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Agronomic biofortification of zinc in wheat (*Triticum aestivum* L.)

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Zinc malnutrition poses a major health issue for human beings globally. Agronomic bio-fortification explores the feasibility to control the zinc deficiency related disorders of the human population. Field experiment was conducted in a red and lateritic soil of Ranchi on 23 wheat cultivars with soil and foliar applications of $ZnSO_4 \cdot 7H_2O$. Zinc content of wheat grain increased from 38.86 to 77.17 mg/kg with soil application and to 76.49 mg/kg with soil + foliar application of Zn. Total Zn uptake by wheat (grain + straw) cultivars with soil + foliar application of Zn was significantly higher in short (933 g/ha) and long (960 g/ha) duration cultivars compared to that with soil application. Apparent Zn recovery in wheat also improved with soil + foliar application of Zn fertilizer, suggested that agronomic bio-fortification of zinc is possible in wheat and can prevent Zn malnutrition in human beings to a considerable extent.

Keywords: Agronomic, biofortification, *Triticum aestivum* L., red and lateritic soil, zinc deficiency.

ZINC (Zn) deficiency affects more than one-third of the human population in the world[1,2]. Its deficiency in soils of India is widespread[1,3,4] and crops grown in these soils suffer from poor or no yield. A close relationship exists among soils, crops and human health nutrition[5]. According to the World Health Organization[6], about 8 lakh people die annually due to zinc malnutrition, among which more than 50% are children below five years of age. Cereal grains are inherently low both in concentration and bioavailability of Zn, particularly when grown on potentially Zn-deficient soils[7,8]. Release of high-yielding cereal cultivars also contributes to the high incidence of Zn deficiency in human beings by reducing Zn concentration in grain through dilution and in soil through depletion[4]. In most cases, there is an inverse relationship between grain yield and grain Zn concentration[9,10]. Breaking the trade-off between grain yield and grain Zn concentration is an important issue and this can be achieved by breeding, transgenic technology or agronomic approaches[11–14]. Wheat is one of the three major cereal crops (viz. wheat, rice and maize) worldwide and represents the main dietary source of calories, proteins and micronutrients for majority of the world's population, especially in the developing countries[15]. Wheat is responsible for up to 70% of daily calorie intake of the population living in rural regions and is an important source of Zn for human beings living in the developing world[4].

Scanty information is available on regional adaptability of Zn fertilization for biofortification of wheat[16–20]. Field studies have been undertaken to evaluate the acquisition and utilization of zinc by promising wheat cultivars grown under red and lateritic soil condition of India.

Twenty-three cultivars of wheat were selected to study the possibility of agronomic biofortification of zinc under red and lateritic soil condition (Table 1). The cultivars were grouped under two categories, i.e. short (11 cultivars) and long (12 cultivars) maturity duration. Field experiment was conducted during winter (*rabi*) season of 2010–11 at the University Research Farm of Kanke, Ranchi, Jharkhand, India. The experiment was laid out in a strip plot design with three replications. The soil had pH 5.50, electrical conductivity (EC) 0.10 dS/m, organic

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Table 1. Grain and straw yield (q/ha) of wheat cultivars affected by zinc application at different maturity periods in red and lateritic soil

	Grain				Straw			
Maturity period	F_1	F_2	F_3	Mean	F_1	F_2	F_3	Mean
Short duration	39.32	40.48	39.47	39.76	65.24	68.73	64.96	66.31
Long duration	37.58	39.00	38.51	38.36	67.21	74.53	72.16	71.30
Mean	38.45	39.74	38.99	–	66.225	71.63	68.56	–

CD at 5% grain: V-6.61, Zn–NS, (V × Zn)-7.41; CD at 5% straw: V-12.64, Zn–NS, (V × Zn)-13.15. F_1, RDF; $F_2 – F_1$ + 100 kg/ha $ZnSO_4 \cdot 7H_2O$; $F_3 – F_2$ + 0.5% spray of $ZnSO_4 \cdot 7H_2O$. NS, Not significant; V, Variety.

carbon 4.7 g/kg and diethylene triamine penta acetic acid (DTPA) extractable Zn 2.91 mg/kg. Three treatment combinations were used; T_1: control (recommended dose of fertilizers (RDF)); T_2, RDF + 100 kg/ha zinc sulphate (soil application) and T_3, T_2 + three foliar sprays of 0.5% zinc sulphate (first at crown root stage, second at pre-flowering stage and third at milking stage). Recommended dose of NPK (100 : 60 : 40) was applied to the crop; full dose of P and K and half dose of N were applied as basal and the remaining of N was applied in two equal splits at crown root stage and pre-flowering stage of wheat respectively. Recommended package of practices for wheat cultivation were followed. After harvest, yield was recorded. Samples of grain–straw were collected and processed for drying and grinding. Ground material (0.5 g) was taken in a conical flask and 10 ml of tri-acid mixture ($HNO_3 : HClO_4 : H_2SO_4$ in 10 : 4 : 1) was added. It was kept in a digestion chamber till complete digestion[21]. The residue dissolved in double-distilled water and after filtration (Whatman filter paper no. 42), its final volume was made to 50 ml. Total Zn content in grain and straw of wheat and DTPA-extractable Zn was extracted by DTPA–$CaCl_2$ solution in soil[22] and determined with the help of atomic absorption spectrophotometer (ECIL-4141). The apparent nutrient recovery (ANR) percentage was calculated as[23]

$$\text{ANR (\%)} = \frac{A - B}{C} \times 100,$$

where A is the nutrient uptake in fertilized plot (kg/ha); B the nutrient uptake in unfertilized (control) plot (kg/ha) and C the quantity of nutrient applied (kg/ha).

