Life Science Informatics Publications
Research Journal of Life Sciences, Bioinformatics, Pharmaceutical and Chemical Sciences
Journal Home page http://www.rjlbpcs.com/
RJLBPCS
ISSN 2454-6348

Original Review Article **DOI: 10.26479/2018.0405.29**

BIOFORTIFICATION OF CROPS USING NANOPARTICLES TO ALLEVIATE PLANT AND HUMAN ZINC DEFICIENCY: A REVIEW

P Solanki, J S Laura*
Department of Environment Science, MDU, Rohtak, India.

ABSTRACT: Zn is essential plant nutrient for alltypes of crops. It is deficient in all parts of the globe with different types of soils. Under theseconditions application of Zn fertilizer is necessary for healthy crop growth and higher yields.Soil and foliar applications of Zn fertilizer are recommended for correcting deficiencies. Soilapplied Zn had a negative impact as the dissolution rates of conventional fertilizer is low, so more and more amount of these fertilizers are needed to be added. This leads to the adding huge amount of chemicals to be added to the soil which is toxic to plants. Small particles size and larger surface area of nanoparticles made it more effective be used as fertilizers. Zinc nanoparticles may have the potential to be used as fertilizers for increasing the growth of plants, grain zinc content to combat the human deficiency of zinc.

KEYWORDS: Micronutrients, Phosphates, Dissolution, Bioavailability.

Corresponding Author: Dr. J S Laura Ph.D.
Department of Environment Sciences, MDU, Rohtak, India.
Email Address: jitender.env.sc@mdurohtak.ac.in

1. INTRODUCTION

Micronutrient malnutrition –also called “hidden hunger” is a widespread global problem [1]. In addition to the direct health effects, the existence of micronutrient malnutrition has profound implications for economic development and productivity, particularly in terms of the potentially huge public health costs and the loss of human capital formation [2]. Dietary micronutrient deficiencies affect a large part of the global population. The World HealthOrganization estimates that globally some two billion people are affected by iron deficiency and around 750 million people suffer from iodine deficiency [2,3]. Also zinc deficiency is increasingly recognized as an important public health problem [4, 5, 6]. In recent years interest in the occurrence of human micronutrient deficiencies has been growing strongly, for several reasons. Human micronutrient deficiencies appear to be much more widely spread than previously thought and information on their geographical distribution is rapidly increasing [7]. There is a considerable amount of new information on the adverse health effects of various micronutrient deficiencies [8]. For example, over past decades it has become increasingly clear that iodine deficiency, apart from causing an enlarged thyroid gland (goiter), can also seriously impair intellectual development of infants and children [9]. And while some years ago there was only limited public health interest in zinc, now it is widely recognized that zinc deficiency is associated with suboptimal growth and reduced immune competence in children. There are a number of reasons for the occurrence of dietary micronutrient deficiencies. First, among poor populations overall food intakes are often below minimum requirements and as a result not only the intake of macronutrients (carbohydrate, fat, protein), but also the consumption of micronutrients (minerals, trace elements and vitamins) can be inadequate. Second, among poor communities diets are often highly monotonous, which increases the risk that the dietary intake of one or more specific micronutrients is below the amounts required for good health? A more specific situation arises when in a country or region the majority of locally produced foods have a low content of a specific mineral or micronutrient, as a result of the fact that the soils on which local foods are grown are low in their contents or availability of this nutrient. When in such places the people are largely dependent on locally produced foods, the intake of this nutrient will most likely be inadequate. Perhaps the oldest and most well known example is iodine. In various regions in the world (India, China) iodine deficiency disorders, such as cretinism and goiter, are widely prevalent and strongly related with low levels of iodine in local soils and, as a result, in foods grown on these soils or in drinking water derived from these soils [10]. In particular, zinc deficiency is now recognized as one of the most severe problems of human malnutrition world-wide [11,12]. It is estimated to affect up to one-third of the global human population [13] and is particularly frequent in India, Southeast Asia, and equatorial Africa.Also in agriculture, micronutrients are an issue of increasing interest and concern. Many research activities are being undertaken which address the relationships between micronutrient provision to plants and associated crop growth, and trace elements such as zinc, manganese and copper are increasingly recognized as essential when aiming for better yields [14, 15, 16, 17, 18, 19, 20, 21].

2. Role of Zinc in Plant Nutrition

Zinc is one of the 17 essential elements necessary for the normal growth and development of plants. It is among eight micronutrients essential for plants. Zinc plays a key role in plants with enzymes and proteins involved in carbohydrate metabolism, protein synthesis, gene expression, auxin (growth regulator) metabolism, pollen formation, and maintenance of biological membranes, protection against photo-oxidative damage and heat stress, and resistance to infection by certain pathogens [22,23,24,25,26]. Zinc deficiency in plants retards photosynthesis and nitrogen metabolism, reduces flowering and fruit development, prolongs growth periods (resulting in delayed maturity), decreases yield and quality, and results in sub-optimal nutrient-use efficiency. Some of the common deficiency symptoms of zinc in plants are light green, yellow or bleached spots in interveinal areas of older leaves; emerging leaves are smaller in size and often termed as "little leaf", and exhibit rosetting, ie, the internodal distance becomes so short that all the leaves appear to come out from the same point [27,28]. Zinc deficiency in crops resulting in heavy yield losses was reported in Afghanistan [25], Australia [29], Bangladesh [25], Canada [30], China [31], Great Britain [25], Turkey [32], India, [33], USA [34], Iraq [35], Pakistan [36,35] and Syria [34].

3. Available forms of Zinc in Soil

Zinc exists in five forms for plant uptake: a) as a free and complexed ion in soil solution; b) as a non-specifically adsorbed cation; c) as an ion occluded mainly in soil carbonates and Al oxide; d) in biological residues and living organisms; e) as lattice structures of primary and secondary minerals [37, 38].Zinc is taken up mainly as divalent cations (Zn^{2+}) by plant roots. However in some cases, organic ligand-Zn complexes are also absorbed by plant roots. Depending upon the ligand secreted by plants roots, two physiological strategies are involved in uptake of divalent cations like Zn^{2+}. Strategy one includes efflux of reductants, organic acids and H^{+} ions, which enhance solubility of Zn-Complexes (Zn phosphates, hydroxides etc.) and release Zn^{2+} ions for absorption by root epidermal cells, include citric acid, malic acid or oxalic acids etc. The other strategy involves afflux of Phytosiderophores which form stable complexes with Zn and their subsequent influx into root epidermal cells. However, this mechanism is limited to cereals roots only. Phytosiderophores are low molecular weight organic compounds which has high binding affinity for their respective metals resulting in their chelation and acquisition [20].

4 Zinc deficiency in soils

Zinc has emerged as the most widespread micronutrient deficiency in soils and crops worldwide, resulting in severe yield losses and deterioration in nutritional quality [34]. It is estimated that almost half of the soils in the world are deficient in zinc. Since cereal grains have inherently low concentrations, growing them on these potentially zinc-deficient soils further decreases grain zinc concentration. The Food and Agriculture Organization of the United Nations (FAO) estimates that 50% of world's soils growing cereal grains are zinc deficient. It further estimates that agricultural production must increase by 70% by 2050 to feed over 9 billion people worldwide.India is no exception. Analysis of over 256,000 soil samples from all over India showed that about 50% of the soils were deficient in zinc (Fig. 1) and that this was the most common micronutrient problem affecting crop yields in India. The reasons for the increase of incidences of zinc deficiency include large zinc removals due to high crop yields and intensive cropping systems, less application of organic manures, use of high analysis fertilizers (such as urea and DAP in place of AS and SSP), increased use of phosphate fertilizers resulting in phosphorus induced zinc deficiency and the use of poor quality irrigation water. The soil conditions that commonly lead to zinc deficiency in crops are low total zinc concentrations, such as sandy soils; highly weathered parent materials with low total zinc contents, such as tropical soils; high calcium carbonate contents, such as calcareous soils; neutral or alkaline pH, as in heavily limed soils or calcareous soils; high salt concentrations, ie, saline soils; peat and muck, as in organic soils; and high phosphate status; prolonged water logging or flooding, as in rice soils; and high magnesium and/or bicarbonate concentrations in soils or irrigation water [25].

