Review Article **Asian J Agri Biol, 2016, 4(4): 140-152.**

ZINC BIOFORTIFICATION OF CEREALS THROUGH FERTILIZERS: RECENT ADVANCES AND FUTURE PERSPECTIVES

Qudsia Nazir[1], Azhar Hussain[2*], Muhammad Imran[3], Sajid Mahmood[4], Maqshoof Ahmad[2] and Muhammad Mazhar Iqbal[5]

[1]Provincial Reference Fertilizer Testing Laboratory, Lahore, Department of Agriculture, Government of Punjab-Pakistan. [2]Department of Soil Science, University College of Agriculture & Environmental Sciences, The Islamia University of Bahawalpur, Pakistan. [3]Department of Soil Science, Muhammad Nawaz Shareef University of Agriculture, Multan, Pakistan. [4]Department of Arid Land Agriculture, King Abdulaziz University, Jeddah-80208, Saudi Arabia. [5]Soil and Water Testing Laboratory for Research, Chiniot, Department of Agriculture, Government of Punjab-Pakistan.

ABSTRACT

Zinc (Zn) is a micronutrient, essentially required by plants, animals and humans. Zn deficiency in humans due to the consumption of food with inadequate Zn content is of global concern. Approximately, one third of poor world's population is at high risk of Zn deficiency due to its reliance on cereals for daily caloric requirements. The cereals, generally grown on calcareous soils have low grain Zn. The major reason of lower Zn content in cereals is poor Zn bioavailability induced by various soil and/or crop management factors. The factors responsible for low grain Zn are high soil pH, low organic matter, salinity/alkalinity, water logging, and poorly managed soil fertility. Due to its critical role in growth and development of humans, food with adequate Zn content is mandatory. This situation demands some effective strategies for the enhancement of grain Zn content to overcome human Zn deficiency. Zinc supplementation of food, Zn pills, breeding of high Zn uptake species, and biofortification through fertilizers are being employed to address the issue. Among all strategies, Zn biofortification through fertilizers is an effective and economical technique. Mineral Zn fertilizers are applied alone or in combination with organic and biofertilizers. Integrated use of mineral, organic and biofertilizers improves Zn uptake and assimilation in cereals grains. Nanotechnology and enrichment/coating techniques are also effective to enhance grains Zn. This review critically discuss the efficiency of various strategies to promote Zn availability and uptake by plants that assure food and nutrition security. Zn enriched/coated urea is considered an effective tool to ensure crops with optimum concentration of Zn for human consumption.

Keywords: Zinc; Bioavailability; Cereals; Biofortification; Biofertilizers; Food Security

1. Zinc and food security

The inadequate supply of food to the poor community of ever increasing world population is a much highlighted issue. This situation has increased the pressure to produce more food, and agriculture has successfully met the challenge of feeding this ever growing population. On the other hand natural resources used to supply food are constant (UN, 2012). But unluckily agriculture system has not been planned with objective to support human health, food/nutrition security instead it has certain other aims e.g. farmers profitability (Mayer et al., 2008).

Food quality is too much poor as most of the diet used is micronutrient deficient (Huang *et al.*, 2002). According to World Health Organization (WHO) report (WHO, 2002), hidden hunger with respect to micronutrients, especially, Zn, Fe, I and Se affects half of the world population. In Pakistan 37% of population is suffering from zinc malnutrition (WHO, 2002; UNDP, 2003; White and Broadley, 2005). In these areas, Zn deficiency is fifth largest cause of deaths and disorders. According to an estimate, 2.7 billion people are suffering from severe Zn deficiency (Anonymous, 2004). Zn deficiency is responsible for 16% of respiratory disorders, 10% of diarrhea and 18% malaria with 800,000 deaths annually in poor world. Zn deficiency also negatively affects the immune system, reproductive system and cell growth, and causes skin disorders and cancer (WHO, 2012). The main cause of Zn deficiency is the cereals based food which is deficient in Zn.

Zn makes 0.02% of the earth crust by weight with the average concentration of 70 μg g^{-1} in soil solution (Welz and Sperling, 1999). It is

**Corresponding author:* e-mail:azharhaseen@gmail.com

released into the soil by various ways but mostly by anthropogenic activities (Sandstead and Au, 2005). Zn is also most deficient element in soil due to its low mobility (ATSDR, 2005). The critical range of diethylene triamine penta acetic acid (DTPA) extractable Zn in soil is 0.6-1.0 mg kg^{-1}, whereas in plants it ranged as 10-20 mg kg^{-1} of dry weight (Katyal and Rattan, 2003). These limits may vary with soil type and crop cultivation. The critical range of DTPA extractable Zn for rice is 0.8 mg kg^{-1} (Kumar et al., 2009). According to review, below critical level Zn deficiency occurs in plants (Hamza, 1998).

Plants act as a main point of entry for Zn and other elements into the food chain (Rouached, 2013). Zinc is an essential micronutrient for various functions in plant's life cycle (Hafeez et al., 2013). Zn as a metal, acts as co-factor in all six classes of enzymes (e. g. oxidoreductase, transferases, hydrolases, lyases, isomerases and ligases) (Tapiero and Tew, 2003). Its importance in metabolic processes, oxidative reactions, structural and catalytic activities, biomembranes stability, DNA replication, protein synthesis and energy transfer reactions cannot be ignored in plants (Broadley et al., 2012; Gurmani et al., 2012). It is required for hydrogenase, carbonic anhydrase, Cu/Zn super oxide dismutase (SOD), RNA polymerase activity, ribosomal stability, and cytochrome synthesis (McCall et al., 2000). Zn regulates auxin synthesis, pollen formation, gene expression and antioxidant's production within plant tissues (Luo et al., 2010). Zn deficiency decreases photosynthetic rate, produces small chlorotic leaves and induces sterility of spikes in wheat. The overall output decreases and fungal infection increases with Zn deficiency (Cakmak et al., 2000). Zn nutrition regulates water uptake and transport, decreases the adverse effect of heat and salt stress (Peck et al., 2010), regulates the tryptophan production which is precursor of indole acetic acid (IAA) (Alloway et al., 2004; Brennan et al., 2005). Zn deficiency badly impacts both flower and fruit formation and ultimately reduces crop yield (Ciftci et al., 2008). The optimum grain Zn concentration should be 50 µg g^{-1} of grains dry weight to fulfill human requirements, while the current status is 20-30 µg g^{-1} of grains dry weight. It is reported that, by proper fertilization of Zn in cereals, 3 folds increase in grain Zn concentration can be achieved (Cakmak, 2008). It is well documented that its application to wheat increases Zn concentration in grains (Waters et al., 2009).

