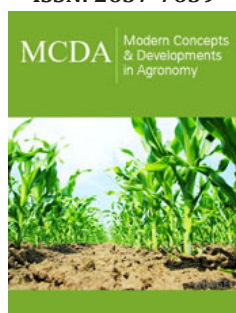


Biofortification: Zinc Enrichment Strategies in Crops

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ISSN: 2637-7659



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Submission: 📅 January 29, 2021

Published: 📅 February 24, 2021

Volume 8 - Issue 1

How to cite this article: Hanife AKÇA, Süleyman TABAN. Biofortification: Zinc Enrichment Strategies in Crops. *Mod Concep Dev Agrono*. 8(1). MCDA. 000679. 2021. DOI: [10.31031/MCDA.2021.08.000679](https://doi.org/10.31031/MCDA.2021.08.000679)

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Abstract

Zinc deficiency causes the major health problems in human. Deficiencies of zinc affect over one-half of the world's population. Food fortification provides especially the improvement of the microelement content of the nutrients and thus the healthy nutrition and the increase of the microelement bioavailability. Progress has been made to control micronutrient deficiencies through food fortification, but new approaches are needed, especially in developing countries. Biofortification is the process of increasing the natural content of bioavailable nutrients in plants. Biofortified crops can reduce the problem of micronutrient malnutrition in a cost-effective way. Different and effective fertilization strategies could be a rapid solution to the zinc deficiency in crops.

Keywords: Biofortification; Zinc; Crops

Introduction

The balanced and healthy nutrition of our population will be one of the priority issues in the future, as it is today. All living organisms need microelements such as: Zn, Fe, Mn, Cu, Mo as well as macro elements to maintain their metabolic activities, and they meet this need with nutrition [1]. Malnutrition is seen by WHO as a worldwide health risk factor as well as infectious diseases and obesity [2]. The malnutrition problem is common in low and middle-income countries. Micronutrient deficiencies such as iron, zinc, and vitamin A are a global health risk in worldwide. Micronutrients play key roles in the normal functioning of the human body system [3].

It has been determined that two thirds of the world population face serious health problems due to not getting one or more of the mineral elements at a sufficient level. Today, it has been determined that people are most commonly affected by zinc [1,4] and iron [1,4-6] deficiency. Zinc deficiency is an important problem especially in cereal-based diets. The mortality rate in children under the age of 5 who cannot get enough zinc from the food they eat has been determined as 4.4% worldwide [7]. Zinc deficiency causes infertility in humans, delayed healing of wounds, mental retardation, etc. it has many negative effects. Besides, zinc is an element that has very important functions in the human body and is necessary for the growth and reproduction of all cells. It is also involved in the structure of enzymes and proteins that play a role in removing free radicals from to cell or cell wall, which are the cause of tissue damage and cell death.

The main reason for Zn and Fe deficiency in humans is due to the widespread nutrition of grains and legumes and the low bioavailability of these elements in cereal and legume groups [8]. The high content of phytic acid, fiber, and tannins in this group of plants significantly reduces the bioavailability of Zn and Fe elements [9]. Therefore, increasing the Zn and Fe contents and/or phytic acid, etc. It is of great importance to increase the microelement content of basic foods in human nutrition by reducing the factors that negatively affect microelement usefulness.

Zinc Enrichment Strategies

The amount of zinc in the soil varies depending on the properties of the main material of the soils. For example, although the zinc concentration is high in soils composed of basic volcanic rocks, the zinc concentration is low in soils composed of the parent material with high silicon content. Similarly, sandy soils contain less zinc than soils with high clay content.

Soil pH is quite effective parameter on the solubility of zinc in soils. Under conditions with soil pH<7, Zn⁺² form of Zn is dominant, whereas under pH>7 ZnOH⁺ is dominant. Under conditions where soil pH is 5, the amount of Zn⁺² is 6.5mg kg⁻¹, while it decreases to 0.007µg kg⁻¹ when the pH is 8 [10]. Zinc: forms soluble complexes in the soil with chlorine, phosphate, nitrate and sulphate ions, and the solubility of the compounds formed with neutral sulphate and phosphate ions is higher. The ZnSO₄ compound increases the solubility of Zn⁺² cations in the soil and the Zn availability increases with the application of fertilizers with a physiological acid character for instance, ammonium sulphate [(NH₄)₂SO₄]. Zinc forms both soluble and insoluble organic complexes with organic matter in the soil, and soluble complexes with organic acids with low molecular weight, and consequently the amount of soluble Zn in the soil increases. The increase in the amount of soluble Zn in the soil with the application of organic fertilizers and it can be explained by the formation of solubility.