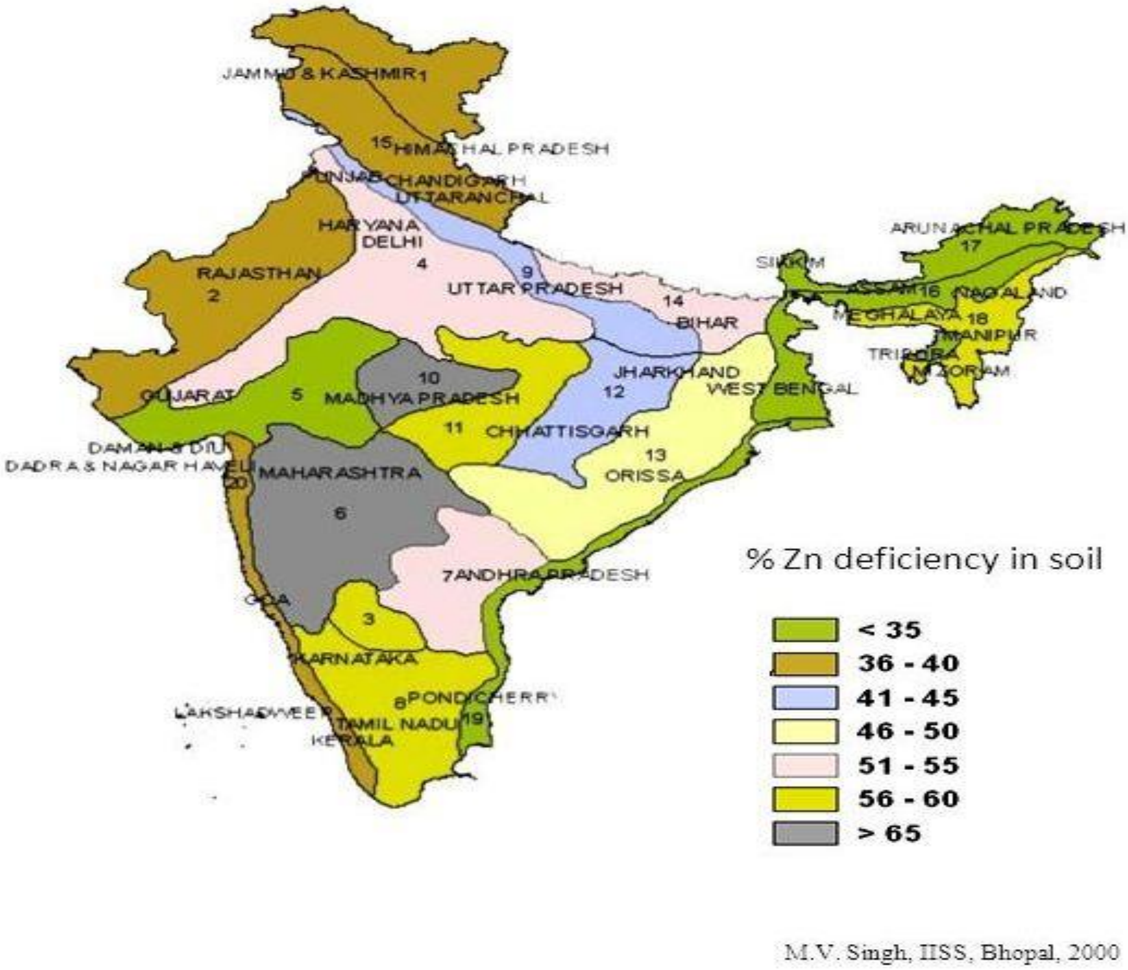

Figure 1: Map showing extent of Zinc deficiency in India

Zinc deficiency in India is expected to increase from the present level of around 50% to 63% in 2025 if the current trend continues. This is also because increasing areas of marginal lands are brought under intensive cultivation without adequate micronutrient supplementation. About 50% or more soil samples tested were deficient in zinc in Maharashtra, Karnataka, Haryana, Tamil Nadu, Bihar, Orissa and Meghalaya. Increased cropping intensity in marginal lands and less use of micronutrients in the states of Bihar, Tamil Nadu, Maharashtra, Karnataka, Chhattisgarh, Jharkhand and the hill region has further escalated the magnitude of zinc deficiency. The states of Punjab, Haryana and part of Uttar Pradesh have, however, shown a build-up of zinc status and decline in zinc deficiency. This likely is due to greater awareness and use of zinc fertilizers by the farmers. This success story needs to be replicated elsewhere in the country.Zinc deficiency is also widespread in soil types and climatic regions where primarily dryland/rainfed farming is practiced [39,40,41]. In these rainfed areas, farmers' fields found to be deficient in zinc were: 82% (out of 1926 samples) in Andhra Pradesh, 82% (out of 82 samples) in Gujarat, 74% (out of 1260 samples) in Karnataka, 18% (out of 28 samples) in Kerala, 100% (out of 73 samples) in Madhya Pradesh, 15% (out of 179 samples) in Rajasthan and 61% (out of 119 samples) in Tamil Nadu. These data show that zinc deficiency is widespread in the rainfed fields of the Indian semi-arid tropics. In a survey of soils across 21 districts, zinc deficiency was widespread. More than 75% soil samples were found to be deficient in zinc in 43% districts [40].

5 Soil Factors Associated with Zn Deficiency

Zinc deficiency is common throughout the arid and semi-arid regions of the world [29] due to low Zn solubility and high Zn fixation under such conditions [42]. A significant amount of Zn is present in the soil matrix, but only a small fraction of that is available to plants [43]. Several soil factors and conditions may render soils deficient in total and available Zn. Weathered parent material, nature of clay minerals, alkaline pH, sandy texture, high salt concentrations, calcareousness, water logging or flooding, organic matter content, high magnesium and/or bicarbonate concentrations (also in irrigation water), more nutrient uptake than application, intensive cultivation and the use of high analysis fertilizers (i.e., poor in micronutrients) are considered to be the major factors associated with the occurrence of Zn deficiency [25]. Variations in soil pH, lime content, organic matter, clay type and the amount of applied phosphorus fertilizer can significantly affect the Zn bioavailability [44]. Apart from other factors, Zn deficiency is one of the factors responsible for low yield. The introduction of high yielding crop varieties in the past and their imbalanced fertilization also contributed towards Zn deficiency in many parts of the world. The problem of Zn deficiency, especially in the developing world, has been further aggravated due to a lack of information on Zn sensitivity and by growing cultivars, which are highly susceptible to Zn deficiency. All types of soil may be affected by Zn including: loams, sands, clays, loess, alluvium and soils formed from basalt, sandstone, granite, volcanic ash and many other rocks. In general, soils of arid and semi arid regions and the slightly acidic, leached soils of warm and tropical climates are most inclined to Zinc deficiency, however crops are not equally susceptible to Zn deficiency and at the same soil some crops may suffer from zinc deficiency while others are not affected. Major Zn deficiency causes include 1). Soils of low zinc content, 2). Soils with restricted zones, 3) pH, 4). Soils low in organic matter, 5). Microbially inactivated Zn, 6). High level of available phosphorous.

5.1 Parent material of soils and Zn content

The amounts of Zn in unpolluted soils typically are lower than 125 ppm [45,46]. The major factors affecting the concentration of Zn in soils is the concentration of Zn in soil parent material. The soils derived from gneisses and granites can be low in total Zn and also those originating from sandstone and limestone had lower Zn contents [47, 48]. Quartz in the soils dilute soil zinc, as quartz has very low Zn concentration with range between 1-8µg/g [49]. Also total Zn is low (30µg/g) in highly leached acid sands. The total Zn concentrations in soils vary between 10-300µg/g with an average of 50µg/g. But the available Zn varied from 1-3µg/g. The problem is that only a small amount of soil Zn is available to the crop because of one or more adverse factors. The remainder of the total Zn is fixes in the soil in an insoluble or un-exchangeable form and difficult to make available to crop.

