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Biofortification of post-rainy sorghum (*Sorghum bicolor*) with zinc and iron through fertilization strategy

J S MISHRA[1], K HARIPRASANNA[2] , S S RAO[3] and J V PATIL[4]

Directorate of Sorghum Research, Hyderabad, Telangana 500 030

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Sorghum [*Sorghum bicolor* (L.) Moench] is the major staple food of millions of rural poor in arid and semi-arid regions of the world. In India, Maharashtra and Karnataka are the major sorghum producing and consuming states. The per capita consumption of the sorghum is 75 kg grain/ year in major sorghum areas in India (Kumar *et al.* 2013). In terms of nutrient intake, sorghum accounts for about 35% of the total intake of calories, protein, iron and zinc in the dominant production/consumption areas. Zinc and Fe deficiencies are a growing public health and socioeconomic issue, particularly in the developing countries (Welch and Graham 2004). Nearly five lakhs children under five years of age die annually because of Zn and Fe deficiencies (Black *et al.* 2008). Although, sorghum is the second cheapest source of energy and micronutrients after pearl millet [*Pennisetum glaucum* (L.) R. Br. emend. Stuntz]; and a majority of the population in central India depends on sorghum for their dietary energy and micronutrients requirement (Parthasarathy Rao *et al*. 2006), few studies indicated that mineral concentrations and bioavailability are limited in cooked sorghum grain (Kayode *et al*. 2006). The intake of iron and zinc in low-income rural households in sorghum consuming regions is lower than the recommended dietary allowance. In India, about 79% of children between 6 and 35 months and women between 15 and 49 years of age are reported to be anaemic (Krishnaswamy 2009). Biofortification of sorghum by increasing mineral micronutrients (especially iron and zinc) in the grains provides a sustainable solution to iron and zinc deficiency (Pfeiffer and McClafferty 2007). Sorghum cultivars differ in Fe and Zn content in grain. Post-rainy (*Rabi*) sorghums that are predominantly grown for food uses had lower Fe and Zn content than that of rainy season sorghums (Kumar *et al.* 2013). Most of the sorghum growing soils of arid and semi-arid regions of India are deficient in zinc and iron contents (Katyal and Vlek 1985, Singh 2001). Any approach which could increase root growth and result in a high transfer of Fe and Zn from the soil to the plant is crucial for biofortification (Zuo and Zhang 2009). Agronomic biofortification (increasing the grain Fe and Zn status through application of Zn- and Fe-containing fertilizers) in post-rainy sorghum cultivars is one of the cheapest options to address the problem of hidden hunger in predominantly sorghum eating populations of semi-arid tropics. Adding zinc-enriched fertilizer to the soil results in increased uptake of zinc in wheat crop, and increases the bioavailable zinc concentration in the edible portion of the plant (Cakmak 2008). The present experiment was conducted to find out the effect of application of Zn-and Fe-containing fertilizers on Fe and Zn contents in sorghum cultivars.

A field experiment was conducted at the research farm (17^0 31' N, 78^0 39' E, and 545 m above mean sea level) of the Directorate of Sorghum Research, Hyderabad India, during the winter seasons of 2010-11 and 2011-12. The climate of the area is semi-arid and tropical, with an average annual rainfall of 857 mm (75-80% of which is received during June-September), minimum temperature of 8-10^{0}C in December, and maximum temperature of 40-42^{0}C in May. The total rainfall received during cropping season (October-February) was 51.8 and 27.5 mm in 2010-11 and 2011-12, respectively. The soil was an Alfisol, Udic Rhodustalf, sandy loam (67% sand, 14% silt and 19% clay), with 7.80 pH, 0.25 dS/m electrical conductivity, 1.63 Mg/m^3 bulk density, 7.34% available soil moisture (mean of available moisture content between field capacity and permanent wilting point); low in organic carbon (0.39%) and available N (163 kg/ha), medium in available phosphorus (29 kg P_2O_5/ha) and high in potassium (360 kg K_2O/ha) content. The soil DTPA- Fe and Zn contents were 5.27 and 1.12 mg/kg as against the critical limit of 4.5 and 0.60 mg/kg, respectively. The treatments consisting of 4 levels of micronutrients [Control {RDF (80:40:40 kg NPK/ha)}, RDF+ $ZnSO_4$ @ 50 kg/ha (soil application), RDF+ $FeSO_4$ @ 50 kg/ha (soil application), RDF+ $ZnSO_4$ + $FeSO_4$ soil application followed by foliar application (0.50%+1.0%) at 45 days after sowing-

