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A review- Zinc role in crop production

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Abstract

Zinc play vital role as micronutrient in growth and development of crop and significantly increase yield. Zinc plays special role in the physiological functions of plants and nowadays its deficiency is common in soil, especially in high phosphorus soil and also in all crops. Zinc deficiency affects plant by retarding its growth, chlorosis, spikelet sterility, decreasing number of bolls, tillers and increase crop maturity period. Plants take Zinc in zn^{+2} form and work as a structural component or regulatory co factor for a wide range of different enzymes and proteins in many biochemical pathways and are mostly concerned with protein metabolism, carbohydrate metabolism, auxin metabolism, pollen formation, photosynthesis, sugar to starch conversion, maintenance of biological membranes and resistance to infection by certain pathogens. High pH and calcareous soil with high phosphorus intake mostly face zinc deficiency. Soils with zinc deficiency can be easily treated with zinc fertilizers to provide an adequate supply of zinc to crop. Zinc deficiency in humans and cereal grains can be increased through fortification or bio fortification.

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Introduction

Micronutrients in soil nutrition are the pillar of agriculture in developed countries. The most important factor for improving the quality and quantity of plants product is proper plant nutrition (Alloway 2002; Mousavi 2011; Yosefi *et al.*, 2011). Zinc has vital in many physiological processes of plant (Van Assche and Clijsters 1986; Baker and Brooks 1989; Ali *et al.*, 1999; Cakmak and Engels 1999; Ali *et al.*, 2000; Reeves and Baker 2000; Cakmak 2000; Doncheva *et al.*, 2001; Stoyanova and Doncheva 2002; Alloway 2002; Di Baccio *et al.*, 2005; Yosefi *et al.*, 2011; Mousavi 2011).

Zinc is also involved in enzyme activation and in many metabolic processes (Vallee and Auld 1990; Brian 2008) such as membrane integrity (Welch *et al.,* 1982; Cakmak and Marschner 1988), trypto-phan biosynthesis (Oosterhuis *et al.*, 1991) protein synthesis (Kitagishi *et al.*, 1987), photosynthate mobilization (Glass 1989), nitrogen (N), phosphorus (P) and potassium (K) uptake and metabolism (Li *et al.*, 1991). Zinc is responsible for the proper function of mitochondria (Sekler *et al.*, 2007) and is the component of plant enzyme carbonic anhydrase (Tobin 1970) which is located in cytoplasm and chloroplast of C3 plants (OHKI 1976).

Zinc deficiency decrease net photosynthesis from 0 to 70% depends on plant species and level of deficiency (Seethambarm and Das 1985; Pandey and Sharma 1989; Shrotri *et al.*, 1989; Hu and Sparks 1991; Brown *et al.*, 1993). Plant tissues with low zinc is the indication of both soil and genetic related factors (Brian 2008). Zinc deficiency ranks 5^{th} among 10 leading risk factors in developing countries while it ranks 11^{th} among 20 leading risk factors at global level including both developed and developing countries. According to an estimate zinc deficiency affects one third of the world population (World Health Organization 2002).

Around 30% of world human population have zinc deficient diet which affects the physical growth, reproductive health, immune system and neuro behavioral development of humans. Therefore zinc content in staple foods is of great importance. The field of plant food biofortification with zinc is developing rapidly which Involves the breeding of crops new varieties with the potential to accumulate high density of zinc in cereal grains. While zinc fertilizers is also used to increase zinc density which is called agronomic biofortification (Brian 2008). Most humans and plants in today's world are affected by hidden hunger of zinc. This review highlights the importance of zinc in humans and plants and how to deal with it to keep humans and plants on safe side from hidden hunger and increase crop production.

Role of zinc in humans

Micronutrients malnutrition is also called "Hidden Hunger". World 50% population is affected by hidden hunger especially women and children's (Welch and Graham 2004). Three micronutrients deficiencies was recognized in humans all over the world including vitamin A, iron and iodine (Bell 2008) but now zinc deficiency is also increasing and cause serious problems to humans. Zinc plays important role in humans and involved in different cellular functions of the body. Zinc insufficiency is the cause of pneumonia and diarrhea in children's (Black *et al.* 2008). Stunted growth in children's is also due to zinc deficiency and about 61 million children's below the age of 15 are reported stunted (Brown *et al.,* 2004). Zinc play role in formation of blood, healing of wounds, production of protein, maintenance of tissues and growth (Dhaliwal *et al.*, 2010). Zn deficiency affects on human health include decrease of nerve conduction, neuro psychiatric disorders, neuro sensory disorder, mental lethargy, thymic arthropy, skin lesions, acrodermatitis, infertility and hypogonadism (Plum *et al.*, 2010). Daily zinc requirement of a normal male is 11mg and normal female is 9mg while during pregnancy and lactation the need increases to 13-14mg. Daily Zn requirement is 3mg for children's from 6 months to 3 years, 5 mg for 4 -8 years and 8 mg for 9-13 years (FAO/WHO 2002; Hotz and Brown 2004). Meat, cereals, pulses and legumes have more concentration of zinc 25-50mg/kg and is a good source of zinc for human while fish, tubers, roots, green leafy vegetables and fruits have less than 10mg/kg of zinc and can be used as modest source of zinc by humans (FAO/WHO 2002).

