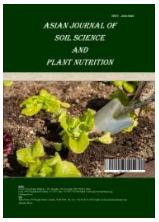

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Zinc Biofortification of Cereal Crops: A Review Article

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Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

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ABSTRACT

Micronutrient deficiency can be considered as one of the yield "quantity and quality" limiting factor in arid calcareous lands and can be considered as the troubling component of hunger. Therefore, enriching food products through adding nutrients to a food product or through increasing soil fertility and breeding crop for nutrient efficiency are alternatives available to improve food quality. However, poor people have no excess to food additives and can benefit from naturally enriched food products or what being called Biofortification. The existence of a general geographical overlap between soil Zn deficiency and human Zn deficiency has been already postulated. As agriculture-based food products are the major source of human nutrition, the relationship between the nutrient status of soils, food crops, and human health is understandable. poor but also deliver all the essential nutrients needed for adequate nutritional health. Sustainable solutions to malnutrition will only be found by closely linking agriculture to nutrition and health. The undergoing review would discuss these concepts and their implementation and uses with special concern on Iraqi conditions.

Keywords: Enrichments; micronutrients; Zn- fertilizers; human health.

1. INTRODUCTION

Diet nutrient deficiencies as well as diet-related to chronic diseases (e.g., heart disease, cancer, stroke, and diabetes), is responsible for more deaths than any other cause, accounting for >20 million mortalities annually. Malnutrition contributes to increased morbidity, disability,

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stunted mental and physical growth, and reduced national socioeconomic development [1]. A troubling component of hunger is micronutrient deficiency called "hidden hunger" it stems from the lack of essential dietary vitamins and minerals such as iron, zinc, iodine, and vitamin A, causing a variety of diseases and other illness such as blindness, brain damage, and death [2]. Micronutrient malnutrition alone makes pains and distress to more than two billion people, mostly among resource-poor families in developing countries, with Fe, I, Zn, and vitamin A deficiencies most prevalent [3]. This occurred due to food systems are dependent on agricultural products as their source of most nutrients, so, agricultural systems must be contributing to the worldwide public health of these people .Unfortunately, agricultural systems mostly designed not to promote human health and, instead, mostly focus on increased portability for farmers and agricultural industries. However, the consequence of that was the rapid rise in micronutrient malnutrition in many nations that adopted the cropping systems that prevented large-scale starvation. Agriculture must now formulate new policies that not only provide enough calories to meet the energy needs of the poor but also deliver all the essential nutrients needed for adequate nutritional health. Sustainable solutions to malnutrition will only be found by closely linking agriculture to nutrition and health [4]. Humans require at least 44 known nutrients in adequate amounts and consistently to live healthy and productive lives. Many agricultural tools (e.g., crop selection, fertilizers, cropping systems, soil amendments, small livestock production, aquaculture, regenerative agriculture, etc.) could be used to increase the nutrient output of farming systems [5]. Biofortification (developing food crops that fortify themselves) is one of the best agricultural tools now being employed to address micronutrient malnutrition worldwide. Minerals and vitamins in food staples eaten widely by the poor may be increased either through conventional plant breeding or through the use of transgenic techniques, a process known as Biofortification. The effort's which should be taken by agencies and decision-maker authorities is to develop and distribute cultivars of food staples such as (rice (*Oryza sativa* L.),wheat (*Triticumaestivum* L.), maize (*Zea mays* L.), beans (*Phaseolus vulgaris* L.), that are high in Fe, Zn, and pro-vitamin A to fulfil the need from such mineral elements and vitamins for developing countries people especially these more remote populations, which comprise a majority of the undernourished in many countries . For Biofortification to be successful. 1st :The breeding must be successful—high nutrient density must be combined with high yields and high profitability. 2nd: efficacy must be demonstrated—the micronutrient status of human subjects must be shown to improve when consuming the bio-fortified cultivars as normally eaten. 3rd , the bio-fortified crops must be adopted by farmers and consumed by those suffering from micronutrient malnutrition in significant numbers.Conventional breeding has been the primary focus of programs to enhance staple food crops with sufficient levels of Fe, Zn, and pro-vitamin A carotenoids to meet the needs of at-risk populations in the Global South(The Global South is made up of Africa, Latin America and the Caribbean, Pacific Islands, and the developing countries in Asia, including the Middle East) [6] The Biofortification strategy is a feasible means of reaching rural families that only have limited access to markets and healthcare facilities needed to provide fortified foods and nutritional supplements .So the issue of having good quality foods (in terms of essential nutrients) is important as the importance of feeding hungry peoples. Traditionally agronomist, in general, was looking mainly at productivity or yield per unit of the area while nutritionist interests in nutritive value. Therefore it is important to be looking at and tackling both issues all together at once and this is what is termed or called "bio-enrichment" or "Biofortification". Therefore, agricultural scientists and others who worked in the same field (plant breeders and plant nutritionists) ought to selectively breed crop plants that would be significantly higher in micronutrients than their predecessors, without negatively affecting crop yield. some researchers consider Biofortification as "mixing Nutrition and Agriculture". Morgan's, [7]said: the success in controlling world hunger and decrease death percent can be achieved through "Biofortification". Biofortification can be defined as the natural enrichment of crops with essential micronutrients mainly through breeding crops to increase their nutritional value. It involves the identification of varieties of a crop that naturally contain a high ability to absorb nutrients (i.e. iron efficient plants or Zinc efficient plants). Plant breeders use these varieties to develop new, productive, and bio-fortified crop lines for farmers to grow for consuming and marketing. The word Biofortification (natural enrichment) differs from ordinary (artificial) fortification or "Enrichment" which means "the process of adding micronutrients (essential trace elements and vitamins) to food. Biofortification makes plant food (eaten or edible parts) naturally more nutritious as the plants are growing without adding food additives when they are being processed [8]. Although the bio-fortified food products will be more natural and environmentally safer it can be more accessible to rural poor peoples, who rarely have access to commercially fortified foods [9]. As such, Biofortification is seen as an upcoming strategy for dealing with deficiencies of micronutrient in the developing world. Therefore, Biofortification represents one promising strategy to enhance the availability of vitamins and minerals for people whose diets are dominated by micronutrient-poor staple food crops.