[1]Present address: Head (e mail: jsmishra31@gmail.com, mishra@sorghum.res.in), Division of Crop Research, ICAR-RCER, Patna, Bihar 800 014; [2]Senior Scientist (Plant Breeding) (e mail: hari@sorghum.res.in), [3]Principal Scientist (Plant Physiology) (e mail: ssrao@sorghum.res.in), [4]Director (e mail: jvp@sorghum.res.in)

Table 1 Characteristics of the grain sorghum cultivars used for the trials during 2010-11 and 2011-12.

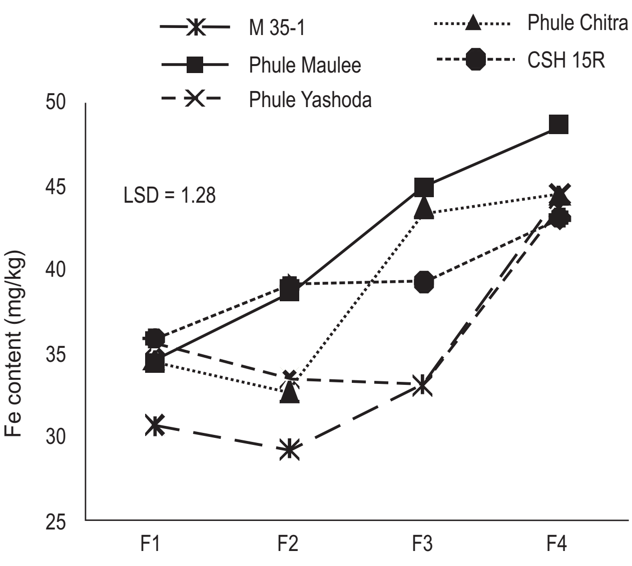
Cultivar	Pedigree	Year of release and place	Plant height (cm)	Days to 50% flowering	Maturity duration (days)
CSH 15R	104 A × RS 585	1995, DSR, Hyderabad	190-210	70-75	110-115
M 35-1	Selection from Maldandi land races	1969, ARS, Mohol	170-210	70-73	110-115
Phule Chitra	SPV 655 × RSLG 112	2006, MPKV, Rahuri	200-220	74-75	110-115
Phule Maulee	M 35-1 × Sel. 3	1999, MPKV, Rahuri	180-210	70-73	110-115
Phule Yashoda	Selection from land race	2000, MPKV, Rahuri	240-270	75-77	120-125

DSR, Directorate of Sorghum Research; MPKV, Mahatma Phule Krishi Vidyapeeth; ARS, Agricultural Research Station

DAS] and 5 cultivars (CSH 15R, M 35-1, Phule Chitra, Phule Maulee, Phule Yashoda) (Table 1) were replicated thrice in a factorial randomized block design. Plots were seeded manually in the second week of November during both the years. Sowing was done in rows 45 cm apart and at an intra-row spacing of 15 cm and was later thinned to one plant per stand at 15 DAS. Atrazine at 0.50 kg ai/ha was applied one day after sowing with 500 l/ha of water with the help of knapsack sprayer, fitted with flat-fan nozzle. Nutrients were applied as per the treatments. All the phosphorus, potassium, zinc sulphate and iron sulphate were applied as basal on the day of planting. Nitrogen as urea was applied in 2 splits, 50% at sowing and remaining at 35 DAS. The crop was raised under irrigated conditions and three irrigations were given during each cropping season. After crop harvest, the grain Fe and Zn concentrations were analyzed using atomic absorption spectrometer (Shimadzu AAF-6701).