5.2 Soil pH

Zinc availability is highly dependent on pH. When the pH is above 6, the availability of Zn is usually very low. The availability of Zn in alkaline soils is reduced due to lower solubility of the soil Zn. The concentration of Zn in the soil solution decreases from 10^{-4} to 10^{-7} M with an increase from pH 5- 8 [50]. Thus it is more probable that Zn deficiency will occur in alkaline rather than acidic soils. The solubility constant values of $ZnCO_3$ and hydroxides suggest that a soil having high pH would usually contain a small amount of available Zn. In the case of soils characterized by high contents of hydroxyl ions, it is difficult to get a crop response even to applied Zn. The lower availability of Zn under alkaline conditions is attributed to the precipitation of Zn as $Zn(OH)_2$ or $ZnCO_3$[51,52]. The concentration of Zinc in shoots of *Thlaspi caerulescens* was found to be highest at lower pH [53] and the uptake by plant decreases with the increase in the pH. According to a study conducted by [54], the soil pH and uptake of Zn by plants shows a negative correlation. Increasing soil pH, especially above 6.5 results in decreased extractability and plant availability of Zn to plants [55]. Availability of zinc decreases with increasing soil pH due to increased adsorptive capacity, the formation of hydrolysed forms of zinc, possible chemisorption on calcium carbonate and co-precipitation in iron oxides. Alkaline, calcareous and heavily limed soils tend to be more prone to zinc deficiency than neutral or slightly acid soils.

5.3 Soil organic matter

Low organic matter contents in soils give rise to Zn deficiency as it is observed that availableZn increases with increase in organic matter in soil. Soil organic matter is an important soil constituent which originates from decomposition of animal and plant products. The most stable organic compounds in soil are humic substances such as humic and fulvic acids. Both of these substances contain a relatively large number of functional groups (OH, COOH, SH) which have a great affinity for metal ions such as Zn^{2+}. Fulvic acids mainly form chelates with Zn over a wide pH range and increases the solubility and mobility of Zn [50]. Simple organic compounds such as amino acids, hydroxyl acids and also phosphoric acids are effective in complexing Zn, thus increasing its mobility and solubility in soils [56]. An increase in the organic matter contents of a soil will increase its Zn availability; however, if the organic matter content in soil is too high, like in peat and muck soils, this can also contribute to Zn deficiency due to the binding of Zn on solid state humic substances [57].A positive correlation has been observed between the soil organic matter and plant zinc uptake [54]. Soil Zn is usually more available in soils with greater organic matter content [58]. Available zinc concentrations in soils with high organic matter contents (peat and muck soils) may be low due to either an inherently low total concentration in these organic materials and/or due to the formation of stable organic complexes with the solid-state organic matter.

5.4 Soil texture

Lighter textured soils (sands) contain low levels of Zn. Fine textured soils like clay have higher CEC values and therefore have highly reactive sites and can retain more Zn than lighter textured soils [51]. Therefore heavier textured soils with larger CEC have higher capacities for Zn adsorption than light textured soils [48]. Consequently, Zn deficiency is more likely to occur in sandy than clayey soils. Clay soils absorb Zn and this adsorption is controlled by CEC and pH [59]. The soil zinc is more available in fine textured soil like clay [60,25]. Sandy soils and acid highly leached soils with low total and plant-available zinc concentrations are highly prone to zinc deficiency [25].

5.5 Phosphate fertilizers

Soils with higher phosphate levels, either from native P or due to application of phosphate fertilizers, can cause Zn deficiency stress in crops [25]. Heavy application or prolonged use of phosphate fertilizers reduces Zn uptake by plants. This effect may be due to the physiological imbalances within the plant [61]. Zinc deficiency due to phosphorus application is termed "P-induced Zn deficiency" [33]. According to [62], Zn extractability and plant availability is negatively related to the phosphate content in the soil.

6 Human Zinc nutrition and deficiency

Zinc is an essential component of a large number (>300) of enzymes participating in the synthesis and degradation of carbohydrates, lipids, proteins, and nucleic acids as well as in the metabolism of other micronutrients. It also plays a central role in the immune system, affecting a number of aspects of cellular and humoral immunity [63]. Similarly, zinc is an essential nutrient for human health. It is vital for many biological functions in the human body. The adult body contains 2–3 g of zinc. It is present in all parts of the body including organs, tissues, bones, fluids and cells. It is vital for more than 300 enzymes in the human body, activating growth (height, weight and bone development), growth and cell division, immune system, fertility, taste, smell and appetite, skin, hair and nails, and vision. Some of the reported symptoms due to zinc deficiency in humans, especially in infants and young children include dwarfism (growth retardation), dermatitis (alopecia), impaired neurology, decreased immune function, infections and death. In industrialized countries, cases of mild zinc deficiency can be observed. The most common symptoms include dry and rough skin, dull hair, brittle finger nails, white spots on nails, reduced taste and smell, loss of appetite, mood swings, reduced adaptation to darkness, frequent infections, delayed wound healing, dermatitis and acne

[65]. The clinical features of severe zinc deficiency in humans are growth retardation, delayed sexual and bone maturation, skin lesions, diarrhea, alopecia, impaired appetite, increased susceptibility to infections mediated via defects in the immune system, and the appearance of behavioral changes [65, 66, 67]. The effects of marginal or mild zinc deficiency are less clear. A reduced growth rate and impairments of immune defense are so far the only clearly demonstrated signs of mild zinc deficiency in humans. Other effects, such as impaired taste and wound healing, which have been claimed to result from a low zinc intake, are less consistently observed [68]. Human population zinc deficiency in an area is highly correlated with zinc deficient soil of that area. It is estimated that about one-third of the world's population suffers from zinc deficiency.Low dietary zinc intake is in general the main cause of zinc deficiency. Zinc deficiency is a problem particularly in regions where the population consumes mainly cereals and where soils are low in phyto-available zinc, as for instance in India [69]. In the developing world, cereal grains provide nearly 50% of the daily calorie intake of the population. This could be as high as 70% in rural areas. Although cereals provide a major part of the total dietary zinc intake in these areas, they are not ideal as sources of nutritional zinc, because they contain high concentrations of phytate, which complexes zinc and hinders its absorption in the human intestine [70,71,72]. While the problem of zinc deficiency in developing countries was recognized decades ago [73]. however the link between human zinc deficiency and low zinc levels in soils and crops has been recognized only recently. [74] found that soil zinc deficiency translated into low zinc concentrations in rice and these in turn into low serum zinc levels of the local population in Andhra Pradesh, as long as there was no sufficient supply from other sources of protein in the diet. It was found that there was a clear link between low zinc status in Central Anatolian soils, zinc deficiency in wheat and zinc malnutrition in school children [75].