Zn is also essential for normal growth and development of human beings (Hafeez et al., 2013). The requirement of Zn for humans depends on age and gender. As compared to adults, infants, children, adolescents, pregnant, and lactating women have higher requirements for Zn and thus, are at increased risk of zinc depletion (Reeves et al., 2008). It is essential for functioning of immune cells, development of reproductive system, gastrointestinal and central nervous system and skeletal organs (Reeves et al., 2008). It is important for enzymes of all six classes as well as transcription and replication factors (Hirschi et al., 1997). Zinc in proteins can either participate directly in chemical catalysis or be important for maintaining protein structure and stability (McCall et al., 2000).

Zinc is critically involved in metabolic homeostasis of the human body. Zinc deficiency increases the chances of occurrence of infectious diseases (diarrhea, pneumonia and malaria) in children (Black, 2008). Due to its deficiency, humans are suffering from skin problems, hair and memory loss (Lukaski, 2004). Moreover, 86% of skeletal muscles consist of Zn. Its concentration is relatively high in pancreas, kidney cortex and hippocampus (Vallee and Falchuk, 1981).

Food insecurity with respect to micronutrients is a global issue (IELRC, 2010). Until 2007, total number of starving people in the whole world was 75 million because of increasing foodstuff prices (FAO, 2008). In 2010, the hungry people increased up to 963 million (Ruane, 2010). Access to adequate, safe and nutritious foodstuffs necessary for a healthy, prosperous and active life by all people at all times is inadequate resulting in micronutrient deficiency including Zn. The quantity and quality of food available for consumption to people determine their micronutrient security level. Inadequate quantity and quality of food available for consumption are causative agents to micronutrient deficiencies or micronutrient insecurity (Prasad, 2010). Table 1 shows the deaths in children due to malnutrition.

Table 1. World's annual mortality in the children of 5 years due to malnutrition

Deficiency	Deaths
Vitamin A	666,771
Zinc	453,207
Iron	20,854
Iodine	3,619

(Black, 2008)

2. Fate of applied Zn in soil

In Pakistan, 70% of agricultural soils are Zn deficient (Kauser et al., 2001). Zinc deficiency is frequent in calcareous, neutral, peat, saline sodic, intensively harvested and highly weathered soils (Alloway, 2008). It mostly occurres in soil as zinc sulphide (ZnS), and less frequently as Zn mineral ores such as, zincite (ZnO), zinkosite ($ZnSO_4$), smithsonite ($ZnCO_3$), hopeite [$Zn_3(PO4)_2.4H2O$], franklinite ($ZnFe_2O_4$). Zinc availability form these sources depends upon atmospheric condition such as surface dust, volcanoes and weathering of parent rocks (Alloway, 1995).

Zn uptake from rhizosphere is first step in its accumulation into plants (Giehl et al., 2009). Roots uptake Zn as Zn^{2+}, which is integral part of mineral and organic fertilizers (Oliveira and Nascimento, 2006). Various soil factors are responsible for its availability to plants. Due to its severe deficiency in soils the applied zinc readily absorbs on the exchange sites (Broadley et al., 2007). The remaining applied Zn is utilized by soil micro biota and very lesser amount is available to plants (Alloway, 2008). The crops grown on such soils are mostly Zn deficient (Gupta, 2005).

3. Factors effecting zinc bioavailability

Low bioavailability of Zn in soils, poor plant capability to assimilate soil Zn into grain, high grain phytate content and milling process of gains are considered major reasons of Zn deficiency in human beings. Despite of fair quantity of total Zn in soil, its bioavailable fraction in soil is very low due to various soil factors (Alloway, 2009). Zinc is the most deficient micronutrient in alkaline calcareous soils after nitrogen and phosphorous (Rashid and Ryan, 2008; Alloway, 2009). In arid and semi-arid areas, soils are deficient in Zn due to high $CaCO_3$ and less organic matter content (Imran et al., 2014). The other reasons of low Zn contents in soils are low Zn in parent material (Kochian, 2000; Hussain et al., 2010), high soil pH (Alloway, 2004), high soil phosphorous content (Alloway, 2008), high salt concentration (Kausar et al., 1976), water logging (Johnson-Beebout et al., 2009), low manure application (Cakmak, 2009) and fixation in soil matrix (Zhao and Selim, 2010). About 50% of the agricultural soils in China, India and Turkey have been affected by zinc shortage (FAO, 2002).

Deficiency of Zn in soil results in low Zn uptake by plants and ultimately less grain Zn concentration. Along with the soil factors, plants also vary in their abilities to uptake Zn from soil and its translocation and assimilation it into grains. Wheat, rice and maize are the major sources of daily calorie intake in under develop countries including Pakistan (Alloway, 2008), which are deficient in Zn content. The much reliance on such foods is considered a main cause of Zn deficiency in humans. Zinc bioavailability to humans for absorption can be increased either by increasing the required element in the cereal grains or decreasing the phytate (anti-nutrient) (Bouis and Welch, 2010). In human intestine, the phytate makes complexes with Zn and in this way Zn becomes unavailable or absorbs in lesser quantity in human body (Brown et al., 2001).

Milling process of cereal grains also results in the loss of a significant quantity of grain Zn. During milling process, bran is removed which contains highest Zn content (Liang et al., 2008). The remaining portion of grain contains less quantity of Zn. (Dewettinck et al., 2008). Approximately 80-85% of carbohydrates and minerals are present in endosperm portion of seed with low concentration of Zn.

4. Strategies to overcome the Zn deficiency

Various strategies have been employed including supplementation (nutrients as clinical treatment), fortification (add particular nutrient in food items), food modification/diversification (cooking and processing of food on nutritional point of view) and biofortification which is a process of enhancing the bioavailable nutrient contents in the edible portion of crops (Mayer et al., 2008). Zinc contents in cereal grain can be improved through breeding crop varieties, which uptake and assimilate more Zn in grain. Since plants are primary producers in food chain, for that reason improving the nutrients' uptake by plants from the soil will be effective for animals and humans (Hirschi, 2008). Zinc biofortification can be done by various ways such as genotype selection and improvement. This can be achieved by using genetic engineering and conventional breeding methods. Although plant breeding and genetics are helpful to obtain crop varieties which can efficiently utilize micronutrients from soil, but it is expensive and time consuming strategy. Furthermore, it depends on bioavailable Zn contents in soil. Increasing Zn contents through fertilizers is a short term solution (Cakmak, 2008). Under such circumstances, biofortification through fertilizers is an attractive way to improve Zn in grain (Rafique et al., 2006).

4.1. Biofortification through mineral fertilizers

Mineral Zn is supplied to plants either by soil application, foliar spray or seed priming. Method of fertilizer application affects the overall yield and Zn concentration in grains of cereals (Table 2).