Zinc is one of the essential microelements for the normal and healthy growth and reproduction of plants. Zinc is included in the group of essential trace elements and also defined as a micronutrient element due to its low concentrations of 5-100mg kg⁻¹ in plant tissues. Among these elements, iron, copper, zinc, manganese as well as cobalt, chromium, iodine and selenium are important microelements in the food chain [11]. Zn plays a role in the activity of many enzymes such as functional, structural and regulatory in plants [12]. Moreover, zinc is effective on carbohydrate metabolism, sucrose and starch formation, protein metabolism, membrane integrity and auxin metabolism in the plant.

Zinc plays important role in the cellular functions of all living organisms and also plays a role in the development of the human immune system. The optimum daily intake of Zn in adults should be 15mg. Zinc acts as a catalytic or structural component in various body enzymes in humans as well as in plants [13,14]. Zinc is a key component of many important enzymes such as RNA polymerase, superoxide dismutase, lactate dehydrogenase, alkaline phosphatase, aldolase, phospholipase (Srivastara and Gupta 1996). Zinc deficiency may cause several serious disorders such as the development of embryos, fetuses, babies, and young children also disrupts the immune system, and causes late recovery of cells [15]. It is stated that 4% of the sickness and disability of children under the age of 5 in low-income countries is due to the lack of Zn [7]. It has been shown that diarrhea and respiratory diseases seen in humans are reduced with zinc supplementation [16]. Insufficient intake of Zn in human dietary cause Zn deficiency. Zn deficiency results negative situations such as hair loss, memory loss and weakening of body muscles occur in human [17]. According to studies, while an adult man needs 11mg of Zn a day, women should consume 9mg of Zn per day. In women, this amount should be 13-15mg Zn day⁻¹ during pregnancy. 3mg Zn day⁻¹ for babies aged 7 months to 3 years, 5mg Zn day⁻¹ for children aged 4-8 years, and 8mg Zn day⁻¹ for children aged 9-13 years [4,18]. Zinc is usually stored in the husks of grains and the grains are transformed into

flour, and it causes Zn deficiency in grain-fed societies. Beef, chicken meat, peanuts, almonds, walnuts, oats, yoghurt, cheese and milk are known as zinc-rich foods [19]. The high content of phytic acid, fiber and tannin, especially in cereal group plants, significantly reduces the bioavailability of Zn and Fe elements [9,20].

The bioavailability of zinc is very low in foods containing high amounts of phytic acid (FA) or phytate [21]. Phytic acid is the main storage form of phosphorus in grains, legumes and oilseeds. Phytic acid forms insoluble complexes, especially Zn, Fe and Ca, which cannot be digested or absorbed in the human body due to the absence of phytase enzymes in the human intestine [22]. Many studies indicated that choosing food with low phytate content increases the absorption of Zn, Fe and, Ca compared to the consumption of food products with high phytate content [23-27]. Weaver [28] and Hussain et al. [29] reported that the FA/Zn molar ratio can be used as an index to determine the unavailability of Zn, moreover, the International Zinc Nutrition Advisory Group (IZiNGC) reported that only the FA/Zn molar ratio can be used to determine the negative effect of FA on Zn bioavailability [30]. If diets with high phytate content (unrefined grain-based diets) have a FA/Zn molar ratio greater than 18, Zn absorption is 18% and 25% for men and women, respectively, and if the FA/Zn molar ratio is 4-8, Zn It is estimated to be 26% and 34% in men and women, respectively [31]. According to the World Health Organization, the FA/Zn molar ratio should be ≤15 for Zn while this ratio should be <1 for Fe [18].

It is a term that encompasses food fortification, the improvement of especially the microelement content of the foods, and consequently, the increase of healthy nutrition and microelement bioavailability [32]. Fortification involves adding nutrients to food products such as adding iodine to table salt or adding Fe, Zn, and folate to flour used in bread making. A disadvantage of these applications is that the additives have limited stability. For instance, folate added to rice becomes more soluble at high temperatures, and when the rice is boiled, it completely dissolves [33]. A second disadvantage is that additives negatively affect the quality of the foods they are added to in the long term. An example of this situation is that ferrous additives oxidize over time and spoil deteriorate the taste of the foods [34]. The third and most limiting disadvantage is that these applications/approaches are suitable for developed countries with technical infrastructure and distribution networks, and this is not suitable for developing countries that earn their living from agriculture [33].