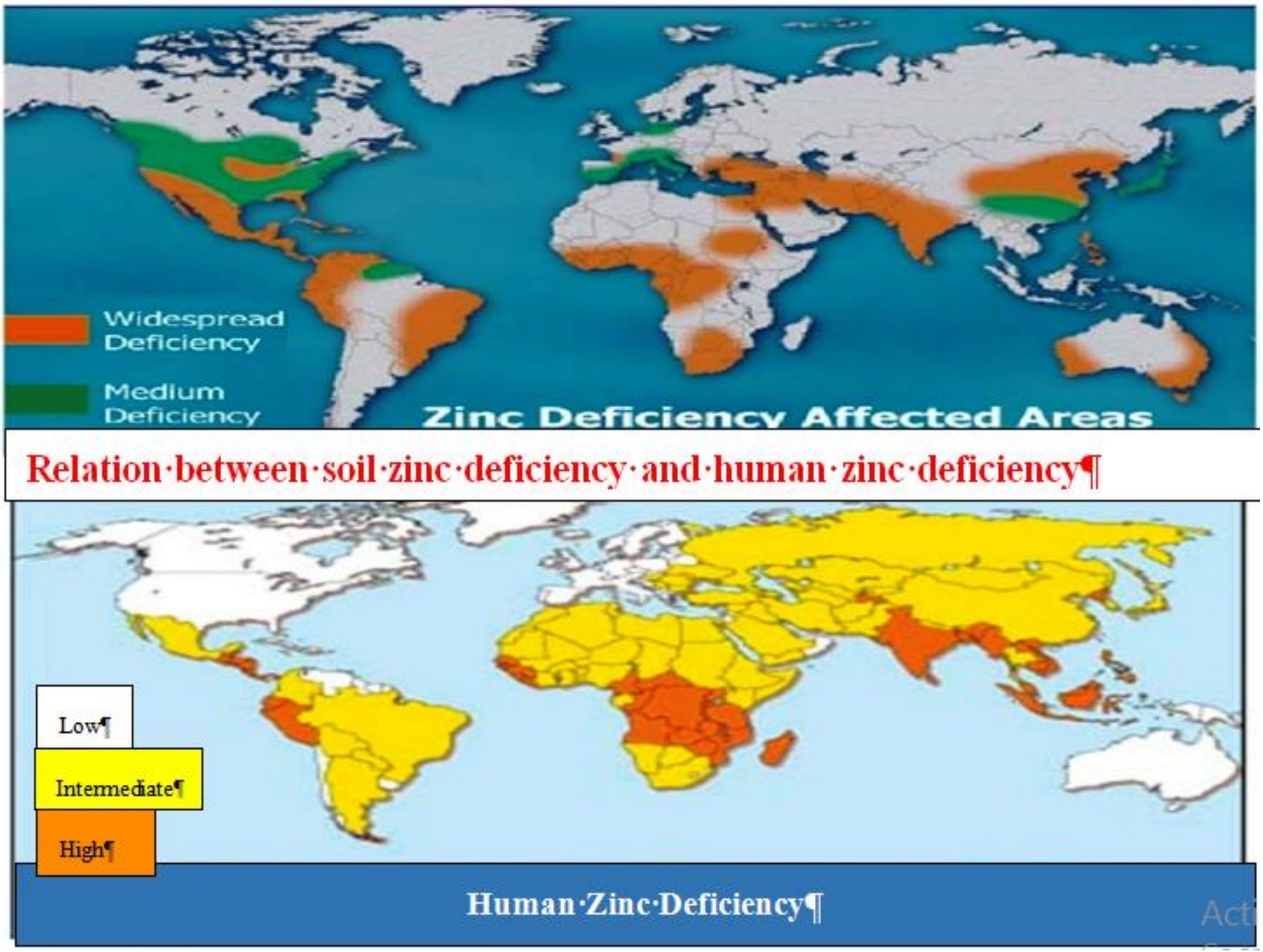

Figure 2: Showing the relation between soil zinc deficiency and human zinc deficiency

6.1 Groups at High Risk

Compared to adults, infants, children, adolescents, pregnant and lactating women have increased requirements for zinc and thus are at increased risk of zinc depletion [76].

6.1.1 Infants and children

Young children are at greater risk of zinc deficiency because of increased zinc requirements during growth. Exclusively breast-fed infants of mothers with adequate zinc nutrients obtain sufficient zinc for the first 5-6 months of their life [77]. After this age, complementary foods containing absorbable zinc are required to satisfy their requirements. In many low-income countries, complementary feeding is delayed and cereal foods are then used for feeding. These foods have low content of total and absorbable zinc and thus fail to meet the needs for zinc. Conversely, early introduction of such foods may interfere with the absorption of zinc from breast milk due to their high phytate content [78]. Zinc requirements of malnourished children are estimated to be between 2-4 mg/kg body weight [79]. These requirements are much higher than those for healthy children (0.17 mg/kg at 1-3 years), presumably because of prior zinc depletion and reduced zinc absorption due to changes in the intestinal tract.

6.1.2 Adolescents

The physiological requirements for zinc peak during adolescence at the time of the pubertal growth spurt, which generally occurs in girls between 10-15 years and in boys between 12-15 years. Even after the growth spurt has ceased, adolescents may require additional zinc to replenish depleted tissue zinc pools [80].

6.1.3 Pregnant and lactating women

Increased nutritional demands during pregnancy and lactation predispose women to zinc deficiency [81]. These demands are greater during lactation, although physiological adjustments in zinc absorption help to meet the needs for lactation. A number of studies have demonstrated a negative impact of therapeutic supplemental iron on zinc absorption during pregnancy [82, 83]. and lactation [84]. In pregnant women, where dietary intakes of zinc were low, supplemental iron, in dosages as low as 60 mg/ day prevented those from meeting their needs for zinc [82]. Situations that seem most likely to encounter problematic interactions are those in which the iron is administered in solution or as a separate supplement rather than incorporated into a meal [85].

6.1.4 Elderly

Diet surveys indicate that zinc intakes by elderly persons are often inadequate, even in rich countries [86]. Several factors may contribute to poor zinc nutrition among the elderly, in particular, reduced consumption of zinc-rich foods. In addition, there is some evidence that the efficiency of zinc absorption may decrease with age.

6.2 Functional Impairments of Zinc deficiency in Humans

6.2.1 Growth and development

One of the most studied clinical features related to zinc deficiency is the impairment of physical growth and development [87, 88]. The mechanisms involved, however, are not well understood. This effect is of most significance during the periods of rapid growth such as pregnancy, infancy and puberty during which zinc requirements are highest [77].

6.2.2 Risk of Infections

Diarrhea: Diarrhea is characteristically, although not inevitably, a prominent feature of acrodermatitisenteropathica[65, 12]. Plausible explanations for a link between zinc deficiency and diarrhea include impairment of the immune system and of intestinal mucosal cell transport [89]. A causal relationship between zinc deficiency and diarrhea is indicated by the beneficial effects of zinc supplements and concurrent increase in growth velocity [90, 91].

6.2.3 Pneumonia

Community zinc supplementation studies in children have demonstrated a substantial and statistically significant reduction in the prevalence of pneumonia in developing countries [90, 77].

7 Fortification of food crops

Biofortification is the process of increasing the content and/or bioavailability of essential nutrients in crops during plant growth through genetic and agronomic pathways [92]. It is a more cost-effective and sustainable strategy to overcome micronutrient malnutrition than supplementation. Where micronutrient deficiency is widely distributed in a population and dietary modification or diversification is difficult to achieve, fortification of centrally processed foods is an appropriate alternative. Mexico provides an example of a country with a nationwide zinc fortification program. Apart from zinc, other micronutrients are added to wheat and corn flours that are used in preparing bread and tortilla, the two principal staple foods in the country. For such multiple interventions synergistic and antagonistic interactions between micronutrients have to be taken into account during the development of appropriate formulations [63]. Fortification programs can also be specifically targeted to increase the intake of zinc in groups of high risk such as infants and young children who consume particular type of food. In many countries, infant formulas and complementary foods are currently fortified with zinc and other micronutrients. Commercially available standard infant formulas contain zinc in concentrations of around 1 mg/L, following current recommendations. In general, the food selected for fortification should be one that is widely consumed in stable and predictable amounts. Among several zinc compounds that are available for fortification, zinc oxide and zinc sulfate are least expensive and most commonly used by the food industry. Suggested levels for fortification of flour are 30-70 mg zinc/kg [93]. Zinc sulfate theoretically provides more absorbable zinc because of its greater solubility, but it is more expensive.

7.1 Methods of Zinc Fortification

Biofortification is an agricultural strategy that aims to increase the content of select micronutrients, including zinc, in staple food crops such as rice, wheat, maize, pearl millet, and others [77]. Dietary zinc intakes can be increased through a variety of interventions [66]. These include both agronomic and genetic biofortification of edible crops [94, 95,96]. Genetic biofortification involves either genetic engineering or classical breeding, the development of crop genotypes that acquire more zinc from the soil and accumulate it in edible portions [97] and agronomic fortification strategies include the application of zinc fertilizers [95]. Agronomic biofortification can be achieved by increasing soil zinc phytoavailability or by applying zinc fertilizers. The biofortification strategy seeks to take advantage of daily consumption of certain food items. It targets towards women and children in particular as they are more prone to micronutrient malnutrition. As a consequence of the predominance of food staples in the diets of the poor, this strategy implicitly targets low-income households [98].