1.1 The Human Need for Micronutrients and Human Health

A healthy diet is considered to be one that satisfies human needs for energy and all essential nutrients, but such a diet is unavailable for poor populations. Roughly one-third of the world's population suffers from a shortage of vitamins (particularly A and C) and minerals (zinc, iodine, and iron), which result in health deterioration [10]. Micronutrient deficiencies, in particular, affect poor rural populations in low and middle-income countries. A familiar example of micronutrient deficiency is in a family who can only afford to eat cheap rice, but not fruit, vegetables, and meat that would provide a balanced diet. When people lack vital micronutrients, they can become weak, sick, and even die. Deficiencies of zinc have been a focus of world organizations for decades and extensive efforts are being made to address this malnutrition. The wheat crop can be considered as the most common dietary staple of the population living in Asia and Africa especially the Middle east part of it, therefore, its grain and flour content of zinc quite significant for human nutrition as well as plants. Hari Ram et al. [11], mentioned that Zinc deficiency is the most widespread micronutrient deficiency in crop plants and humans. Low intake of Zn through diet appears to be the major reason for the widespread prevalence of Zn deficiencies in human populations. Application of Zn fertilizer in soil having low Zn increased the grain yield in wheat up to 6.4–50.1%. Soil having sufficient Zn had no or little effect on grain yield with soil Zn application. The application of foliar Zn resulted in significant increases in grain Zn irrespective of soil Zn status. Hence agronomic Biofortification is possible and could be considered economical. Ali and Salman, [12] found that zinc fertilizer application to soil and as foliar gave a significant increase in grain zinc concentration and uptake. However, application to soil and as foliar gave the best results.

WHO [13] recommended that Wheat flour fortification is a preventive food-based approach to improve the micronutrient status of populations having health problems. Wheat flour fortification programs could be expected to be most effective in achieving a public health impact if mandated at the national level and can help achieve international public health goals. In a study, children who ate the high-zinc wheat—experienced 17% fewer days with pneumonia and 39 percent fewer days vomiting, compared to children who consumed a lower zinc variety typical of conventional wheat. Mothers who ate high-zinc wheat spent 9 % fewer days with fever. In a human's diet, inadequate zinc intake can weaken the immune system, making children more vulnerable to infections and respiratory illnesses like pneumonia, which are the two principal killers of children of this age around the world. For women of reproductive age, poor zinc status has been associated with negative pregnancy outcomes like preterm delivery. Globally, it is estimated that zinc deficiency accounts for 14.4 % of diarrhea deaths, 10.4 percent of malaria deaths, and 6.7 percent of pneumonia deaths among children between 6 months and five years of age. Nowadays, with the COVID19 pandemic in 2020 most people's need Zinc for improving their immune systems. So, last year was the most needed zinc in our diet and hopefully not anymore (Improving Lives with Nutritious Crops and Foods in 2020). Biofortification helps address preventable deficiencies of key vitamins and minerals like iron, vitamin A and zinc. Globally, interventions like Biofortification that reduce micronutrient deficiencies are also considered the highest value-for-money investments for economic development. zinc deficiency is responsible for approximately 4% of deaths and disability-adjusted life-years among under-five children in lower-income countries [14] In addition to the effects of zinc on morbidity and mortality from common childhood infections, a considerable number of studies indicate that preventive zinc supplementation increases the linear growth and weight gain of stunted or underweight children [15].