Table 2: Effect of method of Zn fertilization on grain Zn content

Fertilizer strategy	**Crop**	**Increase in Zn contents with respect to control (%)**	**Reference**
Zn coated urea (2.83 kg Zn ha^{-1})	Rice	19	(Shivay et al., 2015)
PGPR inoculation	Soyabean	15	(Ramesh et al., 2014)
Foliar application of $ZnSO_4$	Chick pea	56.5	(Pathak et al., 2012)
Zn coating on urea	Rice	7.21-20	(Nazir et al., 2016)
$ZnSO_4$ Soil applied	Irarian rice	14.38	(Yadi et al., 2012)
Soil applied $ZnSO_4$	Durum wheat	27.33	(Cakmak et al., 2010)
Foliar application	Wheat	51.01	(Zhao et al., 2009)
Bioinoculation of *Azospirillum* sp. Strain 21	Maize	107	(Biari et al., 2008)
Zn-EDTA	Rice	74.20	(Naiq et al., 2008)
Bioinoculation (consortia: more than 2 PGPR)	Rice	156.5	(Tariq et al., 2007)
Foliar application	Common beans	8.3	(Tolay and Gulmezoglu, 2004)
Soil Application	Rice	183.3	(Rehman et al. 2002)
Soil Application	Wheat	260	Yilmaz et al., 1997

4.1.1. Soil application of $ZnSO_4$

Soil application of mineral fertilizer is one of the oldest ways to supply nutrients to growing plants (Rengel et al., 1999). Yilmaz et al. (1997) observed that soil application of Zn fertilizers made significant increase in Zn content of wheat grains compared to control. Zinc application in soil helps in increasing Zn contents in cereals up to 28% (Cakmak et al., 2010); while in rice this trend can be up to 184% (Rehman et al., 2002). Soil application with other amendments such as (organic matter, sewage sludge and gypsum etc.) is an effective way to increase grain Zn contents (Ascher et al., 1994). According to a group of scientist, 2-3 folds grain Zn concentration can be increased by soil application only (Graham et al., 1992; Singh, 1992). Soil type also influences Zn concentration in root, shoot and grains of cereals. $ZnSO_4$ is mostly used as soil Zn fertilizer (Rengel and Graham, 1995).

The application of Zn fertilizers in cereals improves Zn content in grains up to four folds depending on the application method (Nazir et al., 2016). Combined application of soil and foliar application resulted about 3.5-fold increase in Zn concentration of wheat grain. When a high grain Zn concentration is targeted with high yield of grains, then combined soil and foliar application is recommended (Nazir et al., 2014). In Turkey convincing results have been obtained in field trials, about the importance of zinc fertilizer approach to enhancing Zn concentration in wheat grain e.g. agronomic bio-fortification. Zn application on wheat grown under field trial at Central Anatolia improved Zn concentration in grains and productivity (Yilmaz et al., 1997).

4.1.2. Foliar application of $ZnSO_4$

Plants can absorb soluble compounds through leaves (Kannan, 1990). Due to poor bioavailability of micronutrients in soil, foliar application is preferred over soil application (Ferrendon and Channel, 1988). One most popular agriculture/agronomic strategy to enhance these micronutrients in cereals grain are micronutrient fertilizers (Graham et al., 2007). Foliar Zn application is more effective as compare to soil applied Zn to increase grain Zn contents of cereals, whole grain Zn concentration including endosperm could be increased by this (Cakmak et al., 2010).

4.1.3. Combined application of Zn through soil and foliar spray

Higher grain yield with desired Zn content can be attained through combined (soil and foliar) Zn application (Haslett et al., 2001). Maximum grain Zn is obtained when Zn fertilizers are applied in the late growth stages of crop. Similarly, optimization of foliar or soil applied Zn fertilizer with respect to dose, time and stage of crop is also effective in this regard (Ozturk et al., 2006). Highest Zn concentration is obtained at milking stage of wheat, because at milking stage grains have more Zn concentration. Foliar application increases grain Zn concentration 3 folds, on the other hand $ZnSO_4$ is consider best source of Zn as compare to other sources. Addition of Zn instead of increasing grain Zn contents also provide seedling vigor and seed viability, High grain Zn concentration also provides strong root growth and protection against soil borne diseases (Cakmak, 2012). Some scientists prefer $ZnSO_4$ application along with herbicides, fungicides and insecticides to achieve this purpose as compare to ZnSO4 alone, on the other hand this technique also reduces extra time and cost. The maximum wheat grain Zn concentration was obtained by Ismail and his coworkers in 2010 when 21 kg ha^{-1} Zn was applied as soil and foliar application.

4.1.4. Combined application of organic and inorganic fertilizers

Organic manures like poultry manure, farm yard manure and sewage sludge have complexes of micronutrients like Zn, Fe and Cu, and quite effective to solve the problem of their deficiencies in alkaline calcareous soils. The use of Zn amended poultry manure is effective in case of dry weight, on the other hand Zn uptake by maize was also significantly high in those treatments where Zn amended poultry manure was applied as compared to $ZnSO_4$ alone (Singh et al., 1979). The coating of Zn on small size compost particles (almost 2 mm) is very effective and useful, chicken manure improves water holding capacity of soil, aeration, soil structure and drainage (Cooke et al., 1980) besides containing high amount of macronutrients it also contains micronutrients e. g. Zn, Cu and Fe (Singh et al., 1980; Adediran et al., 1996). It is well documented that the combined use of organic and inorganic fertilizers is effective to enhance required element in grains (Agboola et al., 1982). Zn uptake by plants is improved with the application of $ZnSO_4$ alongwith manure application (Akinrinde et al., 2006). Moreover, organic amendments, improve soil physical, chemical and biological properties (Tolay, et al., 2004), microbial and enzymatic activates (Liang et al., 2003) and it is an indicator of good soil health and fertility. According to previous studies, the application of FYM, Olive husk and compost is profitable with respect to Zn uptake from soil to plants (Clemente et al., 2007). No doubt, Organic amendments is an effective strategy to increase all nutrients in soil and plants including Zn, but nature, type and source of organic matter also have effect in nutrients concentration because sometimes these materials have more heavy metals as compare to essential nutrients (Tlustos et al., 2000).

4.1.5. Zn solubilizers

The naturally occurring micro flora/fauna play unique role in the solubility/availability of most of the nutrients including Zn. The specific groups of microbes which play their role in Zn solubalization are called Zn solubalizers (Chen et al., 2003). These microbes have substantial potential to solubilize Zn in soil and make it available for plants (Subramanian et al., 2009). The role of microbes under drought, saline and toxic soil conditions is also well documented (Khalid et al., 2009), on the other hand they play their role in the production of enzymes, phytohormones and acts as anti-pathogen also (Glick and Bashan, 1997). These microbes can enhance Zn availability to plants either through reduce soil pH, improve root growth or by Zn chelation (Whiting et al., 2001).