7.2 Agronomic Fortification

Application of zinc fertilizers to soil and/or foliar seems to be a practical approach to improving grain zinc concentration (e.g., agronomic biofortification). Very recently, a global zinc fertilizer project has been initiated, so called HarvestZinc project (www.harvestzinc.org) under HarvestPlus program. This project aims at evaluating the potential of zinc containing fertilizers for increasing zinc concentration of cereal grains (e.g., wheat, rice and wheat) and improving crop production in different target countries (e.g., India, China, Pakistan, Thailand, Turkey, Mozambique, Zimbabwe and Brazil). The zinc fertilizer strategy represents an important complementary approach to ongoing breeding programs for developing new genotypes with high zinc density in grain. As described in HarvestZinc project (www.harvestzinc.org), biofortification of cereal grains through use of zinc fertilizers (e.g., agronomic biofortification) is required for i) keeping sufficient amount of available zinc in soil solution, ii) maintaining adequate zinc transport to the seeds during reproductive growth stage and iii) optimizing the success of biofortification of staple food crops with zinc through use of breeding tools. Increasing evidence is available indicating that soil and/or foliar applications of zinc fertilizers greatly contribute to grain zinc concentrations [69]. In the past, numerous studies have been published on the role of soil- and foliar-applied zinc fertilizers in order to correct zinc deficiency and increase yield. However, there are only few studies that investigated the effects of zinc fertilizers on grain zinc concentrations (or in other edible parts). Zinc sulfate ($ZnSO_4$) is the widely applied source of zinc because of its high solubility and low cost. In Central Anatolia, application of $ZnSO_4$ fertilizers was very effective in increasing grain zinc concentration of wheat and foliar-applied zinc resulted in much greater increases in grain zinc concentration than the soil application of zinc. It seems that combined application of soil and foliar zinc fertilizers is the most effective way to maximize grain zinc accumulation. Besides improving grain zinc concentrations, these soil or foliar zinc applications resulted also in significant increases in plant growth and grain yield in various locations in Central Anatolia [76]. However Zn being heavy metal, indiscriminate application of Zn fertilizers to soil over years will lead to accumulation in soil to the levels toxic to the plants. With the current emphasis on Zn in agriculture, care should be taken not to overuse Zn fertilizers. Therefore, an efficient mechanism to reduce the amount of Zn fertilizer application to soil/ foliar without compromising the plant growth and yield is very essential. Hence, in recent years the application of nano-scale particle of Zn is being preferred to enhance agronomic effectiveness of Zn fertilizers. Now, after years of green revolution and decline in the ratio of agricultural products to world population growth, it is obvious that there is necessity of employing new technologies in the agriculture industry more than ever. Modern technologies such as bio and nanotechnologies can play an important role in increasing production and improving the quality of food produced by farmers. Many believe that modern technologies will secure growing world food needs as well as deliver a huge range of environmental, health and economic advantages. Nanotechnology is one of the most important tools in modern agriculture, and agri-food nanotechnology is anticipated to become a driving economic force in the near future. Nano-agriculture focuses currently on target farming that involves the use of nano-sized particles with unique properties to boost crop and livestock productivity. The development of nano-materials could open up the novel applications in plant biotechnology and soil science. It is anticipated that very soon the industrial production of manufactured nano-particles will be increased by manifold and released into the market. However with significant potential benefits, there are considerable uncertainties with regards to potential risks to the environment and human health that needs to be clarified.

7.3 Application of nano zinc oxide

In recent years the application of nano scale particle of Zn is being preferred to enhance the uptake by plants. Particle size may affect agronomic effectiveness of Zn fertilizers. Decreased particle size results in increased number of particles per unit weight of applied Zn and also increases the specific surface area of a fertilizer, which will increase the dissolution rate of fertilizers with low solubility in water such as Zn oxide (ZnO) [99]. Granular Zn sulphate ($ZnSO_4$) (1.4 to 2 mm) was somewhat less effective than fine $ZnSO_4$ (0.8 to 1.2 mm) whereas granular ZnO was completely ineffective [100]. Gradual increase in Zn uptake could be observed with decreasing granule size. Since granules of 1.5 mm weigh less than granules of 2.0 or 2.5 mm, smaller granules were used for the same weight, resulting in a better distribution of Zn and the higher surface area of contact of Zn fertilizer resulted in better Zn uptake [101]. Therefore ample work has been done and emphasis was made on the particle size to increase the efficiency of the fertilizers for better uptake and higher yields. ZnO NPs were used during the seed germination and root growth of *Cicer arietinum*. The effect of ZnO NPs has been observed on the seed germination and root growth of *Cicer arietinum* seeds. ZnO nanoparticles (NPs) have been synthesized by hydrothermal method. This hydrothermally synthesized product has been characterized by powder X-ray diffraction and field emission scanning electron microscopy (FE-SEM) for the study of crystal structure and morphology/size. FESEM image revealed that ZnO NPs are spherical in shape with a diameter of 20–30 nm. The effect of these ZnO NPs on the reactivity of phytohormones, especially phyto stimulatory actions of Indole acetic acid (IAA) is also carried out. Due to oxygen vacancies, the oxygen deficient, i.e. Zn-rich ZnO NPs increased the level of IAA in roots (sprouts), which in turn indicate the increase in the growth rate of plants as Zn is an essential nutrient for plant [102]. The effect of nano ZnO particles on the growth of plant seedlings of mung (*Vigna radiate*) and gram (*Cicer arietinum*) was studied by conducting experiment in agar media. Various concentrations of nano ZnO particles in suspension form were introduced to the agar media and their effect on the root and shoot growth of the seedlings was examined. The main experimental approach using correlative light and scanning electron microscopy provided evidence of adsorption of nanoparticles on the root surface. Absorption of nanoparticles by seedlings root was also detected by inductive coupled plasma/atomic emission spectroscopy (ICP-AES). It was found that at certain optimum concentration, the seedlings displayed good growth over control and beyond that retardation in growth was observed due to toxicity [103]. Effectiveness of ZnO was studied on seed germination, seedling vigour, plant growth, flowering, chlorophyll content, pod yield and root growth of peanut. Peanut seeds were treated with different concentrations of nano ZnO along with chelated Zn Sulphate ($ZnSO_4$). Treatment of nano scale ZnO (25 nm mean particle size) at 1000 ppm concentration promoted both seed germination and seedling vigour and in turn seedlings showed early establishment in soil. Higher leaf chlorophyll content and manifested in early flowering. These particles proved effective in increasing stem and root growth. Pod yield per plant was 34 % higher compared to chelated bulkZnSO4 [104]. Spraying optimum concentrations of nano-ZnO, nano-FeO and nano-Zn-Cu-Feoxide in suspension form on hydroponically grown test units of Mung (*Vigna radiata*) seedling and examining the effect on the shoot growth of seedlings, found that the seedlings displayed good growth over control, demonstrating a positive effect of the nanoparticle treatment. The best performance was observed for nano Zn/CuFe-Oxide followed by nano FeO and nano ZnO. Increased absorption of nanoparticles by plant leaves was also detected by inductive coupled plasma/atomic emission spectroscopy [105]. Different concentration (0.0, 10, 20, 30 and 40 g ml/L) of nano ZnO particles were used for the treatment in onion seeds to study the effect on cell division, seed germination and early seedling growth. Investigators observed decreased Mitotic Index (MI) and increase in chromosomal abnormalities in higher treatments of zinc oxide nanoparticles. Seed germination increased in lower concentrations, however showed decrease in values at higher concentrations. Germination indices showed increased values in lower concentrations; however these decreased significantly at higher concentrations [106]. It was reported an increase in length, width and surface area of leaf, increased protein content and dietary fiber in Spinach sprayed with ZnO NPs at a concentration of 500 PPM [107]. Increased yield and nutritional quality of pomegranate (*Punica granatum cv. Ardestani.*) has also been reported by [108] with foliar application of Zn nanofertilizer. In a study conducted by [109], on *Capsicum annuum* L. it was observed that the percentage germination, root growth, shoot growth increased with increasing the concentration of ZnO NPs from 0-2000ppm in a petri-plate experiment.Similarly, seed priming of wheat with ZnO NPs at a concentration of 0, 25, 50, 75 and 100 PPM increased the growth characteristics, biomass and the content of Zn in roots, shoots and grains of wheat with ZnO NPs than control in a pot experiment. It was hence confirmed that nanoparticles could be a source of Zn aiming to reduce Zinc deficiency in plants [110].