Results revealed that the external application of micronutrients (Fe and Zn) through fertilizers had no significant effect on growth and yield attributes, and grain and fodder yields of sorghum as compared to RDF (Table 2). As the DTPA-extractable Fe and Zn levels in the soil were adequate (>4.5 mg/kg Fe and 0.60 mg/kg Zn), the additional application of these micronutrients through fertilizers did not increase the yields. Among genotypes, Phule Yashoda had the higher leaf area index and plant height. CSH 15 R produced the longest panicle followed by Phule Yashoda. Grain yield differed significantly among genotypes, but the trend was not consistent over the years. On mean basis, Phule Chitra (4.27 tonnes/ha) and Phule Maulee (4.23 tonnes/ha) produced the higher grain yields. Phule Yasoda being on a par with Phule Chitra and Phule Maulee, produced the significantly higher dry fodder yields than that of CSH 15 R and M 35-1 during 2010-11; however in 2011-12, the differences among genotypes for fodder yields were not significant. The interaction effects of micronutrients × cultivars for grain and fodder yields were not significant. Irrespective of the cultivars, soil application of $FeSO_4$ and $ZnSO_4$ along with RDF increased the grain Fe and Zn contents, respectively as compared to RDF alone, but the differences were not significant. Combined application (soil+foliar) of $ZnSO_4$ + $FeSO_4$ significantly improved the Fe and Zn contents in sorghum grains compared to control (RDF alone). Wei *et al.* (2012) reported increased grain Fe concentration and bioavailability in rice with foliar application of $FeSO_4$ and addition of $ZnSO_4$ to foliar Fe application increased both Fe and Zn content without altering Fe content and bioavailability. Improved grain Zn concentration in rice with application of Zn-coated urea fertilizer was also reported by Shivay *et al*. (2008). Sorghum genotypes differed significantly for Fe and Zn content in grains. Among genotypes, Phule Maulee had the highest Fe (41.59 mg/kg) and Zn (20.80 and 26.42 mg/kg). Though the interaction effects of micronutrients × cultivars for Fe and Zn content in grains were not significant, Phule Maulee had the highest Fe (48.54 mg/kg) and Zn (29.46 mg/kg) content with combined application (soil+foliar) of $ZnSO_4$ + $FeSO_4$ (Fig 1).

It may be concluded that the sorghum cultivars vary in grain Fe and Zn content. These micronutrients concentrations in grain could be increased by selecting appropriate cultivar and application of micronutrient rich fertilizers. Sorghum cultivar Phule Maulee with soil application of $ZnSO_4$ + $FeSO_4$ each at 50 kg/ followed by foliar application (0.50%+1.0%) at 45 DAS along with recommended dose of



F1- RDF (80:40:40 kg NPK/ha), F2- RDF+ $ZnSO_4$ @ 50 kg/ha (soil application), F3- RDF+ $FeSO_4$ @ 50 kg/ha (soil application), F4- RDF+ $ZnSO_4$ + $FeSO_4$ (soil application) followed by foliar application (0.50%+1.0%) at 45 DAS.

Fig 1 Grain Fe content in sorghum cultivars as affected by external application through fertilizers.

Table 2 Effect of micronutrients and cultivars on growth and yield of *rabi* sorghum