The response to Zn application on grain and straw yield of wheat was not significant (Table 1). This was primarily due to the level of available Zn in soil (2.9 mg/kg) and harvest index of the varieties tested ranged from 37.60% to 60.76% and 34.35% to 35.86% respectively, for short and long duration of wheat cultivars.

There was a wide variation (29–54 mg/kg) in zinc content of wheat cultivars selected for the present study. Zinc content of wheat grain increased considerably with applied zinc either as soil application or soil + foliar application (Table 2). However, it was apparent that in the different methods of zinc fertilization, i.e. soil application of 100 kg/ha $ZnSO_4 \cdot 7H_2O$ and that with three foliar sprays of zinc, there was no significant difference so far as accumulation of Zn in grain was concerned. Zinc accumulation in different cultivars ranged from 27.33 to 52.67 mg/kg with no zinc, 64.00 to 97.33 mg/kg with soil application of zinc fertilizers and 64.00 to 89.67 mg/kg with soil + foliar application of zinc. Results thus clearly indicate the possibility of enriching wheat grain with zinc, if one resorts to zinc fertilizer application in the crop. Work done on rice, wheat and maize crops across the world suggests that such enrichment of edible grains with zinc is possible through agronomic biofortification[24,25]. Maqsood *et al.*[26] conducted a pot experiment with soil pH 7.36 and DTPA-extractable Zn 0.75 mg/kg, and found that Zn concentration in wheat grain ranged from 34.9 to 69.93 mg/kg after application of 6.0 mg/kg in 12 tested wheat genotypes. Studies have also reported that Zn concentration in wheat grain increases through soil and/or foliar application of Zn over control[23,27,28].

Results of the present study also point out that slight increase in the maturity periods of wheat cultivars does not influence the accumulation pattern of zinc in the edible part of the plant (grain and straw) for human beings and animals (Table 3). Zou *et al.*[19] observed that Zn concentration in wheat leaves increases due to soil and soil + foliar application of Zn compared to its non-application in wheat. Cakmak[4] also observed increase in the Zn concentration in shoot and grain of wheat due to soil and soil + foliar Zn application over control.

Zinc uptake by wheat grain and straw showed an increasing trend in zinc-treated plot (Table 4). Duration of wheat cultivars did not influence zinc uptake under no zinc, soil application of Zn, or soil + foliar application of zinc. Mean values of Zn uptake by wheat cultivars were 149 g/ha for no zinc application, 304 g/ha for 100 kg $ZnSO_4$ as soil application and 296 g/ha for soil + foliar application of zinc fertilizers. Similar trend was observed in case of wheat straw.

Total Zn uptake by wheat ranged from 793.0 (soil application) to 933.0 (soil + foliar) g/ha in case of

Table 2. Initial Zn content (mg/kg) in selected wheat cultivars for the experiment

Maturity period	Cultivar	Duration of maturity (days)	Initial Zn content (mg/kg)	Zn content (mg/kg) after harvesting		
				F_1	F_2	F_3
Short duration	RAJ-4176	113–116	34.85	34.00	64.00	68.67
	HUW-612	113–116	40.60	41.33	72.33	66.67
	KO-716	112–115	35.35	37.33	73.33	73.33
	BIRSA GEHUN-2	112–115	49.46	49.00	70.00	86.00
	HUW-620	112–115	40.12	41.00	78.00	88.67
	DBW-14	112–115	29.16	31.00	80.67	86.33
	KO-811	112–116	36.72	40.00	97.33	78.33
	HI-8381	112–115	36.39	33.67	83.67	75.33
	MP-1237	110–112	36.19	38.67	70.33	64.00
	MP-3304	109–112	40.27	44.33	84.67	79.33
	MP-3324	108–112	32.56	29.33	63.00	67.67
Mean Zn content in short duration of wheat (<116 days maturity period)			37.42	38.15	76.12	75.85
Long duration	NW2036	120–124	54.15	52.67	76.33	68.33
	HD-2967	120–123	38.32	36.33	80.00	78.00
	K-9107	120–125	38.10	37.67	76.33	72.33
	C-306	120–125	39.00	40.00	72.00	88.33
	K-8027	118–120	39.32	43.33	85.67	81.33
	HD-2733	115–120	29.31	29.67	76.33	70.67
	PBW-373	115–120	37.05	39.00	82.67	89.67
	HD-3016	115–117	37.70	35.33	75.67	72.33
	KO-617	115–120	29.32	27.33	69.67	69.00
	BIRSA GEHUN – 3	115–120	40.60	37.33	79.33	79.00
	HUW-468	115–120	39.72	45.00	79.67	77.67
	HD-2888	115–120	47.12	51.33	85.00	79.00
Mean Zn content in long duration of wheat (>116 days maturity period)			39.14	39.58	78.22	77.14