The availability of Zn is very responsive to soil pH. Its availability decreases 100 folds for each degree increase in soil pH (Havlin et al., 2005). So, in Pakistan or the areas where pH is high and Zn bioavailability is a well-known problem either indigenous microbes or bioaugmantation (addition of Zn-solubalizers in soil rhizosphere) can solve this problem (Biari et al., 2008), because they produce organic acids to reduce soil pH and enhance Zn bioavailability (Subramanian et al., 2009). The microbes can produce some organic molecules which binds with metallic ions e.g. Fe, Zn and enhance their availability to plants called chelation (Tarkalson et al., 1998). Some scientists use fungi for this purpose they concluded that mycorrhizal fungi make association with the roots of higher plants and change root architecture to increase nutrients uptake (Tariq et al., 2007).

Several studies indicated that bacterial and fungal inoculation in soil can positively increase Zn uptake by plants (Tariq et al., 2007). *Pencillium bilaji*, *Aspergillus*, *Pseudoumonas*, and *Bacillus* are well known microorganisms to facilitate ZnO, $ZnCO_3$ and ZnS solubalization for plants (Saravanan et al., 2007).

In many studies, the use of PGPR is effective and increase Zn concentration in different parts of plant. Its application increases Zn contents in grains and significantly increase has been observed in biomass e.g. 23% and grain yield 65%, in rice crop. Moreover, PGPR inoculation has positive effect on physical parameters such as root length, shoot length, plant height and plant vigor with respect to control where no PGPR was applied (Tariq et al., 2007). Sometimes only one strain and in many cases consortia multi-strains applied to soil to enhance Zn concentration in crops, in most of cases multi-strains performed well as compared to single strain (Ramesh, 2014).

Whiting et al. (2001) have also recorded through bacterial inoculation about 0.45 fold increase in bioavailable Zn in rhizosphere soil. It has also been widely reported that bacterial inoculation increases plant Zn content (Biari *et al.,* 2008). A 2-fold more Zn concentration in the shoot of *T. caerulescens* compared to control while uptake was increased up to 4-fold observed by Whiting et al. (2001). Likewise, inoculation of corn with *Azotobacter* and *Azospirillum* caused significant increase in Zn content in grain.

Biari et al. (2008) observed up to 107, 85, 95 and 107% increase in Zn content in seed with *Azospirillum sp.* strain 21, *Azospirillum brasilense* DSM2286, *Azotobacter sp*. strain 5, *Azotobacter chrooccoccum* DSM2286, respectively, compared to uninoculated control. While, Tariq et al. (2007) observed 133% increases in Zn concentration in grain with inoculation by conducting experiment on rice. The bacterial application also relieved the deficiency symptoms of Zn in plant. Hussain et al. (2015) also found that zinc solubilizing bacteria could improve maize growth and physiology. Therefore, use of such inoculants could be valuable to increase solubilization of Zn in soil and its subsequent availability to plants. Due to lack of awareness this approach is not common among farmers. As zinc solubilizing microbes have the potential to improve the growth, yield and quality of grains so the researchers should focus on the biotechnology for quality grain production.

5. Zinc coated mineral fertilizers

Zn could apply, as coating on macronutrient; it is an effective technique to overcome farmer's ignorance. It is cost effective strategy because timely application can be insure with less or no labor cost. Nitrogen and Zn can be applied simultaneously because these two nutrients behave synergistically (Kutman *et al.,* 2010), due to this behavior of these two nutrients, coating of Zn on urea is very impressive practice and the beauty of this method is application of nitrogen and Zn side by side (Yadav et al., 2010), they also published that the better quality of rice in which Zn coated urea was applied as compared to only $ZnSO_4$, which is best source of Zn. This technique is much better for those areas where rice- wheat cropping system with low contents of soil Zn (Prasad, 2005). Almost 2% Zn coated urea showed best results in all yield and growth parameter e. g. grain yield, quality and grain Zn concentration (Yadav et al., 2010), they also concluded that ZnO has almost 2.5 folds more Zn contents as compare to $ZnSO_4$ but still $ZnSO_4$ is better as compare to ZnO because $ZnSO_4$ is soluble while ZnO is insoluble Zn source. The coating of micronutrients like Zn and Cu reduce ammonia losses from urea (Ahmad et al., 2006). Figure 1 shows the mechanism of Zn coated urea.

Cereals such as wheat and rice shows very good response to applied Zn fertilizers (Prasad, 2010). Many scientists reported that Zn application as zinc sulphate or zinc enriched/coated urea in soil not only increased growth, yield and vigor of the plants but also zinc concentration in cereals grain (Shivay et al., 2008). Therefore, sufficient fertilizer application of food crops can to some extent.

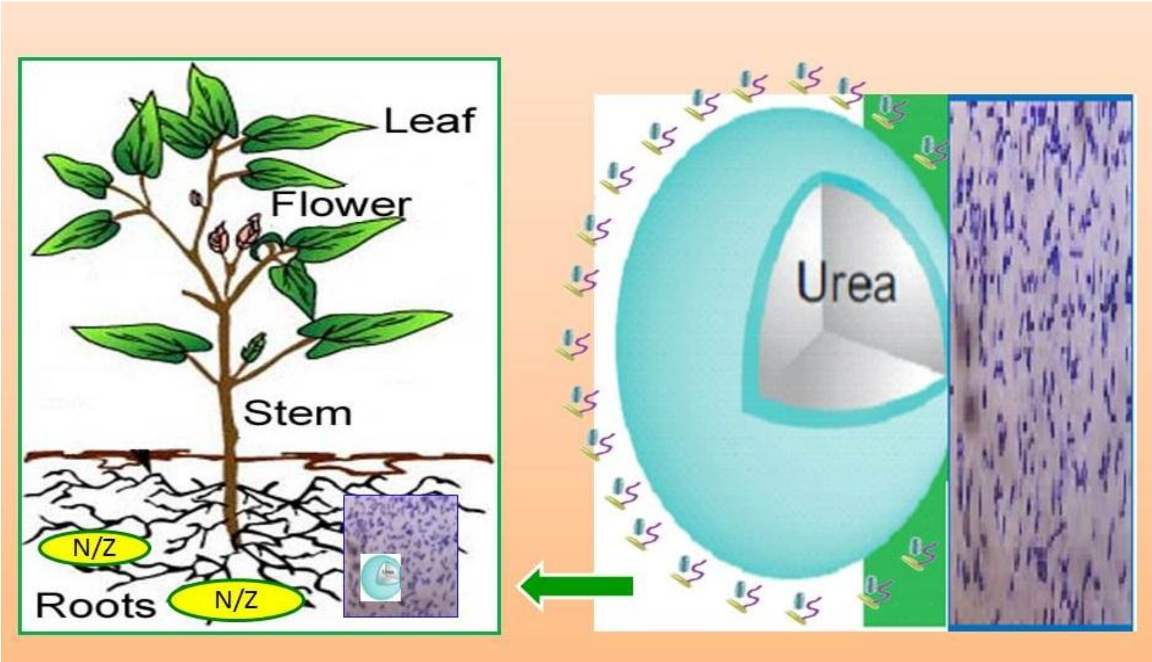

Figure 1. The mechanism of Zn coated urea enhancing nitrogen and zinc availability to plant roots.