1.1.1 Biofortification issues in Iraq

Historically, the agricultural systems have never been purposely designed to achieve better human nutrition and health. Instead, producing more food was always the major aim to avoid hunger problems and famines. Staple cereal grains, like wheat, are however inherently low in micronutrient concentration and bioavailability to adequately meet human nutritional needs. Therefore, it is widely recognized that in areas of the world where staple cereal-based foods are the main dietary source, inadequate dietary intake of micronutrients is the predominant cause of the prevalence of human micro-nutrient deficiencies. In most of the wheat-producing regions, grain Zn usually ranges between 20 and 30 mg Zn kg^{-1} whereas the desirable Zn concentrations to avoid the risk of human Zn deficiency are around 40−50 mg kg^{-1}. Thus, enhancing micronutrient densities in staple cereal grains through agricultural practices is considered an effective approach to combat micronutrient malnutrition in humans.

In most developing countries, wheat is a predominant source of daily calories and micronutrients, especially in resource-poor populations. Biofortification of staple cereals with micronutrients by using agricultural approaches, such as plant breeding and agronomic represents a useful, cost-effective, and sustainable strategy to combat micronutrient deficiencies in human populations. Plant breeding and fertilizer strategies are, indeed, complementary and synergistic. Combining these agricultural approaches would result in additive and synergistic impacts on grain micronutrient concentrations.

Zinc is a micronutrient that holds a very important role in the production of many crops especially in calcareous Iraqi soils [16,17]. However, studies on micronutrients still not as much as macronutrients (in particular N, P, and K). Besides, most of the conducted studies concentrated either on the chemical behavior of micronutrients in the soil to understand the low availability with some attempts to increase their availability. Agronomists and horticulturists concentrated on the responses of crops (field crops or vegetables) and trees to the application of micronutrients either direct to soil or through the foliar application (spraying on leaves) and of course looking for yield increment. some works being conducted for adopting some efficient genotype for iron uptake together with some proper management (e. g. Bio fertilizer application alone or with proper nitrogen source) to increase soil iron availability and iron uptake [17] and works to increase Zn availability through applying chelated source(e.g. Zn-DTPA of micronutrient) . As related to Zinc, Ali, and Al-Amery [18] results from a field trial indicated that Zinc application as Zn-DTPA (10 kg Zn ha^{-1}) improved the bioavailability of Zn, and in turn contributed to the productivity and profitability of commercial crop production (increased grain yield from 6.93 to 9.50 Mg ha-1 with an increment of 37.1%), especially with Iraqi soils which can be considered as among soils with low Zn availability and most crops, especially cereals, show Zn deficiency [19] Applying Zn-DTPA (10 kg Zn ha^{-1}) increased Zn content in maize grains by 210% compared to control (0 kg Zn ha^{-1}) [18]. This signifies the importance of Zn Biofortification which is very important for human health. My Ph.D. student and I made a wheat variety selection to choose the best two varieties for Zn uptake after that we study the effect of Zn fertilizer application on Zn Bio fortifying of wheat grains. Results indicated that Zn fertilizer application increased Zn concentration and uptake by wheat grains [12]. Applying Zn to soil and by foliar gave better results compared to foliar alone. Therefore methods of Zn application can have different results together with the rate of applied Zn, sort of Zn fertilizer, and Wheat variety. In another experiment with another MSc student, we concluded that Zn-DTPA was the best source for Zn application to Wheat to a calcareous soil [16]. Therefore with good soil management (good source with good rate) with good crop management (the right variety through genetic engineering and breeding selection) we can get good fortification to Zn in wheat grain and wheat bread flour and put a brick in the task of fighting Zn malnutrition.