Treatment	Leaf area index at 60 DAS		Plant height at harvest (cm)		Panicle length (cm)		100-grain weight (g)		Grain yield (tonnes/ha)		Dry fodder yield (tonnes/ha)		Fe content (mg/kg)	Zn content (mg/kg) in grain	
	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2	in grain*	Y1	Y2
Micronutrients															
RDF (80:40:40 kg NPK/ha)	4.76	3.44	228	246	21.13	19.60	3.29	3.21	3.27	4.88	10.10	9.00	35.00	16.88	23.71
RDF+ $ZnSO_4$ @ 50 kg/ha (soil application)	4.79	3.78	232	250	21.13	19.60	3.28	3.13	3.29	4.56	10.12	9.10	38.75	18.11	25.34
RDF+ $FeSO_4$ @ 50 kg/ha (soil application)	4.59	3.94	235	251	20.60	19.20	3.35	3.15	3.15	4.67	9.98	9.29	34.68	17.94	25.26
RDF+ $ZnSO_4$ + $FeSO_4$ soil application *fb* foliar application (0.50%+1.0%) at 45 DAS	4.50	3.67	233	244	20.60	19.60	3.31	3.35	3.09	4.52	10.19	9.44	44.06	18.65	27.47
LSD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	5.7	NS	2.76
Cultivars															
CSH 15R	4.18	3.42	216	235	24.50	21.42	3.64	3.12	2.47	5.28	5.96	8.78	39.22	19.13	26.29
M 35-1	4.83	3.59	239	250	19.42	18.58	3.18	3.43	2.86	3.97	9.78	9.35	34.37	18.99	24.42
Phule Chitra	4.06	3.88	232	252	20.08	19.00	3.32	3.19	3.92	4.62	11.36	9.24	39.00	15.50	25.16
Phule Maulee	4.41	3.76	217	235	18.00	17.17	3.21	3.17	3.95	4.50	11.40	9.24	41.59	20.80	26.42
Phule Yashoda	5.81	3.90	256	267	22.33	21.33	3.07	3.14	2.81	4.93	12.00	9.42	36.42	15.04	24.93
LSD (P=0.05)	0.74	NS	11	14	1.16	0.93	0.19	0.24	0.58	0.79	1.30	NS	6.40	4.02	NS

Y1- 2010-11, Y2- 2011-12, *2010-11

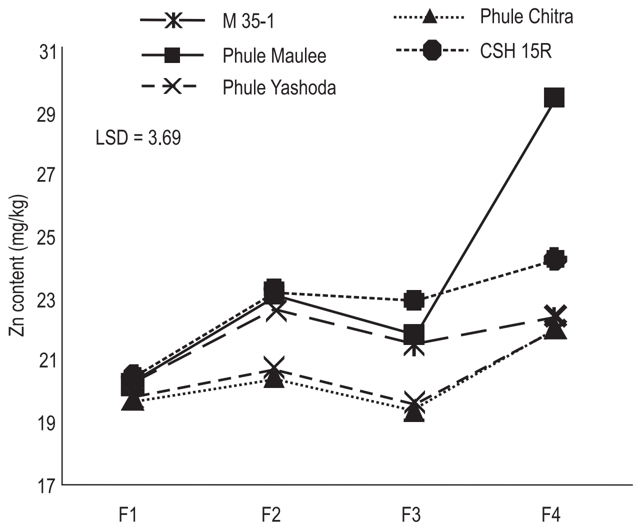


Fig 2 Grain Zn content in sorghum cultivars as affected by external application through fertilizers.

fertilizer (80:40:40 kg NPK/ha) could be used to produce micronutrient (Fe and Zn) rich post-rainy sorghum and to improve the micronutrient nutritional status of farmers.

SUMMARY

A field experiment was conducted during *rabi* 2010-11 and 2011-12 to see the effect of external application of Fe and Zn on grain yield and quality of 5 *rabi* sorghum cultivars. The treatments consisting of 4 levels of micronutrients [Control {RDF (80:40:40 kg NPK/ha)}, RDF+ $ZnSO_4$ @ 50 kg/ha (soil application), RDF+ $FeSO_4$ @ 50 kg/ha (soil application), RDF+ $ZnSO_4$ + $FeSO_4$ soil application followed by foliar application (0.50%+1.0%) at 45 DAS] and 5 cultivars (CSH 15R, M 35-1, Phule Chitra, Phule Maulee, Phule Yashoda) were replicated thrice in a factorial randomized block design. External application of micronutrients (Fe and Zn) through fertilizers had no significant effect on growth, yield attributes and grain and fodder yields as compared to RDF alone. Sorghum genotypes differed significantly for Fe and Zn content in grains. Among genotypes, Phule Maulee had the highest Fe (41.59 mg/kg) and Zn (20.80 and 26.42 mg/kg). Sorghum cultivar Phule Maulee with soil application of $ZnSO_4$ + $FeSO_4$ each at 50 kg/ followed by foliar application (0.50%+1.0%) at 45 DAS along with recommended dose of fertilizer (80:40:40 kg NPK/ha) is recommended for producing micronutrient (Fe and Zn) rich post-rainy sorghum.

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