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Agro-biofortification of iron and zinc in edible portion of crops for the global south

Abstract

Iron (Fe) and zinc (Zn) are essential micronutrient for both human and plants, but Fe and Zn deficiency is prevalent in the world especially developing countries including India and China. Biofortification is considered the most promising approach to alleviate Fe and Zn malnutrition in developing countries. While agricultural approaches are also useful to gain Fe and Zn enriched cereals. Therefore, agro-biofortification of Fe and Zn by agricultural approaches was reviewed for possible solution in intensive agriculture system at developing countries.

Keywords: iron, zinc, cereal, agro-biofortification

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Introduction

Iron (Fe) and zinc (Zn) are essential micronutrients for human growth, development, and maintenance of immune system. Iron is needed for psychomotor development, maintenance of physical activity and work capacity, and resistance to infection.[1] Zinc is needed for growth and for maintenance of immune function, which enhances both the prevention of and recovery from infectious diseases.[2] But Fe and Zn deficiencies remain a global problem that over three-billion populations are suffering from, especially among women and children in developing countries including China.[3] Meat products are the beat source of both Fe and Zn. Nevertheless, Fe and Zn deficiencies result primarily from a too narrow staple food based on cereals like rice, wheat, maize and others that are low in density and bioavailability.[4]

Many approaches are used to alleviate micronutrient deficiencies such as pharmaceutical preparation, food fortification, and dietary diversification. But these strategies have proved to be unrealistic, restrained, because of many reasons.[5] As a consequence there is an increasing interest in breeding for staple crops that have higher contents of micronutrients, naming biofortification.[6] Cereals are the primary staple food of humankind and are accordingly central in strategies at alleviating micronutrient deficiencies by biofortification. Although biotechnology and transgenetic crops offer us a new strategy to solve these malnutrition problems,[7] Agricultural approaches are also useful to improve the micronutrient density in edible parts of field crops,[8,9] therefore the latter was focused only in this mini review.

Balanced nutrition output, especially micronutrient (such as Fe, Zn, I, Se and Vitamins) in agricultural system is the third concern after production and environment. Evidence is growing that our global food systems are failing to deliver adequate quantities of healthy, nutritionally balanced food especially to poor people globally.[10] A new paradigm for world agriculture is urgently needed to meeting human needs by productive, sustainable, nutritious agriculture.[11] So, crop management practices must aim both the yields and the mineral nutrient concentration.[8,9]

Fertilization

Over 30% arable land is calcareous soil where Fe and Zn bioavailability is low and crop productions and qualities are restricted. Fertilization is a most common agricultural practice to correct Fe or Zn deficiency for improving crop productions or qualities.[8]

Soil application of Zn increased grain yields in various cereal crops, such as wheat, rice, maize, peanut, soybean.[12] Increasing grain Zn concentration by soil Zn application depended on species, soil conditions, and crop genotypes. Some results increased grain Zn concentration to some extent, 18.8% in field wheat, or 1 to 16 folds in pot wheat.[9] And some results had effect on neither yields nor grain Zn concentration. Soil Zn Application also was used in vegetable and fruits production. In contrast to Zn, soil application of inorganic Fe fertilizers to Fe-deficient soils is usually ineffective because of quick conversion of Fe into plant-unavailable Fe (III) forms. It is likely to be even more uneconomic if the aim is to increase Fe concentration of the seeds. Although some result showed synthetic Fe-chelates were effective for correction of Fe deficiency.[13] So many forms of Fe fertilizers were produced to alleviate Fe deficiency such as, FeS_2, Fe-organo complexes, Manure and humid Fe.[14] When micronutrient fertilization is exceeded a certain limit, further increases in fertilizer application cause not only a reduction in the yield, but a decrease in micronutrient density in grain as well. Two key points should be considered:

1. most soil-applied micronutrients are quickly fixed into plant-unavailable forms;
2. soil-applied nutrients are not readily transported down the soil profile. Both of them weaken the effect by soil Fe and Zn application.[8]

