to Zn molar ratios or the phytate and/or Ca to Zn ratio, has also been found to vary greatly among different crop species and genotypes. The edible parts of a plant contain various amounts of antinutrients (Table 1), with the amounts being dependent on both genetic and environmental factors that can reduce the bioavailability of dietary Zn. Phytic acid, which is widespread in plants, can fix Zn in plants, making it hard to digest and absorb and, consequently, decreasing its bioavailability. Reducing the level of antinutrients in the edible parts of crops, such as reducing the level of phytic acid by modifying the phytase activity and/or decreasing the concentration of phytin in the edible plant parts, can increase Zn bioavailability. On the other hand, plants also contain substances, mostly metabolic products that promote the bioavailability of Zn. Slight improvements in the concentration of these metabolic products would greatly increase the bioavailability of Zn.

Fertilization for Enhancement in Productivity

Fertilizer strategy could be a rapid solution to the problem and can be considered an important complementary approach to the on-going breeding programs. For this purpose, Zn can be directly applied to soil as both organic and inorganic compounds. Zinc sulfate is the most widely applied inorganic source of Zn due to its high solubility and low cost. Zn can also be applied to soils in the form of ZnO, Zn-EDTA and Zn-oxysulfate. The agronomic effectiveness (e.g. magnitude of the crop response per unit applied micronutrient) of Zn fertilizers is higher with Zn-EDTA than the inorganic Zn fertilizer (such as ZnSO4). However, due to its high cost, use, of Zn-EDTA in cereal farming is limited. Good responses to Zn fertilization have been reported for a number of crops including rice and wheat. Zn fertilization is now recommended for most regions of the country. Further, Zn application to soil as Zinc sulphate or Zn enriched/ coated urea not only increased yield (Table 2) but also Zn concentration in rice and wheat grain. Zn deficiency in wheat can easily be corrected, and yield maximized by broadcast application of Zn fertilizers; however, broadcast application of Zn is not very effective in increasing Zn concentrations in grains up to desired levels to meet human requirements. Enhancing Zn Concentrations at Harvest Increasing the concentrations of Zn in cereal grains is a high priority research task. One important strategy to increase Zn concentrations in grains is fertilization of plants via soils or foliar applications. Depending on the plant species, basal application of Zn to soil can increase Zn concentration of plants by as much as 2-3 fold. However, even with very high Zn fertilization rates, the Zn concentration in wheat grain does not show correspondingly high increases from Zn fertilization. Under Zn-deficient soil conditions, the highest concentrations of Zn in grain could be obtained by a combined soil and foliar application of Zn (Table 3). However, if this type of fertilization schedule improves crop yields as well as nutritional quality of the produce, farmers would be likely to adopt such practices (Table 4).

Problems in Alleviating Zn Deficiencies

• Difficulty in the identification of field crop deficiency symptoms.

• Variation in soil Zn status, soil pH, rainfall duration and intensity, and seasonal fluctuations in the groundwater levels and temperature regimes in the region.

• Inadequate facilities and field tests to validate critical levels of soil and plant micronutrients in the region.

Summary

Plant nutrition-based research activities are indispensable in meeting food security needs. The fact that at least 60% of the presently cultivated soils globally are deficient in Zn, makes plant nutrition-based research a major promising research area needed to meet the demand for massive increases in food production required for the growing world population. One of the high priority objectives of plant-nutrition research will be ensuring a long-term sustainable nutrient management system for crop production, and developing more efficient mineral nutrient uptake by crop plants and improving intra- and intercellular use of nutrients without detrimentally affecting the environment. More research activities are, therefore, needed aiming at improving the bioavailable levels of Zn in cereal grains.

Table 1. Important anti-nutrient and promoter to reduce vs. promote Zn bioavailability

Anti-nutrient	Major dietary source	Promoter substances	Major dietary source
Phytic acid or phytin	Whole legume seeds and cereal grains	Certain organic acids	Fresh fruits and vegetables
Fiber (cellulose, hemicellulose and lignin)	Whole cereal grain products	Certain amino acids	Animal meats
Tannins and polyphenolics	Tea, coffee, beans, sorghum etc.	Long-chain fatty acids	Human breast milk
Hemagglutinins (e.g. lectins)	Most legumes and wheat	Beta carotene	Green and yellow vegetables
Heavy metals	Plant foods obtained from crops grown on metal polluted soils		

Table 2. Grain yield (q/ha) of rice as affected by different methods of Zn fertilizer application (from Saha et al., 2014)

Cultivars	No Zn	Soil applied	Soil + Zn Foliar Zn
HYV	35.3	42.8	45.2
Hybrid	28.7	37.1	39.5
Local	10.8	14.2	14.8
Aromatic	22.7	26.5	27.7
Mean	30.7	37.5	39.5

Table 3. Effect of modes of Zn fertilization on Zn content in edible plant parts (mg/kg)

Zn content in brown rice (from Saha et al., 2014)					Zn content in bread wheat (from Yilmaz et al., 1997)		
Methods	HYV	Hybrid	Local	Aromatic	Methods	Gerek-79	Kunduru-1149
No Zn applied	29.3	25.9	29.0	32.0	No Zn applied	9	12
Soil Zn	33.8	36.2	33.7	35.8	Soil Zn	17	19
Foliar Zn	42.2	47.5	45.6	39.1	Foliar Zn	30	20
Soil + Foliar Zn	56.7	61.8	57.8	55.0	Soil + Foliar Zn	34	35

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Table 4. Some agronomic prescriptions for correcting Zn deficiency

Cakmak (2008)	Ali and Venkatesh (2009)	Saha of al. (2014)
An increase in grain Zn concentration in bread wheat was found with the soil plus foliar application method that result in about 3.5 fold increase in the grain Zn concentration.	Application of 10-25 kg ZnSO4.7H20/ha was found optimum for increasing pulse productivity.	Soil plus foliar application of Zn was very effective than alone soil application. Two foliar spraying of Zn (@ 0.5% ZnSO4.7H20) along with basal application (@ 20 kg Zn/ha) increased the rice grain Zn content to the level of two to three times.