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Enrichment of Cereal Grains with Iron through Ferti-Fortification

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SUMMARY

A number of elements are known to be needed in small amount for proper plant growth and development. Such elements are called Micronutrients. Deficiency of such nutrients can adversely affect plant growth and development. Some of the best known trace mineral deficiencies include Zinc Deficiency, Boron deficiency, iron deficiency and manganese deficiency. In plants Iron is essential for chlorophyll a synthesis which is why an iron deficiency results in chlorosis. Iron is essential in human growth and development also. Micronutrient malnutrition afflicts over three billion people worldwide and the numbers are continuously increasing it is due to strong detrimental dietary preferences, low consumption of animal products, fruits and vegetables, intake of poor quality diets like cereals as these are inherently very low in zinc and iron contents particularly when grown on potentially deficient soils. A rapid and complementary approach is therefore required for biofortification of food crops with Fe in the short term. In this regard, agronomic biofortification (fertilizer strategy) seems to be a very cost-effective, fast and practical approach to improve Fe concentration in cereal crops. Agronomic approaches to Biofortification includes Ferti-fortification (adequate fertilization, method of fertilization, time of application), FYM application, intercropping and Crop rotation. Ferti - fortification is the application of fertilisers to seeds, soil and/or foliage, at rates greater than those required for maximum yield, to increase the uptake of nutrients into the plants and its translocation into seeds..

INTRODUCTION

Iron is essential for formation of chlorophyll and releases energy from sugars and starches during respiration. About 12 per cent of Indian soils are deficient in iron (Fe). International Rice Research Institute (IRRI, 2006) reported that polished rice contains on an average only 2–5 mg kg^{-1} Fe, whereas the recommended daily dietary intake of Fe for people is 10–15 mg kg^{-1} (Table 1). Critical limits of Fe in soil and plant are shown in Table 2. In many Asian countries, rice provides 50–80% of the energy intake of the poor but it does not provide enough essential micronutrients to eliminate iron deficiency (anaemia). Iron (Fe) is essential for plant growth and development. Vasconcelos *et al.* (2003) reported that the ferritin protein takes up Fe, stores it in a non-toxic form, and releases it when needed for metabolic functions as Fe stored in ferritin rice is bio available. Bioavailability is the fraction of the ingested nutrient that is utilised for normal physiological functions or storage (King, 2002). However, the dietary availability of iron in wheat flour is limited due to the loss of the iron-rich bran during milling and processing and the presence of anti-nutrients like phytic acid that keep iron strongly chelated in the grain. In humans it is the component of heam protein. Its deficiency can lead to anaemia and some neuro degenerative diseases are triggered by Fe deficiency. Breeding new plant genotypes for high grain concentrations of Fe (genetic biofortification) is the most cost-effective strategy to address the problem; but, this strategy is a long-term process. A rapid approach is therefore required for biofortification of food crops with Fe in the short term and represents useful complementary approach to on-going breeding programs. In this regard, agronomic biofortification or fertilizer strategy (ferti-fortification) represents an effective way and rapid process for combating human Fe malnutrition in developing countries (Cakmak, 2010). Ferti-fortification is the application of fertilisers to seeds, soil and/or foliage, at rates greater than those required for maximum yield, to increase the uptake of nutrients into the plants and its translocation into seeds.

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Fageria (2009) reported that Fe concentration in plant tissues varied with plant age, crop species and plant part analyzed.

Table 1: Recommended dietary allowance (RDA) of Fe

Micronutrients	Recommended dietary allowance (mg/day)
Iron (Fe)	Infants and children: 6-10 Males: 10-12 Females: 15

Table 2: Critical limits of micronutrients in soil and plant

Micronutrient	Soil (mg/kg)	Plant (mg/kg)
Zn	Low < 0.6 Medium – 0.6-2.4 High - >2.4	15
Fe	Low - <4.5 Medium – 4.5-18 High - >18	20
Mn	Low - <3.5 Medium – 3.5-14 High - >14	15

Source – Soil Practical Manual, Dept. of Soil Science, PAU

Table 3: Effect of foliar sprays on Fe concentration (mg kg^{-1}) in different rice cultivars at post anthesis stage

	Rice cultivars				
Treatments	**PR113**	**PR116**	**PR118**	**PR120**	**PAU 201**
Control	38.7	35.0	33.6	34.6	32.2
0.5% FeSO4	49.7	62.0	40.3	67.7	69.0
% Increase over control	28.4	77.1	19.9	95.6	114.2
1% FeSO4	68.9	84.7	58.6	102.0	122.0
% Increase over control	78.0	142.0	74.4	194.7	278.8
CD (*P*=0.05)	9.5	9.9	3.7	14.4	10.5
Interaction (Cultivars x Treatments)				7.4	

Table 4: Effect of ferti-fortification with Fe on grain yield and grain Fe concentration in different maize cultivars

Maize cultivar	Grain yield (q/ha)			Grain Fe conc. (mg/kg)		
	Control	Fe spray	Mean	Control	Fe spray	Mean
PMH 1	42.82	**45.60**	44.21	23.53	38.23	30.88
JH 3459	43.11	44.12	43.62	32.57	**39.90**	36.24
30V92	46.33	**49.00**	47.67	31.23	38.53	34.88
Prabhat	38.71	40.33	39.52	25.80	36.23	31.02
Navjot	41.89	43.56	42.73	28.37	**39.57**	33.97
Mean	42.57	44.52	48.55	28.30	38.49	33.40
CD(0.5%)	6.55	4.86	-	3.65	3.84	-

Fe(1%) spray at knee high, pre tasseling and post tasseling stage: Design - RBD

Fernandez and Ebert (2005) found that foliar applied compound penetration would occur via the cuticle through cuticular cracks and imperfections, through stomata, leaf hairs and other specialized epidermal cells.