Zinc Deficiency

Zinc deficiency can be found in almost every part of the world and mostly crops respond positively to Zn application (Welch and Shuman 1995). By plant leaves analysis and soil testing we can identified the zinc deficiency and then by comparing the result with the critical level of zinc in that soil we made decision that either zinc fertilizer is required or not (Brian 2008). Reduction in crop yield and nutritional quality of grain is associated with zinc deficiency (Graham and Welch 2002). Pollen grains viability and development is also adversely affected by deficiency of zinc because it play important role in the formation of growing sink organs (Sharma *et al.*, 1990). Deficiency of zinc also increases in cold and wet weather condition may be due to reduction of microorganism activity, slow release of zinc from organic material and root growth limitation in cool soil (Trehan and Sekhon 1977; Alam *et al.*, 2010; Soaud *et al.*, 2011). According to Food and Agriculture Organization about 30% of the world cultivatable soil contain low level of plant available zinc (Sillanpaa M 1990). Generally Sandy soil, saline and sodic soil, calcareous soil, strongly weathered deep tropical soil, waterlogged soil, vertisols and gleysols have more chances of zinc deficiency (Brian 2008). Soil with low zinc content, Soil with low organic matter, soil with restricted root zone, calcareous soil, cool soil temperature, microbialy inactivated zinc, high level of available phosphorus, nitrogen effect, plant species and varieties are also some factors which affect zinc availability and leads to deficiency (Lindsay 1972). High pH, organic matter, high content of $CaCO_3$, Clay and phosphate fix zinc in soil and gave rise to deficiency of zinc by reducing the available zinc (Imtiaz 1999). Plant inclination to injury by high temperature, quality of harvested products and fungal diseases are also affected by Zn deficiency (Marschner 1995; Cakmak 2000). Today about 50% of soil with wheat cultivation have low level of available zinc (Cakmak and Kutman 2018)

Zinc Deficiency symptoms

Zinc deficiency has multiple symptoms which vary from plant to plant. The most common types of deficiency symptoms are chlorosis, bronzing of leaves, retarded growth of plant, necrotic spots on leaves, leaves resetting, dwarf leaves and malformed leaves (Brian 2008). Both new and old leaves shows the deficiency of zinc while iron, manganese, copper and sulfur deficiency symptoms are found on new leaves only. The macronutrients NPK, magnesium and molybdenum shows deficiency symptoms on older leaves (Reddy and Reddi 1997). In rice after 2-3 weeks of seedling transplantation brown spots appears on older leaves which affect the growth and plant remain stunted or die, while those plants which recover their growth shows decrease in yield with late maturity (Yoshida and Tanaka 1969; Van Breemen *et al.*, 1980; HU and RS 1994; Marschner 1995; Reddy and Reddi 1997).

Role of Zinc in Plant production

Zinc as micronutrient is involved in several physiological function of plants and its unbalance supply reduce yield (Hafeez *et al.*, 2013). Zinc is also the major component for protein production and ribosome development in plant. It shows impact on pollen tube formation and thus contribute to pollination (SL *et al.*, 1984; Marschner 1995; Outten and TV 2001; Pandey *et al.*, 2006). Plant production is related to photosynthesis and chlorophyll content (Gitelson *et al.*, 2003) which reduce with much higher dose of zinc while increase with addition of low concentration of zinc (Sharma *et al.*, 2010). Zinc is the main building component of some enzymes like carbonic anhydrase, alcohol dehydrogenase and activates many enzymatic reactions as a catalyst (Pedler *et al.*, 2000). Carbonic anhydrase enzyme activity location is chloroplast and its smooth activity depends on zinc level in the plant (Marschner 1995). Zinc also play role in metabolism of plant hormones like Auxin, tryptophan (Pedler *et al.,* 2000; Brennan 2005), biosynthesis of indole acetic acid (IAA) and gibberellins, metabolism and uptake of nitrogen, chlorophyll synthesis and photosynthesis, resistance to biotic and abiotic stresses (Brian 2008; Cakmak 2008; Mousavi 2011).