1.2 Fertilizers Use to Enhance Micro-nutrient Elements in Staple Food Crops

Both macronutrient fertilizers containing N, P, K, and S, and certain micronutrient fertilizers (e.g., Zn, Ni, I, Co, Mo, and Se) (some of them essential)(Zn, Mo, Ni) and for plant life and some beneficial (Co, Se) which can be taken up by plant edible parts when they are applied to soils or when used as foliar sprays [20]. Fertilizers can be used as an effective agricultural tool to improve the nutritional health of people in the developing world. For more detail on the subject the paper written by Graham et al. [5] can be of help.

Zulfiqar et al. [21] investigated the comparative effect of four Zn application methods: Zn seed coating (2 g Zn kg^{-1} seed), Zn seed priming (0.25 M Zn solution), basal application (10 kg ha^{-1}), and Zn foliar spray (0.5% Zn solution) and control with no Zn in improving the productivity and Biofortification of rice under puddled transplanted (PudTR) and direct-seeded rice (DSR) system. The found that regardless of application methods, Zn nutrition significantly improved the yield and related traits and grain Zn concentration in both production systems. Averaged across 2 yr, the increase in grain yield under different Zn application treatments was in the order of seed priming (23%) >foliar application (18%) >basal application (18%) >seed coating (13%), compared with the control. However, grain Zn concentration was the highest with seed priming in PudTR (33% over control) and with basal application in DSR (45% over control). The maximum net benefits were obtained through Zn seed priming in both production systems. They conclude that, Zn seed priming improved the yield and was the most cost-effective method in PudTR and DSR system.

Zinc oxide, zinc sulfate, Zn-EDTA, Zn-DTPA can be used to fortify wheat grains. The best fertilizer to be used depends on fertilizer properties, soil properties, soil management, wheat variety, and environmental conditions. In arid and semi-arid regions chelated zinc especially Zn-DTPA proved to be the best source for soil application [16,18]. The view of the soil scientists and the agronomists concentrate on the bioavailability of Zinc source in the soil to be absorbed by plant roots or by above soil parts when foliar applied. This is can be affected by soil type, environmental conditions, fertilizer source, in addition to the crop itself.

Medical nutritionists or human nutritionists concentrate on zinc absorption from the human diet. Zinc seems to be absorbed equally well from foods fortified with zinc oxide or zinc sulfate, the two cheapest sources of zinc that are generally recognized as safe for human consumption, although an extension of this conclusion to infants and young preschool children remains to be confirmed. Several zinc compounds are generally regarded as safe(GRAS) for human consumption and are, therefore, available for use in food fortification. Zinc oxide, which is the cheapest GRAS zinc compound, is insoluble at neutral pH, so concerns have been raised about its bioavailability from fortified foods. There were no differences in zinc absorption by healthy US adults from the two zinc compounds [22, 23]. By contrast with the foregoing results, Hotz et al. [24] found no difference in zinc absorption from meals containing several foods, fortified with zinc oxide alone, zinc oxide plus Na_2H_2EDTA, or $Na_2ZnEDTA$ in a study of 42 adult Mexican women, but this subject still needs further study.

1.2.1 The bioavailability issue

Bioavailability of nutrient elements for crop plants means the presence of nutrient in the soil in available form which can be absorbed by plant roots .The concept bioavailable for humans mean the ability for human body to absorb such nutrients .The high bioavailability of nutrient to plants will end in increasing concentration in edible parts of plants . Increasing the concentrations of micronutrients in staple food crops is only the 1st step in making these foods richer sources of these nutrients for humans. As stated previously, this is because not all of the micronutrients in plant foods are bioavailable to humans who eat these foods. Plant foods can contain substances that can interfere with the absorption or utilization of these nutrients in humans [25-32]. In general, staple food crop seeds and grains contain very low bioavailable levels. Therefore ,using conventional breeding, can improve the bioavailability of Fe and Zn but this is not easy to be done especially by farmers .Authorizes and Agencies can supply farmers with good crop varieties (high ability to absorb micronutrients –plant Zn or Fe-efficient)and farmers can make the best of that through good soil and crop management (fertilizer management and water management …).Moreover, having interdisciplinary communication between plant scientists and human nutrition scientists holds great potential.

2. CONCLUSION

From the above review, it can be concluded that a line of plant breeding to choose the best efficient variety combined with the best Zn fertilizer management can achieve a bio-fortified food product rich In Zn, especially for boor nations. This kind of program should be made through the collaboration of different sectors of government, private and international organizations.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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