2.CONCLUSION

Micronutrient deficiency is a global problem affecting the plant and humans adversely. Since the amount of zinc in parent soil material is very low, moreover various soil factors like pH, Organic matter, phosphate in soil, texture of soil affects the uptake of zinc by plants and finally leading to diet based low zinc in the humans. Various enzyme activation, pollen formation in plants are directly linked to the content of zinc as micronutrient. Moreover the growth and development in humans is influenced by the zinc in their diet. The available zinc in the World soil is relatively very low; hence there is a widespread zinc deficiency in humans in those areas. Fortification of food crops can be a substitute to the problem which will help to promote plant growth, increased yield and grain zinc density many folds. But huge quantities of conventional fertilizers have been added to overcome the soil zinc deficiency, which leads to soil toxicity. Nanoparticles can be a replacement to the conventional fertilizers with small size, larger surface area. Various studies have shown that using Zn Nanoparticles have increased uptake of Zinc and its assimilation in grains. Consuming these grains can help to alleviate the human zinc deficiency. So reviewing the current studies available it can be concluded that there is need to study the use of nanoparticles in agriculture with field trails.

CONFLICT OF INTEREST

Authors do not have any conflict of interest.

REFERENCES

1. Welch RM. The impact of mineral nutrients in food crops on global human health. Plant and Soil. 2002;247:83-90.
2. WHO. Preventing and Controlling micronutrient deficiencies in populations affected by an emergency, WHO, WFP, UNICEF. 2006.
3. UNICEF. State of the World's Children. New York.2008.
4. Ramakishnan U. Prevalence of micronutrient malnutrition worldwide, *Nutri Reviews*. 2002; 60(II):S46-S52.
5. Black RE. Micronutrient deficiency-an underlying cause of morbidity and mortality. B of the World Health Org. 2003a;81-79.
6. Black RE. Zinc deficiency, infectious diseases and mortality in the developing World. J of Nutri. 2003b; 1:1484S-1489S.
7. ACC/SCN. Nutrition for improved development outcomes. Fifth Report on the World Nutrition Situation. Standing Committee on Nutrition, Geneva, 2004.
8. Black RE. Micronutrients in pregnancy. British J of Nutri. 2001;2:S193-197.
9. WHO. Iodine status worldwide, WHO Global Database on Iodine Deficiency, de Benoist B, Andersson, M, Egli I, Takkouche B, Allen H, Editors, World health Organization, Geneva. 2004.
10. Abrahams PW. Soils: Their Implications to human Health. The Science of the Total Environ. 2002; 291:1-32.
11. Prasad AS Discovery and importance of zinc in human nutrition. Fed. Proc.1984;43: 2829-2834.
12. Gibson RJ and Keefe DM. Cancer chemotherapy-induced diarrhoea and constipation: mechanisms of damage and prevention strategies.Support Care Cancer. 2006;14(9):890-900.
13. Hotz C, Brown KH. Assessment of the risk of zinc deficiency in populations and options for its control. Food Nutr Bull. 2004;25:S91–S204.
14. White JG, Zasoski RJ. Mapping soil micronutrients. Field Crops Res. 1999;60:11-26.
15. Mann EN, de Resende PM, Mann RS, de Carvelho JG, Von Pinho EVD. Effect of manganese application on yield and seed quality of soybean. Pesquisa Agropecuaria Brasileira. 2002;37:1757-1764.

16. Sotomayor-Ramirez D, Gonzalez-Velez A, Roman-Paoli E. Yam (Dioscorea spp.) response to fertilization in soils of the semiarid southern coast of Puerto Rico. J of Agri of the University of Puerto Rico. 2003;87:91-103.
17. Fageria NK, Breseghello F. Nutritional diagnostic in upland rice production in some municipalities of State of Mato Grosso, Brazil. J of Plant Nutri. 2004;27: 15-28.
18. Rashid A, Ryan J. Micronutrient constraints to crop production in soils with Mediterranean-type characteristics- A review. J of Plant Nutri. 2004;27: 959-975.
19. Welch RM, Graham RD. Breeding for micronutrients in staple food crops from a human nutrition perspective. J of Experi Bot. 2004;55:353-364.
20. Gupta AP. Micronutrient status and fertilizer use scenario in India. J of Trace Elements in Medicine and Biol.2005;18:325-331.
21. He ZL, Yang XE, Stoffella PJ. Trace elements in agro ecosystems and impacts on the Environment. J of Trace Elements in Medicine and Biol. 2005;19: 125-140.
22. Marschner H. Mineral Nutrition of Higher Plants. Academic Press, London. 1995.
23. Cakmak I. Plant nutrition research: Priorities to meet human needs for food in sustainable Ways. Plant and Soil. 2002;247:3-24.
24. Kasim WA. Physiological consequences of structural and ultra-structural change sinduced by Zn stress in *Phaseolus vulgaris*.I. Growth and Photosynthetic apparatus. Int. J. Bot. 2007;3(1):15-22
25. Alloway BJ. Zinc in soils and Crops production. International Zinc Association, Brussels, 2008.
26. Tavallali V, Rahemi M, Eshghi S, Kholdebarin B, Ramezanian A. Zinc alleviates salt stress and increases antioxidant enzyme activity in the leaves of pistachio (*Pistacai vera* L.) seedlings, turk. J Agr. Forest. 2001:34(4):349-359.
27. Snowball K, Robson AD. Symptoms of Nutrient Deficiencies: Lupins.University of Western Australia Press, Nedlands Australia. 1986.
28. Brennan RF, Armour JD, Reuter JD. Diagnosis of Zinc Deficiency. In Robson, A. D. Kluwer (ed.) Zinc in soils and plants.(pp. 167-181) Dordecht: Academic Publisher. 1993.
29. Takkar PN, Walker C. The Distribution and Correction of Zinc Deficiency. In A.D. Robson (ed). Zinc in Soils and Plants London: Kluwar Academic publisher; 1993; 51.
30. ILZRO. Zinc in Crop Nutrition, International Lead Zinc Research Organisation Inc, Research Triangle Park. 1975.
31. Xie J, Xing W, Zhou J. Current use and requirement for nutrients for sustainable food production in China. In: Johnston, A. and Syers, J. (eds). Nutrient Management for Sustainable Crop Production in Asia. CAB International, Wallingford, Connecticut, USA. 1998;267-277.
32. Yakan H, Gurbuz MA, Avsar F, Surek H, Beser N. The effect of zinc application on rice yield and some agronomic characters. CIHEAM-Options mediterraneennes.2000;58:1-5.