Zinc have a role in the RNA polymerase and protein synthesis enzyme activity, which increases seed protein content by increasing the activity of these enzymes with the application of zinc (Sangwan and Raj 2004; Rahman *et al.*, 2008; Akhtar *et al.*, 2009; Alam *et al.,* 2010). Zinc increases the efficiency with which the plant use water for dry matter production and help the plant to respond water stress through osmotic adjustment (Khan *et al.*, 2005). Zinc application have significant role in the increase of growth, yield and quality of different plants like wheat, cotton, maize, rice and chick pea (Bukvi *et al.*, 2003; Kinaci and Kinaci 2005; Efe and Yarpuz 2011; Xi-wen *et al.*, 2011; Yosefi *et al.,*2011). Zn play important role in enzyme activation which are involved in photosynthesis, cell elongation, carbohydrate metabolism, pollen formation, cell division, auxin and protein synthesis (Marschner 1995; Cakmak 2008)

Zinc Toxicity

Zinc is dangerous for plant both in low concentration and excess and affect plant growth (Brian 2008). Growth and development of plant is affected by zinc toxicity and decrease leaf and root growth, plant biomass as well as decrease production of NADPH in chloroplast with increase in concentration of zinc (Basha and Selvaraju 2015). Zn toxicity decrease photosystem II and activity of RUBP caboxylase enzyme. Zn toxicity also decreases photosynthesis by reducing chloroplast activity and ATP synthesis.

Interaction of Zn with Nitrogen

Nitrogen is the primary macronutrient and is important for plant growth and development. Nitrogen affects zinc status of crop and change the pH of root environment. Mostly crop respond positively to nitrogen and zinc interaction but not to Zn alone (Kirk and Bajita 1995).

According to agriculture experts Zn play role in plant basic processes of photosynthesis, carbon anhydrase activity, uptake and metabolism of nitrogen, chlorophyll synthesis, resistance to biotic and abiotic stresses and many more (Brian 2008; Cakmak 2008; Potarzycki and Grzebisz 2009). Nitrogen nutritional status of plant has positive effect on zinc concentration in grain. In case of wheat when zinc concentration is high in soil and plant tissues, so application of nitrogen to soil enhance zinc concentration in grain (Kutman *et al.*, 2010).

Interaction with phosphorus

Phosphorus is second important element for plant growth and it affect zinc uptake (Mousavi 2011). With increase of phosphorus in soil zinc uptake by plant decreases (Das *et al.*, 2005; Salimpour *et al.*, 2010). High level of phosphorus in soil is the common cause of Zn deficiency in plants all over the world (Brian 2008). According to (Streeter *et al.*, 2001) phosphorus zinc have two types of interaction; one in which the increase in phosphorus application decrease Zn concentration in shoot while in other the increase in phosphorus application do not decrease Zn concentration in shoot. Phosphorus reduces Zn absorption from soil by four possible mechanisms: 1) Phosphorus enhances Zn adsorption onto soil constituents. (2) Hydrogen ions generated by phosphate salts slow down absorption of Zn from solution. (3) Absorption of zinc from solution is reduced by cations added with phosphate salts (4) Infection of roots by Arbuscular mycorrhizae is suppressed by high concentration of phosphorus (Brian 2008). According to (Loneragan and Webb 1993) Zn deficiency increase phosphorus toxicity in plant shoots of clover, potato, okra, wheat and cotton.

The reasons for high levels of phosphorus on Zn deficiency is following (Stukenholtz *et al.*, 1966; Gobarah *et al.*, 2006) :

a) High concentration of phosphorus reduces Zn movement from plant roots to shoot and thus plant roots decrease uptake of Zn.
b) Zn uptake increases in plant with increase in plant growth but its concentration decreases in plant tissues (dilution effect)
c) Metabolism in plant cell is affected by imbalance of Zn and phosphorus, so Zn tasks impaired at specific positions in cells with increase in phosphorus concentration.

Zinc fertilizers

Deficiency of nutrients affects the plant growth and yield. The easiest way to deal with that deficiency is the application of fertilizers. Fertilizer is that substance which contains one or more recognized plant nutrients and is used to enhance plant growth. Proper management and fertilizer are used to deal with nutrient deficiency. Zinc application can be done either to soil, leaves and seeds (Johnson *et al.*, 2005). Soil analysis is used to diagnose plant nutrient deficiency and to take action to stop crop from yield reduction (Alloway 2002; Mousavi 2011). Zn deficiency is related to soil pH and calcareous soil with high pH have very low concentration of Zn (Brian 2008; Alam *et al.*, 2010).According to (Brian 2008) three types of compounds are used as Zn fertilizers which are different in Zn content, price and response to crop in different type of soils. These Zn sources include;

(1) Inorganic compounds which include zinc oxide, zinc carbonate, zinc sulphate, zinc nitrate and zinc chloride (ZnO, ZnCO3), ZnSO4, Zn(NO3)2, ZnCL2) (Table 1). The most common source of Zn used all over the world is zinc sulphate (ZnSO4) available in the form of monohydrate and heptahydrate.