6. Zinc biofortification for food/ nutrition security

Food security may be defined as when all people, at all times, have physical and economic access to enough, safe, and nutritious food to full fill their dietary requirements and food preferences for an energetic and healthy life (Gross et al., 2000).

Nutrition security is a broader term than food security because it incorporates some other help in Zn intake by humans. aspects for example biological utilization, which refers to the aptitude of a person to consume foodstuff and metabolize nutrients and meet the requirements of necessary nutrients needed by the body (Gross et al., 2000). Proper food with adequate amount of micronutrients is necessary for a healthy generation and maintenance of successful life and social development (Quisumbing, 1995). The necessity of the time is to incorporate nutrition (micronutrients) into food items and crops and nutrition security is said to have been achieved 'if adequate food (quantity, quality, safety, socio-cultural acceptability) is available and accessible for and satisfactorily utilized by all individuals at all times to achieve good nutrition for a healthy and happy life (Thompson, 2009). The goals of food security provide a holistic approach towards achieving the targets set in the MDGs Millennium Development Goals (FAO, 2006; Shetty, 2009). Zn fertilization of crops grown on Zn deficient soils are helpful to attain both food security and it will also overcome Zn malnutrition among humans (Takkar et al., 1997).

7. Nanotechnology and coated fertilizers

Nanotechnology is an emerging field in this century; nano-particles are sized between 1-100 nm (Buzea et al., 2007). These particles are used in Agriculture as fertilizers, medical fields as medicines and in food quality to reduce health risks (Hulse, 2002). The application of nanoparticles as fertilizers (smart fertilizers) moved away from experimental to practical side (Cui et al., 2010). The slow release fertilizers are critically important to increase fertilizer use efficiency and plant health (Naderi and Danesh, 2013). The undesirable loss of nutrients from soil can be minimized with the increase in fertilizer use efficiency (Rai et al., 2012).

These nanofertilizers combine with nanodevices to detect the nutrient release and synchronize it with uptake by plants, in this way less interaction of nutrients with soil and microbes and maximum available to crops (DeRosa et al., 2010). Encapsulation/Coating of macronutrients within nanoparticles of micronutrients is effective to maximize fertilizer use efficiency and can be achieved by 3 ways: a) coating with thin polymer film b) Coating of nanoemulsions c) encapsulated inside nonporous dimensions (Rai et al., 2012). Pokhrel and his coworker (2013) reported that the application of nanoparticles of ZnO improved germination and root elongation of maize and cabbage. They also reported that nanoparticles are less toxic as compare to free ions.

Nanotechnology is very effective to improve growth, yield and concentration of Zn in cereal grains due to its small size and more efficiency. So, the use of nanofertilizers can improve plant health by slow and in time release of nutrients. Biofertilizers and coating of micronutrients on macronutrient fertilizers are the best sources to increase zinc concentration in cereal grains.

CONCLUSIONS

Zinc deficiency in soil, plant and humans is well documented. Its biofortification in cereal is a safe and environmental friendly strategy for enhancing the zinc concentration in the population of developing world, who consume cereals for their daily caloric intake, adequate amounts of biofortified cereal flour through agronomic practice (use of fertilizers) is effective on large-scale. Zinc coated urea and nanotechnology are seemed to be a very effective strategy in the near future to ensure valuable Zn contents in crops especially in cereals. Zinc biofortification programs to control zinc deficiency are also require to sort out this problem in poor world. The appropriate level of fortification depends on the population and extent of Zinc deficiency in them. The milling process is also important because due to this process a lot of Zinc is losses. So, whole grain should be consumed. Proper fertilization of Zinc in crops is also required to fulfill human zinc requirement. It is needed to make sure healthy, nutritious and safe food for the whole nation. In this way, we can achieve a prosperous community and optimum Zn concentration in cereals grain as well.

ACKNOWLEDGEMENT

Authors are thankful to the Institute of Soil and Environmental Sciences, University of Agriculture Faisalabad, Pakistan for providing working environment.

REFERENCES

Adediran JA, Taiwo LB and Sobulo RA. 1996. Comparative nutrient value of some solid organic wastes and their effect on tomato yield. Institute of Agriculture Research and TrainingObafemi Awolowo University. Moor plantation, Ibadan, Nigeria. 99-116.

Agboola AA, Obigbesan GO and Fayemi AA. 1982. Effect of organic matter (FYM), lime and phosphorous fertilizer on the yield of cowpea. FAO Soil Bullitin, 27: 339.

Ahmad OH, Aminuddin H and Husni MHA. 2006. Reducing Ammonia loss from urea and improving soil exchangeable ammonium retention through mixing triple superphosphate, humic acid and zeolite. Soil use Manage. 22: 315- 319.

Akinrinde EA, Olubakin OA, Omotoso SO and Ahmed AA. 2006. Influence of Zn fertilizer, poultry manure and Application levels on the performance of Sweet Corn. Agric. J. 1(2): 96-103.

Alloway BJ. 1995. Heavy metals in soils, 2nd edn. Blackie academic & professional, London.

Alloway BJ. 2004. In zinc in soil and crop nutrition. International Zinc Association. Brussels, Belgium.

Alloway BJ. 2008. Zinc in soils and plant nutrition, 2nd edition. International fertilizer Industry. Association, Paris, France.

Alloway BJ. 2009. Soil factor accociated with Zn deficiency in crop and humans. Environ. Geochem. Health. 31: 537-548.

Anonymous, 2004. Fifth report on the world nutrition situation. United Nations, Administrative Committee on Coordination/Sub-Committee on Nutrition, Geneva.

Ascher JS, Graham RD, Eilliott DE, Scott JM and Jessop RS. 1994. Agronomic value of seed with high nutrient contents in: Wheat in stressed environments: Irrigated dry areas and Rice-Wheat farming system. CIMMYT. Mexico, D.F. pp. 297-308.

ATSDR, 2005. Toxicology profile for Zinc, US Department of Health and Human Services, http://www.atsdr.cdc.gov/tfacts60.html (accessed 16.06.08).

Biari A, Gholami A and Rahmani HA. 2008. Growth promotion and enhanced nutrient uptake of maize (Zea mays L.) by application of plant growth promoting rhizobacteria in arid region of Iran. J. Biol. Sci., 8: 1015-1020.

Black RE. 2008. Maternal and child under nutrition: global and regional exposure and health consequences. 371: 243–260.

Bouis HE and Welch RM. 2010. Biofortification: A sustainable agriculture strategy for reducing micronutrient malnutrition in the globle south. Crop Sci. 50: S20-S32.

Brennan RF. 2005. Zinc Application and its availability to plants. Ph. D. dissertation, School of Environmental Science, Division of Science and Engineering, Murdoch University.

