Available online at www.agrifarming.org

DOI: http://dx.doi.org/10.18782/2582-7146.174

ISSN: 2582 – 7146

Curr. Rese. Agri. Far. (2022) *3*(5), 11-16

Current Research in Agriculture and Farming

Research Article

Peer-Reviewed, Refereed, Open Access Journal

Biofortification of Cereals with Iron through Agronomic Practices

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Received: 13.06.2021 | Revised: 27.08.2022 | Accepted: 10.09.2022

ABSTRACT

Iron is one of the micronutrients required for normal crop production and human developmental concerns. Iron deficiency leads to major hindrance towards crop production and extensive problems in developing countries. Iron deficiency in developing countries of Asia and Africa extensively threatens millions of people. Iron is one of the essential nutrients for crops and plays a key role in human growth and development. Almost all plant species uptake iron in the form of chelation; iron uptake could occur through the following two (I and II) strategies. In strategy, I plant releases organic acids and different compounds for the availability of iron in ferric form, and in strategy II, different cereals form chelation with ferric for uptake. Plant iron mobility occurs through the xylem in chelation form and is available to all plant parts. Iron biofortification by agronomic practices can be done through I) the application of iron fertilizer through soil and different chelation compounds to increase their availability II) combined application of iron through foliar and soil to increase biofortification level. So, an agronomic strategy with chelation increases the iron level in cereals to many folds.

Keywords: *Cereals, chelation, agronomic strategies, human development, iron deficiency.*

INTRODUCTION

Iron is one of the micronutrients required for crop production and human constraints. The concern of "hidden hunger" is now seriously threatening the global human population. Under five years of age, about 5 lac children annually die due to deficiency of zinc and iron (Black et al., 2008). According to FAO, (2013), more than one-third of the world's population (two billion people) is affected by the micronutrient deficiency known as hidden Hunger.

Cite this article: Ali, S., Riaz, A., Shafaat, S., Sidra, Shakoor, K., Sufyan, M., Huzaifa, M., Imtiaz, S., & Ur Rehman, H. (2022). Biofortification of Cereals with Iron through Agronomic Practices, *Curr. Rese. Agri. Far. 3*(5), 11-16. DOI: http://dx.doi.org/10.18782/2582-7146.174

For human Malnutrition of micronutrients is always a serious problem (Copenhagen Consensus, 2008). In developing countries, deficiency of elements in staple food such as in cereals crops sorghum and maize in Africa and wheat or rice in Asia malnutrition of micronutrients is taken place (Fang et al., 2008). About 14 % population of the world is affected by iron deficiency (Matres et al., 2021).

Globally Malnutrition of micronutrients is a serious problem in humans (Copenhagen Consensus, 2004; http://www.copenhagenconsensus.com).

Micronutrients deficiency occurs by growing crops in those areas where is soil show deficiency of that nutrient in staple crops and lack of animal products and fish in their diet (Welch & Graham, 2002; Poletti et al., 2004; White Broadly, 2005a; Gibson, 2006; & Graham et al., 2007).

For the welfare of human beings twenty-two (22) elements are required (Welch & Graham, 2004; & Graham et al., 2007). Iron plays important metabolic functions in the human body, i.e. transfer of oxygen from the lungs to tissue. In haemoglobin and cytochrome, iron is the basic component (Bouis & Saltzman, 2017). Iron deficiency leads to the impaired physical growth, mental ability and learning process. Iron play role in the maintenance of the immune system, growth and development in humans (Shenkin, 2006). In pregnant women, a deficiency of iron causes fetal brain damage (Gordon, 1997). Haemoglobin is essential for oxygen transport iron is its central ion. It's also a part of muscle protein known as myog*l*obin and various enzymes. A deficiency of iron causes a disease known as anaemia (haemoglobin concentration decrease in the blood) which disturbs physical fitness, growth and development (Kiran et al., 2022). Worldwide, about 38% of pregnant women and 43 % of children under the age of 5 years are affected with anaemia. Low birth weight and mental mortality increase with the deficiency of haemoglobin (Caulfield et al., 2006).

Uptake, accumulation of iron by plants:

All plant species can uptake nutrients like iron by roots and in the form of metal chelates. In soil, most mineral nutrients are present in the form of free ions, as dissolved compounds, ions adsorbed at organic surfaces or minerals and within the soil biota. Mineral availability is affected by water content, soil pH, soil organic matter, microbes activity, cation exchange capacity of soil and redox conditions (Shuman, 1998; & Frossard et al., 2000).

Plants can obtain iron by two strategies (Welch, 1995; & Puig et al., 2007a). Strategy **I** which is characteristic of non graminaceous species which release phenolic compounds and organic acid to increase Fe^{3+} concentration in the soil solution by acidify the rhizosphere in plasma membrane of root epidermal cells Fe^{3+} chelate by these compounds (organic acid and phenolic compounds) to Fe^{2+} by ferric reductase (Robinson et al., 1999; Wu et al., 2005; & Mukherjee et al., 2006) to increase the solubility of iron release of proton via H^+-ATPase's.

Strategy **II** which is characteristics of graminaceous like grasses and cereals Fe^{3+} is chelates in the rhizosphere by structural derivatives of mugineic acid (phytosiderophores) whose complex is taken up by roots of plants (Von Wiren et al., 1995; & Ishimaru et al., 2006).