They reported that both the upper and the lower leaf surface are involved in the process of penetration of an applied solution. Ferti-fortification is a technique to increase Fe content in rice grains and brown rice. Bio-fortification and commercial ferti-fortification though are slow processes and show low efficiency of nutrient enrichment, but still these are highly complementary (Singh *et al*. 2013).Through ferti-fortification with Fe, the maximum Fe enrichment was observed in grains of PR116 (20.5 mg kg^{-1}) and PAU 201 (28.8 mg kg^{-1}) cultivars of brown rice (Pawitar *et al*. 2013). Singh *et al*. (2013) reported maximum Fe concentration in panicle samples of PAU 201 cultivar (69.0 mg kg^{-1} and 122.0 mg $kg^{-1,}$ respectively) with three sprays of 0.5% and 1.0% ferrous sulphate ($FeSO_4.7H_2O$) (at maximum tillering stage, pre-anthesis stage and post anthesis stage (at 50% flowering) (Table 3). Dhaliwal *et al* (2013) in Ludhiana observed higher grain Fe concentration in JH 3459 as compared to other varieties with iron spray (Table 4).

Bilski *et al*. (2012) reported the highest concentration Fe upto 17 times in rye seedlings grown on coal ash based media as compared to plants grown on soil and all cereal crop plants expressed hyper accumulating ability of Fe (Table 5). Mohammed *et al* (2011) also reported the highest concentration of grain Fe and Mn with the foliar application of Mn + Fe under saline conditions of Egypt (Table 6).

Table 5. The concentration of Fe in growth media (%) and in plants (mg x kg^{-1}) grown on media consisting of soil control, FA1, FA2, BA or FA2+BA.

Media	Fe content in Growth Medium	Barley	Oats	Rye	Triticale	Winter wheat
Soil	0.87± 0.04a	175± 29a	138± 23a	99± 11a	103± 21a	102± 13a
FA1	4.32± 1.0b	834± 49b	834± 62b	**1621±109b**	397± 50b	435± 59b
FA2	3.80±0.63b	524± 44c	612± 55c	1120± 104c	401± 51b	441± 40b
BA	1.26±0.17c	362±51d	358± 27d	349± 32d	199± 28c	219± 26c
FA2+BA	2.08±0.37d	407± 37e	452± 39e	405± 47e	203± 21d	247± 37d

Soil as a control
FA (Fly ash) from lignite coal (FA1)
FA from semi-bituminous coal (FA2)
BA (bottom ash) from semi-bituminous coal
FA/BA (1:1 weight based) from semi-bituminous coal

Table 6: Enrichment of wheat grains with foliar spray of Fe & Mn under saline condition

Saline treatment	Foliar spray treatment	Grain Fe (ppm)	Grain Mn (ppm)
Saline water	Control	94	6.0
	Mn	102	8.5
	Fe	144	7.4
	Mn + Fe	146	10.1
Tap water	Control	104	7.0
	Mn	103	10.1
	Fe	197	9.2
	Mn + Fe	201	11.0

Foliar sprays at tillering stage
Design- Split complete randomized design
Pot experiment
Available Fe:Mn:Zn:Cu (mg/kg soil)= 4.30:3.101.90:0.90

CONCLUSION

To alleviate the major concern of under nutrition all the approaches of fortification in general and bio fortification in particular are complementary to each other and should go hand in hand. Ferti-fortification can be a rapid solution to enrich the cereals. As compared to chemical methods seed bio fortification by foliar feeding is more excellent to increase the grain yield and micronutrient concentration in grain part and has low cost. However, foliar sprays should be done at proper stages of crop growth. Priming seeds in micronutrient-containing solutions is an alternative way to increase micronutrient seed concentration prior to sowing. Seedlings grown on coal ash based media also showed hyper accumulation of Fe as compared to plants grown on normal soil thus coal combustion residues can be treated Fe fertilizers especially desirable in various developing countries. Moreover, intercropping and crop rotation systems also contribute to grain Fe concentrations and the combined applications of Fe fertilizers together with organic materials (like farmyard manure and green manures) are effective in facilitating Fe uptake by roots and correcting Fe deficiency. There are also promising cultivars for higher accumulation of Fe. Agronomic experiments need to be planned and conducted for developing micronutrient fertilizer doses, methods and timings for their application for increasing not only yield but also the concentration of micronutrient in grains.

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