33. Singh JP, Karamonas RE, Stewart JWB. Phosphorus-induced zinc deficiency in wheat on residual phosphorus plots. Agronomy J. 1986;78:668-675.
34. Sillanpaa M. Micronutrients and the nutrient status of soils: A global study. FAO Soil Bulletin No. 48. Rome, Italy: Food and Agriculture Organization. 1982.
35. Sillanpaa M. Micronutrients Assessment at the Country Level. An international Study FAO Soils Bulletin. Food and Agriculture Organization of the United Nations. 1990;63.
36. Hamid A, Ahmad N. Integrated Plant Nutrition System: Development and Rural Poverty Alleviation. Regional Workshop on Integrated Plant Nutrition System (IPNS), FADINAP, 18-20 September, Bangkok, Thailand. 2001
37. Iyengar SS, Martens DC, Miller WP. Distribution and plant availability of soil zinc fractions. Soil Sci Soc Am J.1981;45:735–739.
38. Neilsen D, Hoyt P, Mackenzie A. Distribution of soil Zn fractions in British Columbia interior orchards soils. Can J Soil Sci. 1986:66:445-454.
39. Rego TJ, Wani SP, Sahrawat KL, Pardhansaradhi G. Macro-benefits from Boron, Zinc and Sulfur application in India SAT; A step for gray to green revolution in agriculture. Global Theme on Agroecosystems Report no. 16. Patancheru, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 2005.
40. Sahrawat KL, Wani SP, Rego TJ, Pardhasaradhi G, Murthy KVS. Widespread deficiencies of Sulfur, Boron and Zinc in dryland soils of the Indian Semi-arid tropics. Current Sci. 2007;93(10):1428-1432.
41. ICRISAT. Innovations for a change World. Annual Report 2008, Patancheru, Andhra Pradesh, India. International Crops Research Institute for the Semi-Arid Tropics. 2009; 16–17.
42. Donner E, Howard DL, de Jonge MD, Paterson D, Cheah MH, Naidu R, Lombi E. X-ray Absorption and Micro X-ray Fluorescence Spectroscopy Investigation of Copper and Zinc Speciation in Biosolids. Environ Sci Technol. 2010;45:7249–7257.
43. Ratmattullah MS, Sheikh BZ. Distribution and availability of zinc in soil fractions to wheat on some alkaline calcareous soil. Z. Pflanzernahr. Bodenk. 1988;151:385-389.
44. Adiloglu A, Adiloglu S.. The effect of boron (B) application on the growth and nutrient contents of maize in zinc (Zn) deficient soils. Res. J. Agric. Biol. Sci. 2006;2:1-4.
45. Di Baccio DR, Tognetti L, Sebastiani C, Vitagliano. Responses of *Populus deltoides* x *Populus nigra (Populas X euramricana)* clone I-214 to high zinc concentrations. New Phytol. 2003;159:443-452.
46. Hussain S, Maqsood MA Rahmatullah. Increasing grain zinc and yield of wheat or the developing World: A Review. Emir. J. Food Agric. 2010;22(5):326-339.
47. Barak P, Helmke PA. The chemistry of Zinc. In Zinc in Soils and Plants. (ed.) A.D. Robin. Dordecht: Kluwer Academic Publishers. 1993.

48. Stahl RS, James BR. Zinc sorption by B Horizons Soils as a function of pH. J of Soil Sci Society of America.1991;55:1592-1597.
49. Brehler B, Wedepohl KH. In K.H. WedepohlKH. (ed). Handbook of Geochemistry. Vil II/3. Springer-Verlag, Berlin.1978;125.
50. Kiekens L. Zinc in Heavy Metals. In B.J. Alloway (Ed.). Soils. London: Blackie Academic and Professional. 1995.
51. Shukla UC, Mittal SB. Characterization of zinc application in some soils of India. J of Soil Sci Society of America.1979;43:905-908.
52. Saeed M, Fox RL. Relation between suspension pH and Zn solubility in acid and calcareous soils. Soil Science. 1977;124:199-204.
53. Wang AS, Angle JS, Rufus L, Chaney Thierry A, Delorme RD. Soil pH Effects on Uptake of Cd and Zn by *Thlaspi caerulescens.* Plant and Soil. 2006;281(1):325–337.
54. Zeng F, Ali S, Zhang H, Ouyang Y, Qiu B, Zhang G, Wu F. The influence of pH and organic matter content in paddy soil on heavy metal availability and their uptake by rice plants. Enviorn Poll. 2011;159:84-91.
55. Rengel Z. Soil pH, soil health and climate change. In: B.P. Singh, A.L. Cowie, K.Y. Chan (ed.) Soil Health and Climate Change. Springer, Berlin Heidelberg. 2011;68-95.
56. Kabata-Pendias A, Pendias H. Trace elements in soils and plants, CRC Press, Boca Raton - London - New York - Washington D.C. 2001.
57. Katyal JC, Randhawa NS. Micronutrients FAO Fertilizer and Plant Nutrition Bullet in Rome: Food and Agriculture Organization of the United Nations. 1983.
58. Iratkar AG, Giri JD, Kadam MM, Giri JN, Dabhade MB. Distribution of DTPA extractable micronutrients and their relationship with soil properties in soil of Parsori watershed of Nagpur district of Maharashtra. Asian J of Soil Sci. 2014;9:297-299.
59. Ellis BG, Knezek BD. Adsorption Reactions of Micronutrients in Soils. In Mortvedt, J., Giordano J. and Lindsay W.L. (ed.) (Micronutrient in Agriculture). Soil Sci Society of America. Madison, Wis. 1972;59-78.
60. Rengel Z. Agronomic approaches to increasing zinc concentration in staple food crops. In: I. Cakmak, R.M. Welch (ed.) Impacts of Agriculture on Human Health and Nutrition. UNESCO, EOLSS Publishers, Oxford, UK. 2002a.
61. Olsen SR. Micronutrient Interactions. In J.M Mortved, J.J. Goirdano, and W.L. Lindsay (ed.) Micronutrients in Agriculture. Soil Sci. Society of America, Madison, WI. 1972; 243-264.
62. Yang X, Tian X, Lu X, Gale William J, Cao Y. Foliar zinc fertilization improves the zinc nutritional value of wheat (*Triticum aestivum* L.) grain. Afr J Biotechnol 2011;10:14778–14785.

63. FAO/WHO. Expert Consultation on Human Vitamin and Mineral Requirements, Vitamin and mineral requirements in human nutrition: report of joint FAO/WHO expert consolation, 2nd edition. Bangkok, Thailand. 2004;341.
64. Black RE. Zinc deficiency, infectious disease and mortality in the developing World. J of Nutri. 2008;133:1485-1489.
65. Hambidge KM.. Zinc. In: Trace elements in human and animal nutrition, Mertz W, ed).Orlando:Academic Press. 1987;5(1):1–137.
66. Stein AJ. Global impacts of human mineral malnutrition. Plant Soil. 2010;335:133–154.
67. Prasad R. Zinc biofortification of food grains in relation to food security and alleviation of zinc Malnutrition. Current Sci. 2010;98(10):1300-1304.
68. Hambidge M. Human Zinc Deficiency. J Nutr. 2000;130(5S Suppl):1344S-1349S.
69. Cakmak I. Enrichment of fertilizers with zinc: An excellent investment for humanity and crop production in India. J Trace Elem Med Biol. 2009;23(4):281-289.
70. Frossard E, Bucher M, Machler F, Mozafar A, Hurell R. Potential for increasing the content and bioavailability of Fe, Zn and Ca in plants for human nutrition. J of the Sci of food and Agri. 2000;80:861-879.
71. Graham RD, Welch RM, Bouis HE. Addressing micronutrient malnutrition through enhancing nutritional quality of staple foods: principles, perspectives and knowledge gaps. Adv Agron. 2001;70:77-142.
72. Rimbach G, Pallauf J, Moehring J, Kraemer K, Minihane AM. Effect of Dietary Phytate and Microbial Phytase on Mineral and Trace Element Bioavailability - a Literature Review. Curr Top Nutraceutical Res. 2008;6:131-144.
73. Cakmak I, Kalacyi M, Ekiz H, Braun HJ, Kilinc Y, Yilmaz A. Zinc deficiency as a practical problem in plant and human nutrition in Turkey: A NATO-science for stability project. Field Crops Res. 1999;60:175-188.
74. Sunanda L, Sumathi S, Venkatasubbaiah V. Relationship between soil zinc, dietary zinc and zinc nutritional status of humans. Plant Foods for Human Nutrition. 1995;48:201-207.
75. Cakmak, I., Sari, N., Marschner, H., Kalayci, M., Yilmaz, A., Eker, S. and Gulut, K.Y. Dry matter production and distribution of zinc in bread and durum wheat genotypes differing in zinc efficiency. Plant and Soil. 1996;180(2):173-181.
76. King JC, Cousins RJ. Zinc. In: Modern nutrition in health and disease, 10th ed (Shils ME, Shike M, Ross AC, Caballero B, Cousins RJ, eds). Baltimore: Lippincott Williams & Wilkins. 2006;271–285.
77. Hotz C, Brown KH. Guest Editors, Assessment of the risk of zinc deficiency in populations and options for control, IZiNCG Technical Document 1. Food and Nutrition Bull. 2004;25.