Broadley, Broown MP, Cakmak I, Rengel Z and Zhao F. 2012. Function of nutrients: Micronutrients. In: Marchners's Mineral Nutrition of Higher Plants, 3rd edition. P. Marschner (ed). Academic Press, London, UK. Pp. 208-265.

Broadley, White MR, Zelko PJ and Lux A. 2007. Zinc in plants. New Phytol. 173: 677

Brown KH, Wuehler SE, Peerson JM. 2001. The importance of Zinc in human nutrition and estimation of the global prevalence of zinc deficiency. Food Nutr. Bull. 22: 113-125.

Buzea C, Pacheco I and Robbie K. 2007. Nonmaterials and Nanoparticles: Sources and Toxicity. Biointerphases 2: MR17-MR71.

Cakmak I, Pfeiffer WH and Mcclafferrty B. 2010. Biofortification of durum wheat with Fe and Zn. Cereal. Chem. 87: 10-20.

Cakmak I. 2000. Role of Zinc in protecting plant cells from reactive oxygen species. New Phytol. 146: 186-205.

Cakmak I. 2008. Enrichment of cereal grains with Zinc: Agronomic or genetic biofoitication Plant and Soil. 302: 1- 17.

Cakmak I. 2009. Agronomic approaches in biofortification of food crops with micronutrients. The proceedings of the international plant nutrient colloquium XVI UC Davis.

Cakmak I. 2012. Harvest plus Zinc fertilizer project. Harvest Zinc. Better Crop. 96: 17-19.

Chen BD, Li XL, Tao HQ, Christie P and Wong MH. 2003. The role of arbuscular mycorhiza in zinc uptake by red clover growing in a calcarious soil spiked with various quantities of zinc. Chemosphere, 50: 839-846.

Ciftci-Yilmaz S and Mittler R. 2008. The Zinc finger network of plants cell Mol. Life Sci., 65: 1150-1160.

Clemente, Paredes RC and Bernal MP. 2007. A field experiment investigating the effects of olive husk and cow manure on heavy metal availability in a contaminated calcarious soil from Murcia (Spain). Agric. Ecosyst. Environ. 118: 319-326.

Cooke GW.1980. Fertilizer for maximum yield Granada Publishing Ltd. London.

Cui HX Sun, CJ Liu, Jiang Q J and Gu W. 2010. Applications of nanotechnology in agrochemical formulation, perspectives, challenges and stratigies. International conference on Nanoagri, Sao pedro, Brazil, 20-25.

DeRosa MR, Monreal, Schnitzer C, Walsh M and Sultan RY. 2010. Nanotechnology in fertilizers. Nat. Nanotecnol. J. 5:91.

Dewettinck K, Van Bockstaele F, Kuhne B, Van de Walle D, Courtens TM and Gellynck X. 2008. Nutritional value of bread: Influence of processing, food interaction and consumer perception. J. Cereal Sci. 48: 243-257.

FAO. 2002. Human vitamin and mineral requirements. Food and Agriculture Organization of the United Nations, Bangkok, Thailand. ISBN. 1014-9228.

FAO. 2008. The state of food insecurity in the world: High food prices and food security - threats and opportunities. http://www.fao.org/SOF/sofi/.

Ferrendon M and Channel AR. 1988. Cuticular retention foliar absorption and translocation of iron and menganise and Zinc supplied in organic and inorganic form. J. plant Nutr. 11: 247-264.

Food and Agriculture Organization of the United Nations. 2006. The State of Food Insecurity in the World 2005. FAO, Rome.

Giehl RFH, Meda AR and Wiren N. 2009. Moving up, down and everywhere: signaling of micronutrients in plants. Curr Opin plant Biol. 12: 320-327.

Glick BR and Bashan Y. 1997. Genetic manipulation of plant growth- promoting bacteria to enhance biocontrol of phytopathogens. Biotechnol. Adv., 15: 353-378.

Graham RD, Ascher JS and Hynes SC. 1992. Selecting Zn efficient cereal genotype of soils of low zinc status. Plant and Soil. 146: 241-250.

Graham RD, Welch RM, Saunders DA, Ortiz MI, Bouis HE, Bonierbale MD, Haan S, Burgos G, Thiele G, Liria R, Misner CA, Beebe SE, Potts MJ, Kadian M, Hobbs M, Gupta RK and Tomlow S. 2007. Nutritious subsistence Food system. Advance Agron. 92: 1- 74.

Gross R, Schoeneberger H, Pfeifer H and Preuss HJ. 2000. The four dimensions of food and nutrition security: definitions and concepts. SCN News 20, 20–25; available at http://www.unsystem.org/SCN/ archives/scnnews20/index.htm (accessed 12 October 2009).

Gupta AP. 2005. Micronutrient status and fertilizer use scenario in India. J Trace Elem. Med. Biol. 18:325–331.

Gurmani AR, Khan SU, Andaleep R, Waseem K and Khan A. 2012. Soil application of zinc improves growth and yield of tomato. Int. J. Agric. Biol., 14: 91-96.

Hafeez B, Kanif YM and Saleem M. 2013. Role of Zinc in plant nutrition- A Review. Am. J. Experi. Agric. 3(2): 374-391.

Hamza S. 1998. Effect of organic farming on nutritional uptake yield and quality of ginger. Ind. Soc. Of for spices, Calicat. 89-94.

Haslett BS, Reid RJ and Rengel Z. 2001. Zinc mobility in Wheat: uptake the distribution of Zinc to leaves and roots. Ann. Bot. 87: 379-386.

Havlin J, Beaton JD, Tisdale SL and Nelson X. 2005. Soil fertility and fertilizers: An introduction to nutrient management. Upper Saddle River Enj: Pearson Prentice Hall.

Hirschi AM, Fang X, Asad S and Kapulnik Y. 1997. The role of phytohormons in plant microbe symbiosis. Plant soil. 194: 171-184.

Hirschi K. 2008. Nutritional improvements in plants: time to bite on biofortified foods. Trends Plant Sci. 13.

Huang J, Pray C and Rozelle S. 2002. Enhancing the crops to feed the poor. Nature 418: 678-684.

Hulse JH. 2002. Ethical issues in biotechnologies and international trade. J. Chem. Tec. and Biol, 77(5):605-615.

Hussain S, Maqsood MA and Rahamatullah. 2010. Increasing grain zinc and yield of wheat for the developing world. A Review. Emir. J. Food Agric. 22(5): 326-339.

Hussain A, Arshad M, Zahir ZA and Asghar M. 2015. Prospectus of zinc solubilizing bacteria for improving growth and physiology of maize. Pak. J. Agri. Sci., 52(4): 915-922

IELRC. 2010. Biotechnology and food security in Africa: Some Policy and institutional considerations.http://www.ielrc.org/content /fo204.htm. 1- 3.

Imran M, Arshad M, Khalid A, Kanwal S and Crowley DE. 2014. Perspectives of Rhizosphere microflora for improving Zinc Bioavailability and Acquisition by higher plants. Int. J. of Agric. and Biol. 16(3): 653-662.