Biofortification, on the other hand, avoids the other three applications/approaches by covering the development of nutrient-intensive plants that can be grown and distributed using existing agricultural practices. While unnatural additives are required with fortification, nutrients are naturally synthesized and accumulated by plants in biofortification [35]. Agricultural biofortification, or biological enrichment, is based on the application of inorganic fertilizers to increase the mineral element concentration in the edible parts of plants and/or the movement and solubility of mineral elements in the soil [36]. Agronomic biofortification is

simple and inexpensive but needs special attention in terms of the source of nutrients, application method, and effects on the environment. Biofortification is an effective and inexpensive method of increasing and improving the microelement content of foods, which are of great importance for the health of the human population especially in developing countries but needs special attention in the way of source of nutrients and effects on the environment [37]. Application of zinc in soil and/or foliar offers

a quick solution to increase Zn concentration in cultivated plants [20,38-54] (Table 1). Although zinc application is an effective way to increase the yield and microelement concentration of crops, many producers in the world (especially in developing countries) [55]. Zn absorption in humans can be increased by decreasing the phytic acid/zinc molar ratio by reducing the phytic acid content of the grain, especially with agricultural biofortification (soil/foliar fertilization, etc.) [56,57].

Table 1: Different methods used for zinc biofortification in some crops.

Crops	Methods	References
Wheat (<i>Triticum aestivum</i>)	Soil, Foliar, Priming, Soil+Foliar	Taban et al. [38], Dhawial et al. [39], Pavia et al. [40], Liu et al. [41], Akça [20]
Maize (<i>Zea Mays</i>)	Soil, Foliar, Priming	Liu et al. [42], Zhang et al. [43], Martínez-Cuesta et al. [44]
Rice (<i>Oryza Sativa</i>)	Soil, Soil+Foliar	Özcan [45], Özcan et al. [46], Özcan [47], Phuphong et al. [48], Grija Veni et al. [49]
Lettuce (<i>Lactuca sativa</i>)	Foliar	Tang et al. [50], Gao et al. [51], Adrees et al. [52]
Onion (<i>Allium cepa</i>)	Foliar	Rafie et al. [53]
Common bean (<i>Phaseolus vulgaris</i>)	Foliar+Priming	Tabesh et al. [54]

The source, method, time, and rates of Zn applications in agricultural biofortification should be well known and developed [5]. Zinc is usually applied to plants in the form of $ZnSO_4$ or synthetic chelates [20,37,38,57] (Shuman 1998, Broadley et al. 2007). The enrichment process with zinc can be exemplified as soil applications, root dipping, seed coating (priming) and leaf application [58]. Soil applications give more results in applying macronutrients to the plant. For micronutrients, it is more effective to apply mostly by spraying from the leaves (Harris et al. 2008). Examples of inorganic zinc sources are zinc oxide (ZnO), zinc carbonate ($ZnCO_3$), zinc sulphate ($ZnSO_4 \cdot 7H_2O$), zinc nitrate [$Zn(NO_3)_2$] and zinc chloride ($ZnCl_2$). Among the inorganic zinc sources, zinc sulphate ($ZnSO_4 \cdot 7H_2O$) is one of the most widely used Zn fertilizers in the world. Foliar concentrated zinc oxide (ZnO) solutions can be used in zinc fertilization, but its use is restricted due to particle size [59]. Synthetic chelates are usually a special complex formed by having chelating properties like Ethylene Diamine Tetra-Acetic Acid (EDTA) and combined with a metal ion [60]. Other synthetic chelates are ligands such as Diethylene Triamine Penta-Acetic Acid (DTPA) and Hydroxy-EDTA (HEDTA), but EDTA is by far the most widely used chelating form. In recent years, Zn-amino acid complexes (histidine, lysine, glycine, methionine, etc.) have been

synthesized and applied as a natural and effective Zn source in foliar fertilization [20,61]. The transport of amino acids in plants is of great importance for plants. Translocation of amino acids occurs in both phloem and xylem. Therefore, the translocation of amino acids helps the recycling of nitrogen between roots and shoots and accelerates the translocation of immobile nutrients, namely Zn, in the plant [62]. Besides, the addition of urea to zinc fertilizer in the foliar application is an effective strategy for increasing the transport of zinc within the plants [20,63]. In the application of zinc from the soil, zinc applications will be a separate strategy, taking into account the plants growth periods.

Conclusion

Plants are at the beginning of the food chain and make loads of nutrients for other organisms to eat. Therefore, improving the uptake of minerals from the soil and increasing their movement and bioavailability in the edible parts of the plant will benefit human and animal nutrition. Besides, biofortification will be necessary in the future to fully understand the number of nutrients in the soil-plant ecosystem and holds great effect for malnutrition problems in human health and it will be the potential way to provide more nutrients for the world population.

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