78. FNB/IOM. Food and Nutrition Board/Institute of Medicine. Dietary reference intakes of vitamin A, vitamin K, arsenic, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon and zinc. Washington DC. National Academy Press. 2002.
79. Müller O, Becher H, van Zweeden AB, Ye Y, Diallo DA, Konate AT, Gbangou A, Kouyate B, Garenne M. Effect of zinc supplementation on malaria and other causes of morbidity. In West African children: randomized double blind placebo controlled trial. BMJ. 2001;322(7302):1567–1572.
80. Maret W, Sanstead HH. Zinc requirements and the risks and benefits of zinc supplementation. J Trace Elem MedBio. 2006;20:3–18.
81. King JC, Shames DM, Woodhouse LR. Zinc homeostasis in humans. J Nutr. 2000;130:1360S–1366S.
82. O'Brien KO, Zavaleta N, Caulfield LE, Wen J, Abrams SA. Prenatal iron supplements impair zinc absorption in pregnant Peruvian women. J Nutr. 2000;130(9):2251–2255.
83. Hambidge KM. Zinc and diarrheal disease in young children Acta Paediatr Suppl. 1992;381:82–86.
84. Fung EB, Ritchie LD, Woodhouse LR, Roehl R, King JC. Zinc absorption in women during pregnancy and lactation: a longitudinal study. Am J Clin Nutr. 1997;66:80–8.
85. Whittaker P.Iron and zinc interactions in humans. Am J Clin Nutr 1998; 68:S442–446.
86. Andriollo-Sanchez M, Hininger-Favier I, Meunier I, Toti E, Zaccaria M, Brandolini-Bunlon M, Polito A, O’Connor JM, Ferry M, Coudray C, Roussel AM.Zinc intakeandstatus in middleaged and olderEuropeansubjectsTheZENITHstudy. EuropeanJofClinicalNutri. 2005;59(2):S37–S41.
87. Brown KH, Peerson JM, Rivera J, Allen LH. Effect of supplemental zinc on the growth and serum zinc concentrations of prepubertal children: a meta-analysis of randomized controlled trials. American J of Clinical Nutri. 2002;75:1062-1071.
88. Anderson JJ. Minerals in “Krause’s food, Nutrtionand Diet Therapy”. 11th Edition. 2004, Saunders Publication. 2004;143-147.
89. Ghishan FK. Transport of electrolytes, water and glucose in zinc deficiency. J Pediatr. Gastro. Nutr. 1984;3:608–612.
90. Bhutta ZA, Black RE, Brown KH, Gardner JM, Gore S, Hidayat A, Khatun F, Martorell R, Ninh NX, Penny ME, Rosado JL, Roy SK, Ruel M, Sazawal S, Shankar A. Prevention of diarrhea and pneumonia by zinc supplementation in children in developing countries: pooled analysis of randomized controlled trials. Zinc Investigators' Collaborative Group.J Pediatr.1999;135(6):689-97.
91. Brown KH, Dewey KG, Allen LH. Complementary feeding of young children in developing countries: a review of current scientific knowledge. World Health Organization, Geneva. 1988a.

92. Bouis HE, Eozenou P, Rahman A. Food prices, household income, and resource allocation: socioeconomic perspectives on their effects on dietary quality and nutritional status. Food Nutr. Bull. 2011;32(1):S14-S23.
93. WHO, FAO, UNICEF, GAIN, MI, FFI. Recommendations on wheat and maize flour fortification. Meeting Report: Interim Consensus Statement. Geneva, World Health Organization. 2009.
94. Graham RD, Welch RM, Saunders DA, Monasterio I, Bouis, HE, Bonierbale M, Hann de, Burgos G, Thiele G, Liria R, Meisner CA, Beebe SE, Potts MJ, Kadiajn M, Hobbs PR, Gupta RK, Twomlow S. Nutritious Subsistence Food Systems. Advances in Agronomy. 2007;92:1-74.
95. White P, Broadley MR. Biofortifying Crops with Essential Mineral Elements. Trends in plant Scie. 2005;10:586-593.
96. Bouis HE, Welch RM. Biofortification–a sustainable agricultural strategy for reducing micronutrient malnutrition in the global South. Crop Sci.2010;50:S20–S32.
97. Saltzman MS, Andersson D, Asare-Marfo K, Lividini FF, DeMoura M, Moursi A, Oparinde V, Biofortification Techniques to Improve Food Security. Reference Module in Food Sciences.2015;1-9.
98. Bouis HE. Micronutrient fortification of plants through plant breeding: can it improve nutrition in man at low cost? Proceedings of the Nutri Society. 2003;62:403-411.
99. Mortvedt JJ. Crop response to level of water-soluble zinc in granular zinc fertilizers. Fertilizer Res. 1992; 33(3):249–255.
100. Allen SE, Terman GL. Response of Maize and Sudangrass to Zinc in Granular Macronutrients. Comm. II & IV. Int. Soc. Soil Sci., Aberdeen.1966;255-266.
101. Liscano JF, Wilson CE, Norman RJ and Slaton NA. Zinc Availability to Rice from Seven Granular Fertilizers. AAES Res Bull. 2000;963:1–31.
102. Avinash CP, Sharda SS, Raghvendra SY. Application of ZnO nanoparticles in influencing the growth rate of *Cicer arietinum.* J of Exper. NanoSci. 2010;5(6):1-12.
103. Pramod M, Dhoke SK, Khanna AS and Tarafdar JC. effect of nano-zno on growth of mung bean (*Vigna radiata*) and chickpea (*Cicer arietinum*) seedlings using plant agar method. App Biol Res. 2011;13(2):54-61.
104. Prasad TNV, Sudhakar KVP, Sreenivasulu Y, Latha P, Munaswamy V, Raja Reddy K, Sreeprasad TS, Sajanlal PR, Pradeep T. Effect of nanoscale zinc oxide particles on the germination, growth and yield of peanut. J. Plant Nutr.2012;35(6):905-927.
105. Dhoke SK, Mahajan P, Kamble R, Khanna A. Effect of nanoparticles suspension on the growth of mung (*Vigna radiata*) seedlings by foliar spray method. Nanotechnol Dev. 2013;3(1):1-5.

106. Raskar SV, Laware SL. Effect of zinc oxide nanoparticles on cytology and seed germination in onion. Int. J. Curr. Microbiol. App. Sci.2014; 3(2):467-473

107. Kisan B, Shruthi H, Sharanagouda H, Revanappa SB, Pramod NK. Effect of Nano-Zinc Oxide on the Leaf Physical and Nutritional Quality of Spinach. Agrotechnol. 2016;5(1):135.

108. Davarpanha S, Tehranifar A, Davarynejada G, Abadia J, Khorasani R. Effects of foliar applications of zinc and boron nano-fertilizers on pomegranate (*Punica granatum* cv. *Ardestani*) fruit yield and quality. Scientia Horticulturae.2016;210:1–8.

109. Afrayeem SM, Chaurasia AK. Effect of zinc oxide nanoparticles on seed germination and seed vigour in chilli (*Capsicum annuum* L.). J of Pharmacognosy and Phytochemistry. 2017; 6(5):1564-1566.

110. Rizwa TMM, Kashif NM, Shahzad A, Ali S, Zahid R, ALam MFE, Imran M, Amin N. effect of zinc oxide nanoparticles on the growth and Zn uptake in wheat (*Triticum aestivum* L.) by seed priming method. Digest J of Nanomaterials and Biostru. 2018;13(1):315-323.