Johnson-Beebout SE, Lauren JG and Duxbury JM. 2009. Immobilization of Zinc fertilizers in flooded soils monitored by adaptd DTPA Soil test. Commun. Soil Sci. Plant Analy. 40: 1842-1861.

Kannan S. 1990. Role of foliar fertilization in plant nutrition in: Baligar, V.C. Duncan, R.R. (Eds.). Crops as enhancers of Nutrient use. Acadamic press. San. Diego. Pp 313-348.

Katyal JC and Rattan, RK. 2003. Secondary and micronutrients research gaps and future needs. Fert. News. 48(4): 9–20.

Kausar MA, Chaudry FM, Rashid A and Latif A, Alam SM. 1976. Micronuyrients availability to cereals from calcarious soils. I. Comparative Zn and Cu deficiencyand their mantual interactionin rice and wheat. Plant and soil. 45: 397-410.

Kauser MA, Hussain F, Ali S and Iqbal MM. 2001. Zinc and Cu nutrition of two wheats varieties on a calcareous soil. Pak. J. Soil Sci. 20: 21-26.

Khalid A, Arshad M, Shaharoona B, Mahmood T, Khan MS, Zaidi A and Musarrat J. 2009.

Plant growth promoting rhizobacteria and sustainable agriculture. In: Microbial Strategies for crop Improvement. Khan MS, Zaidi A, Musarrat J. (eds). Pp: 133-160. Springer-Verlag, Berlin, Heidelberg.

Kiekens L. 1995. Zinc in heavy metals in BJ Alloway (Ed.). Soils. London: Blackie Academic and professional.

Kochian LV. 2000. Molicular physiology of mineral nutrient acquisition transport, and utilization. Biochem. Mol. Boil. Plants, 20: 1204-1249.

Kumar R, Menhotra MK, Nutiyal BD and Sing PK. 2009. Effect of Cu on growth, yield and concentration of Fe, Mn, Zn and Cuin wheat plants. J. Environ. Biol., 30: 485-488.

Kutman UB, Yildiz B, Ozturk L and Cakmak I. 2010. Biofortification of durum wheat with Zn through soil and foliar applications of nitrogen. Cereal Chem. 87: 1- 9.

Liang J, Li Z, Tsuji K, Nakano K, Nout MJR and Hamar RJ. 2008. Milling characteristics and distribution of phytic acid and Zinc in long, medium and short grain rice. J. Cereal Sci. 48: 83-91.

Liang YC, Chen Q, Liu Q, Zhang WH and Ding RX. 2003. Exogeneous silicon (Si) increases antioxidant enzyme activity and reduce lipid peroxidation in roots of salt-stressed barley. J. Plant Physiol., 160: 1157-1164.

Lukaski HC. 2004. Vitamin and mineral status effects on physical performance. Nutrition. 20: 632-644.

Luo ZB, He XJ, Chen L, Tang L, Gao SHUN and Chen FANG. 2010. Effect of zinc on growth and antioxidents responses in Jatropha curcas seedlings. Int. J. Agric. Biol., 12: 119-124.

Mayer JE, Pfeiffer WH and Beyer P. 2008. Bio-fortified crops to alleviate micronutrient malnutrition. Curr. Opin. Plant. Biol. 11: 166-170.

McCall KA, Huang C and Carol AF. 2000. Function and mechanisms of Zinc metalloenzymes. J. Nut., 130: 1437-1446.

Naderi MR and Danesh SA. 2013. Nanofertilizers and their roles in sustainable agriculture. Inter. J. agric and crop Sci. 2229-2232.

Naiq KS and Das DK. 2008. Relative performance of chelated Zinc and zinc sulfate for low land rice. Nutr. Cycel. Agro. Eco. 81: 219-227.

Nazir Q, Arshad Q, Kanwal S and Mahmood S, 2014. Zinc deficient cereals in developing world. Technology Times. 05:37.

Nazir Q, Arshad M, Aziz T and Shahid M, 2016. Influence of zinc impregnated urea on growth, yield and grain zinc in rice (*Oryza sativa*). Int. J. Agric. Biol. 18: 1195-1200.

Obrador, Novillo AJ, and Alvarez JM, 2003. Mobility and availability to plants of two zinc sources applied to a cacarious soil. Soil Sci. Soc. Amer. J., 67: 564-572.

Oliveira AB and Nascimento CWA. 2006. Formas de manganese ferroem solos de de referência de Pernambuco. R. Bras. Ci Solo, 30(1): 99-110.

Oztirk L, Yazici MA, Toran A, Cekic C, Begic A, Ozkan H and Cakmak I. 2006. Concentration and localization of Zinc during seed development and germination in Wheat. Physiol. Plant. 128: 144-152.

Pathak GC, Gupta B and Pandey N. 2012. Improving reproductive efficiency of Chickpea by foliar application of Zn. Braz. Soc. Plant Physiol. 24(3): 173-180.

Peck AW and McDonald G.K. 2010. Adequate zinc nutrition alleviates the adverse effects of heat stress in bread wheat. Plant Soil. 337: 374- 389.

Pokhrel LR and Dubey B. 2013. Evaluation of developmental responses of two crop plants exposed to silver and zinc oxide nanoparticles. Sci. Environ. 452(453): 321-332.

Prasad R. 2005. Zn enriched urea in rice-wheat cropping system Adv. Agron. 86: 255- 339.

Prasad R. 2010. Zinc biofortification of food grains in relationto food security and alleviation of zinc malnutrition. J. Curr. Sci. 98: 1300-1304.

Quisumbing AR, Brown LR, Feldstein HS, Haddad L and Pena C. 1995. The Key to Food security. Food Policy Report. International Food Policy Research Institute, Washington, DC.

Rafique E, Rashid A, Ryan J and Bhatti AU. 2006. Zinc deficiency in rainfed wheat in Pakistan: Magntude, Spatial variability, management and plant analysis diagnostic norms. Commun. Soil Sci. Plant Anal. 37:181-197.

Rai V, Acharya S and Dey N. 2012. Implications of nano biosensors in agriculture. J. of Biomaterials and Nanobiotechnology 3: 315-324.

Ramesh A, Sharma SK, Sharma MP, Yadav N and Joshi OP. 2014. Inoculation of zinc solubilizing *Bacillus aryabhattai* strains for improved growth, mobilization and biofortification of zinc in soybean and wheat cultivated in Vertisols of central India. Appl. Soil Ecol. 73: 87-96.

Rashid A and Ryan J, 2008. Micronutrient constrains to crop production in the Near East: Potential significance and management strategies. In: Micronutrient Deficiencies in Global Crop Production. Alloway BJ. (ed.). Springer, Dordrecht, Netherlands. pp. 149-180.

Reeves PG and Chaney RL. 2008. Bioavailability as an issue in risk assessment and management of food cadmium: a review. Sci. Total Environ. 398: 13-19.