Distribution of iron in plants:

Metals have a characteristic to move throughout the plant from roots to the point where they are required by symplastic passage ion can move to the epidermal cell of roots and then epidermis to pericycle and loaded into the xylem. Metals move from the xylem to the aerial parts of the plant by transpiration. Developing leaves receive necessary metals through phloem because the xylem is not fully developed (Kerkeb & Connolly, 2006).

Iron chelates with another molecule to translocate throughout the plant. Iron is loaded into the xylem by chelator candidates, which are nicotianamine (NA) and citrate. Iron chelates complex are formed which are responsible for distribution throughout the plant. Nicotianamine act as chelates which transport to the xylem (Kerkeb & Connolly, 2006). To developing tissues metal transport through phloem as NA chelates (Ghandilyan et al., 2006). Iron transported to proper tissue-required distribution at cellular and subcellular levels. About 90% of iron is stored in chloroplast. For utilization of iron in cell mitochondria and chloroplast is an important site for storage which is required in primary carbon metabolism and the electron transport chain (Pilon et al., 2009).

Biofortification via agronomic practices:

Application of micronutrients to plants, leaves and soil for improvement in the nutritional value of edible portion of crop (de Valencia et al., 2020) to increase nutrients requirement of human nutritional value of crop increase temporarily (Cakman & Kutman, 2018). Factors which affect the nutrient production system are fertilization methods, cropping system; availability of nutrients in soil alteration (Bruulsema et al., 2012). The nutritional status of crop in edible portion of crop is altered by bioavailability at different stage of growth, translocation and nutrient allocation (Welch & Graham, 1999).

Biofortified product are released after testing of different nutrients level (Meena et al., 2018).

Crop	Country of 1st release	Nutrient	Releasing Year
Wheat	Pakistan	iron	2013
Beans	Rwanda	zinc	2011
Maize	Zambia	Pro-vitamin A	2013
Pearl millet	India	Iron, zinc	2011
Rice	Bangladesh	iron	2012

Through soil application:

The availability of iron can be enhanced by application within the soil. Inorganic Iron fertilizers application to soil shows ineffectiveness due to precipitation, oxidation reaction and adsorption. Soil application of micronutrients is more efficient in case more nutrients are needed to crop, but soil application is more preferred for grain yield, not for iron content in grain. But some factors that affect on uptake of micronutrients from soil is organic matter, soil aeration, pH, soil moisture content and interaction between different nutrients (White & Broadley, 2011). Macronutrients such as nitrogen, potassium and phosphorus (N, K, and P) positively interact with iron, increasing iron content in rice by 15% (Sperotto et al., 2012; & Bindraban et al., 2015). Environmentally friendly biofertilizers enriched in microelement are used for crop production by mycorrhizal fungi and plant growth promoting bacteria. Nutrients mobilize by plant growth promoting bacteria (PGPR) in various forms like chelation, the release of organic acid, acidification and exchange reaction (Triticum et al., 2015). Nano-fertilizer is the decrease in particle size to deliver at the right place, at right time and right dose of nutrient. The specific surface area of particles increases by reducing particle size. Effect of Fe in iron deficient tobacco cultivar as bulk Fe complex (Fe (III) EDTA) and Fe as Nano studied (Bastani et al., 2018). After two weeks of application dry weight of plants with Nano Fe as three-time greater then Fe complex.

Through foliar application:

By foliar application, we improve iron deficiency. We apply iron by spraying it on leaves and aerial parts of plants. A high surface area is required for foliar application so leaves absorb more fertilizer. The foliar application is considered a more efficient method, but immediate rainfall cause washes out of applied nutrients that cause environmental pollution (Sanchez et al., 2012). Crops growing in iron deficient soils foliar application of iron are made, but these are not translocated within plants application repeated throughout the growing season (Loneragan, 1997; & Cakmak, 2002).

Table: 1 Cereals crops released after bio-fortification with Fe or pro vitamin and their achieved concentration in edible parts.

Nutrient	Crop	Increment in nutrients (mg/kg)	References
Iron	Wheat	>54	Cakmak et al., 2010
Pro vitamin A	Maize	>8.0	Hossain et al., 2018
Iron	Pearl millet	> 70.0	Govindaraj et al., 2019
Zinc	Rice	> 20.0	Yadava et al., 2020

CONCLUSION

From the reviewed literature, it could be concluded that millions of people deal with hidden Hunger now a day. Micronutrient deficiency not only deals with crop production but also concerns with human growth and development. In pregnant women and children, micronutrient deficiency i.e. iron causes damage to fetal brain development. Micronutrient deficiency is directly related to soil micronutrient status that's in concern to control micronutrient deficiency for the welfare of human beings; it's time to improve the micronutrient status of the soil. Many strategies have been developed to biofortified the cereals with micronutrients such as soil, foliar or combined application. Many genetic engineering approaches have developed and should remain in practice to develop new varieties with agronomic practices to compete with hidden Hunger.

Acknowledgement:
This creative scientific literature, an acknowledgement, is an expression of gratitude for assistance in creating original work.

Funding:
No Funding for this paper

Conflict of Interest:
There is no conflict of interest between authors.

Author's Contribution:
All authors are contributed equally, and equal response is observed from all authors.

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