Micronutrients are needed for small amount by plants and foliar micronutrient application is more suitable than soil application. Plants are capable of absorbing soluble compounds and gases through leaves, phenomena that have been utilized for delivering plant nutrients by foliar spraying. Increasing interest is focus on the effects of foliar application on improving the micronutrient density and other quality characters in crop edible portions. Foliar $ZnSO_4$ application both increased the yield and leaf Zn concentration of hollow vegetable. Recent study reported that pea Fe and Zn concentration was improved by foliar Fe & Zn complex-fertilizer.[15] Some results increased wheat grain Zn concentration by 2-3 folds by foliar or soil Zn application.[8] Yilmaz et al.,[16] reported foliar plus soil Zn application was the best methods to improve wheat grain Zn concentration;[16,17] Yin et al.,[18] showed that foliar Zn application increased both rice grain and brown rice Zn concentration.[18] Cakmak et al.,[9] showed than foliar Zn application indeed creased wheat grain Zn concentration, and also showed that Zn was concentrated in embryo where proteins were also concentrated.[9] It may be used to gain both Zn and protein density wheat in future.[19] Most of the results proved that Fe or Zn can re-translocate from source leaf to grain to some extent.

NPK nutrient management and organic fertilizer application can decrease the soil pH and increase soil available Fe and Zn concentration, and finally increase the yield and total Fe and Zn content in grains.[20] More researches focused on the effect of alternating effect between different elements. The Fe or Zn bioavailability is tremendously affected by pH in rhizosphere. NH^{4+}-N application decreased pH in rhizosphere and apoplast of root, thus favor the Fe or Zn activation. But NO_3^--N increased pH and decreased Fe or Zn bioavailability. In sand culture, NH^{4+}-N improved Zn uptake by aerial rice root and Zn translocation to shoot. More phosphorus can decrease Zn uptake by forming insoluble phosphate and finally dilute grain Zn concentration.[21]

Micronutrient management in late growth stage of crops

Micronutrient management must be done under high yield crop system. High yield is an important way to solve food supply issue. There would be inconsistent between need of micronutrient by crops and supply of micronutrient by roots at crop reproductive (late) stages, finally restrict the grain yields and qualities. So micronutrient manipulation in crop late stage should be useful tool to supply enough micronutrient, especially Fe and Zn by soil or foliar application. However, little attention has been paid to this field, and unfortunately no result has got.

Other Agricultural Approaches

Cropping system is also important way to alleviate Fe or Zn deficiency.[8] Intercropping is a normal cropping system in China. In peanut-maize intercropping system, peanut Fe nutrition was improved by partly using PS excreted by maize.[22] Crop rotations are suitable to special areas and climate. And the beneficial effects of rotation including improving soil chemical and physical fertility, reduced weed infestations, less diseases and available micronutrients (Fe, Zn and Cu). Rotation only focuses on yield and little result was available about improving the edible portion micronutrient density.[7,8] Soaking and planting Fe (Zn)-rich seed are easy, economical and effective agricultural practices in poor soil. Both the approaches could improve seed Fe (Zn) content, supply enough micronutrient at seedling, improve resistance in stress conditions and finally gain more high yield and good quality.[23]

Cakmak summarized that the factors affecting grain Fe, Zn accumulation included soil type, nutrition availability, agricultural approaches, and species, climate and crop genotypes [8]. Thus a single approach can not get the best effect and an integrated micronutrient management is urgently needed to meet the need of the yield and Fe, Zn enriched grain.

Conclusion

We here concluded an integrated nutrition management framework for intensive agriculture:

i. Yield, environment and balanced nutrition should be considered in a sustainable agricultural system.

ii. Better species and genotypes are used to improve resistance and efficiency, and harvest high yields and Fe, Zn enriched grains.

iii. Balanced fertilization between NPK fertilizer and micronutrient fertilizer.

iv. Manipulate micronutrient at crop late stage by foliar application of micronutrients like Zn, Fe along or combined with pesticides control, which is economically and technologically feasible.[24]

v. Combine other agricultural approaches to grain high yields and Fe, Zn enriched grains with high qualities.

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Conflict of interest

The author declares no conflict of interest.

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