(2) Natural organic compounds which includes complexes that are manufactured by reacting Zn salts with citrates but are less effective and are cheaper than synthetic chelates (Table 1).

(3) Synthetic chelates are manufactured by combining chelating agent (i.e: Ethylene Diamine Tetra acetic acid) with a metal ion which results unique type of micronutrient and the strength of metal chelate make the metal available to the plant. Different zinc fertilizers and response of different crops to Zn presented are in Fig. 1 (Brian 2008).

Table 1. Different types of Zn fertilizers.

Compound	Formula	Zinc Content (%)
Inorganic compounds		
Zinc sulphate monohydrate	$ZnSO_4.H_2O$	36
Zinc sulphate heptahydrate	$ZnSO_4.7H_2O$	22
Zinc oxysulphate	$xZnSO_4.xZnO$	20-50
Basic zinc sulphate	$ZnSO_4.4Zn(OH)_2$	55
Zinc oxide	ZnO	50-80
Zinc carbonate	$ZnCO_3$	50-56
Zinc nitrate	$Zn(NO_3)_2.3H_2O$	23
Zinc phosphate	$Zn3(PO_4)_2$	50
Zinc frits	Fritted glass	10 -30
Ammoniated zinc sulphate solution	$Zn(NH_3)4SO_4$	10
Organic Compounds		
Disodium zinc EDTA	Na_2 Zn EDTA	8-14
Sodium zinc HEDTA	Na Zn HEDTA	6-10
Sodium zinc EDTA	Na Zn EDTA	9-13
Zinc polyflavonoid	-	5-10
Zinc lingo sulfonate	-	5-8

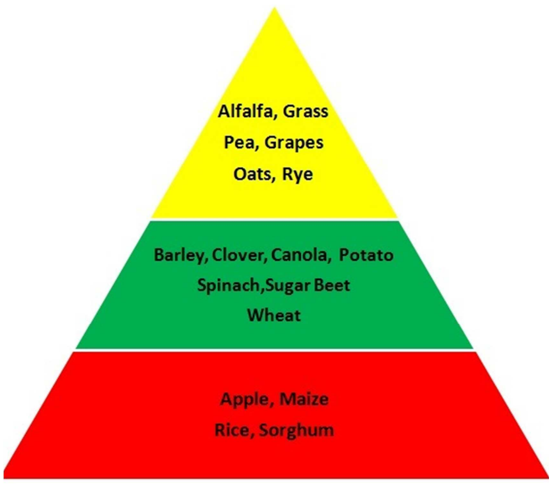

Fig 1. Different Crops response to Zn.

Biofortification of cereals

Fortification is the practice of increasing micronutrients like vitamins and minerals in food to improve nutritional quality of food to benefit humans health while biofortification is the process in which nutritional quality of crops is enhanced through plant breeding, agronomic practices or biotechnology (World Health Organization 2019). Zinc deficiency in humans and plants can be decreased with food fortification or with bio fortification. Both genetic and agronomic bio fortification can be used to deal with zinc deficiency. Genetic bio fortification will take more time while the shortest and quick action can be taken only through agronomic bio fortification, which is also called ferti-fortification (Prasad 2010). Agronomic bio fortification can increase grain yield of the crop and also zinc percentage in grains which help in decrease of zinc deficiency in humans. In agronomic bio fortification mostly zinc enriched urea and other zinc enriched fertilizers are used. Application of zinc increase concentration of zinc in grain of rice by 141% and 73% in maize (Hossain *et al.*, 2008). Foliar application of zinc sulphate (0.5% solution) also increase zinc concentration in grain (Dhaliwal *et al.*, 2010). According to (Cakmak and Kutman 2018) bio fortification through zinc fertilizer application is an effective way because along with increasing zinc concentration in grain, it also increase yield of the crop. Agronomic bio fortification increase zinc concentration in crops and decrease the risk of malnutrition and chronic diseases in children's which is caused due to zinc deficiency (Domingos *et al.*, 2016).

Conclusion

From our review it is concluded that zinc is necessary nutrient for growth and development of plant and its deficiency affects production of crop which further affect human's health. Its deficiency can be treated with foliar application and soil fertilizer application. While fortification and biofortification strategies are also applied to compete with deficiency of zinc and improve plant growth and human health.

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