Rehman A, Yasin M, Akram M and Awan ZI. 2002. Response of Zn applied and N sources in calcarious soils. Science vis. 8(1): 100-104.

Rengel Z, Batten GD and Crowley DE. 1999. Agronomic approaches for improving the micronutrient concentration in edible portion of field crops. Field Crops Res. 60: 27-40.

Rengel Z and Graham RD. 1995. Importance of seed Zn contents for wheat growth on Zn deficient soils. I. Veg. growth. Plant sci. 173: 259- 266.

Rouached H. 2013. Recent developments in plant zinc homeostasis and the path toward improved biofortification and phytoremediation programs. Plant Signal Behav. 1: 1-8.

Ruane S. 2010. Agricultural biotechnologies in developing countries: Options and opportunities in crops, forestry, livestock, fisheries and agro-industry to face the challenges of food insecurity and climate change (ABDC - 10). Guadalajara, Mexico, 1-4 March, 2010. Background document to the FAO e-mail conference on “Learning from the past: Successes and failures with agricultural biotechnologies in developing countries over the last 20 years. Pp.1-18.

Sandstead H and Au W. 2005. Human Zinc deficiency: discovery to translocation. Adv. Nutr. 14(1): 76-81.

Saravanan VS, Madhaiyan M and Thangaraju M. 2007. Solubilization of Zinc Compounds by the diazotrophic, plant growth promoting bacterium Gluconacetobacter diazotrophicus. Chemisphere, 66: 1794-1798.

Shetty PS. 2009. Incorporating nutritional considerations when addressing food insecurity. *Food Security* 1, 431–440.

Shivay SY, Rajendra P, Rajiv KS and Madan P. 2015. Relative Efficiency of Zinc-Coated Urea and Soil and Foliar Application of Zinc Sulphate on Yield, Nitrogen, Phosphorus, Potassium, Zinc and Iron Biofortification in Grains and Uptake by Basmati Rice (*Oryza sativa* L.). J. of Agric Sci. 7(2):161-174.

Shivay YS, Prasad R and Rahal A. 2008. Relative efficiency of zinc oxide and zinc sulphate enriched urea for spring wheat. *Nutr. Cycl. Agroecosyst.* 82: 259–264.

Singh JP and Balasubramanian V. 1980. Organic recycling in Asian agriculture. In FAO organic recycling in Africa. FAO Soils Bulletin, 43: 235-278.

Singh K. 1992. Criticle soil level of Zinc for wheat grown in alkaline soils. Fert. Res. 31: 253-56.

Singh SP, Singa MK and Randhawa NS. 1979. Effect of Zn amended poultry manure and Zn sulphate on the growth and uptake of Zn by corn. Plant and soil. 52: 501-505.

Subramanian KS, Tenshia V, Jayalakshmi K and Ramachandran V. 2009. Roleof arbuscular mycorrhizal fungus in zinc nutrition of maize. Agric. Biotechnol. Sust. Dev., 1: 29-38.

Takkar PN, Singh MV and Ganeshamurthy AN. In Plant Nutrient Needs, Supply, Efficiency and Policy Issues: 2000–2025 (eds Kanwar JS, Katyal JC.), National Academy of Agricultural Sciences. 1997. New Delhi, 238–264.

Tapiero H and Tew KD. 2003. Trace elements in human physiology and pathology: zinc and metallothioneins. Biomed. Pharmacother. 57: 399-411.

Tariq M, Hameed S, Malik KA and Hafeez FY. 2007. Plant root associated bacteria for zinc immobilization in rice. Pak. J. Bot., 39: 245-253.

Tarkalson DD, Jolley VD, Robbins CW and Terry RE. 1998. Mycorrhizal colonization and nutrient uptake of dry beans in manure and composted manure treated subsoil and untreated topsoil and subsoil. J. Plant Nutr. 21: 1867-1878.

Thompson B, Amoroso L and Meerman J. 2009. Promoting the Expression ‘Food and Nutrition Security – FNS’. A Strategy Note from the Nutrition and Consumer Protection Division. Food and Agriculture Organization of the United Nations, Rome.

Tlustos P, Balik J, Pavlikova D, Szakova J and Kaewrahum S. 2000. The Accumulation of potentially toxic elements in spinach biomass grown on nine soils treated with sewage sludge. Rost. Vyroba. 46: 9-16.

Tolay I, Gulmezoglu N. 2004. Effect of Manganese and Zinc Foliar application on common bean. Baglar Campus, Eskisehir. Turkey.

United Nations Development Programme (UNDP). Human development report. 2003. Themillennium development goals: a compact among nations to end human poverty.

United Nations. 2012. World population prospects: The 2010 Revision. Online at http://esa.un.org/unpd/wpp/Documentation/publications.htm.

Vallee BL and Falchuk KH. 1981. Zinc and gene expression. Philos Trans R Soc. Lond Biol.Sci.294: 185-197

Waters BM, Uauy C, Dobcovsky J and Grusak, MA. 2009. Wheat NAM proteins regulate the translocation of iron, zinc and nitrogen compounds from vegetative tissues to grain. J. Exp Bot. 60: 4263-4274.

Welz B and Sperling M. 1999. Atomic absorbtion spectrometery. Weinheim: Wiley-VCH.

White PJ and Broadley MR. 2005. Biofortifying crops with essential mineral elements. Trends Plant Sci. 10: 586-593.

Whiting SN, De Souza M and Terry. 2001. Rhizosphere bacteria mobilize Zn for hyperaccumulator by Thlaspi caerulescens. Environ. Sci. Technol., 35: 3144-3150.

WHO. 2002. World Health Report 2002: Reducing Risks, Promoting Healthy Life. World health organization, Geneva, Switzerland.

WHO. 2012. World Health Report 2012: Reducing Risks, Promoting Healthy Life. World health organization, Geneva, Switzerland.

Yadav SG, Danish K, Shivay YS and Harmandeep S. 2010. Zinc enriched urea improves grain yield and quality of aromatic rice. Better crops. 94(2): 6-7.

Yadi R, Dastan S and Esmaeil Yasari. 2012. Role of zinc fertilizer on grain yield and some qualities parameters in irarian rice genotypes. Annal Bio. Research. 3(9): 4519-4527.

Yilmaz A, Ekiz H, Torun B, Gultekin I, Karanlik S, Bagci SA and Cakmak I. 1997. Effect of different zinc application methods on grain yield and zinc concentration in wheat grown on zinc-deficient calcareous soils in Central Anatolia. J Plant Nutr. 20: 461–471

Zhao FJ, Dunham SJ and Shewry PR. 2009. Variation in mineral micronutrient concentration in grain of wheat lines of diverse origin. J. Cereal. Sci. 49: 290-295.

Zhao K and Selim HM. 2010. Adsorption-desorption kinetics of Zn in soils: influences of phosphate. Soil Sci., 4: 145-153.