Table 3. Accumulation of zinc (mg/kg) in wheat grain and straw affected by zinc application at different maturity periods in red and lateritic soil

Maturity period	Grain				Straw			
	F_1	F_2	F_3	Mean	F_1	F_2	F_3	Mean
Short duration	38.15	76.12	75.85	63.37	26.06	70.21	99.36	65.21
Long duration	39.58	78.22	77.14	64.98	26.30	67.81	93.33	62.48
Mean	38.86	77.17	76.49	–	26.18	69.01	96.34	–

CD at 5% grain: V-6.57, Zn-6.51, (V × Zn)-11.04. CD at 5% straw: V-6.83, Zn-1.29, (V × Zn)-10.26. F_1, RDF, $F_2 – F_1$ + 100 kg/ha $ZnSO_4·7H_2O$; $F_3 – F_2$ + 0.5% spray of $ZnSO_4·7H_2O$.

short-duration cultivars, while this increase was to the tune of 809.0 (soil application) and 960.0 (soil + foliar) g/ha in case long-duration cultivars. Maqsood *et al.*[26] have reported that Zn uptake increases from 390.23 to 778.94 μg plant^{-1} and 542.89 to 975.23 μg plant^{-1} with no application and application of 6.0 mg/kg in wheat genotypes respectively, in controlled condition experiments.

Apparent Zn recovery was 2.25% and 2.30% with soil application of zinc and 2.64% and 2.73% with soil + foliar application of zinc respectively, in short- and long-duration wheat cultivars. Interestingly, zinc recovery was considerably higher with soil + foliar application compared to soil application (Table 5), showing the effectiveness of foliar feeding of zinc in wheat to enhance grain zinc level.

Application of zinc sulphate did not show significant impact on soil pH and EC and organic carbon. While, DTPA-extractable Zn accumulated about 2.88 and 3.15 times in soil to 2.91 mg/kg initial Zn content in soil after soil Zn application and also soil + foliar application of Zn respectively, showing Zn build-up in red and lateritic soil.

Thus, small but non-significant variations have been recorded in wheat cultivars of varying maturity periods, to increase the grain Zn content with fertilizer Zn use. Field studies have shown that it is possible to increase Zn content in edible parts of wheat by fertilizer zinc application. Among the methods, soil + foliar application of

Table 4. Zinc uptake (g/ha) of wheat grain and straw affected by zinc application at different maturity periods in red and lateritic soil

	Grain				Straw			
Maturity period	F_1	F_2	F_3	Mean	F_1	F_2	F_3	Mean
Short duration	149.30	304.61	296.04	249.98	170.88	488.16	637.10	432.04
Long duration	148.69	303.98	296.89	249.85	177.65	504.82	663.49	448.65
Mean	148.99	304.29	296.46	–	174.26	496.49	650.29	–

CD at 5% grain: V-50.54, Zn-36.09, (V × Zn)-66.84. CD at 5% straw: V-104.91, Zn-44.47, (V × Zn)-119.42. F_1, RDF; F_2 – F_1 + 100 kg/ha $ZnSO_4 \cdot 7H_2O$; F_3 – F_2 + 0.5% spray of $ZnSO_4 \cdot 7H_2O$.

Table 5. Total Zn uptake (g/ha) and apparent Zn recovery (%) by wheat (grain + straw) affected by Zn application in different maturity periods of the cultivars

Maturity period	Cultivar	RDF (F_1)	RDF + 100 kg $ZnSO_4 \cdot 7H_2O$ (F_2)	AZnR in soil application (%)	RDF + 100 kg $ZnSO_4 \cdot 7H_2O$ + 3 foliar spray of 0.5% $ZnSO_4 \cdot 7H_2O$ (F_3)	ANR in foliar application (%)	Mean
Short duration	RAJ-4176	298.0	894.0	2.84	1008.0	3.06	733.0
	HUW-612	333.0	704.0	1.77	841.0	2.19	626.0
	KO-716	308.0	895.0	2.80	947.0	2.76	717.0
	BIRSA GEHUN-2	404.0	906.0	2.39	1047.0	2.77	786.0
	HUW-620	334.0	702.0	1.75	1050.0	3.08	695.0
	DBW-14	324.0	858.0	2.54	1083.0	3.27	755.0
	KO-811	258.0	586.0	1.56	852.0	2.56	566.0
	HI-8381	225.0	541.0	1.50	733.0	2.19	500.0
	MP-1237	406.0	876.0	2.24	843.0	1.88	708.0
	MP-3304	376.0	1063.0	3.27	1034.0	2.83	824.0
	MP-3324	256.0	695.0	2.09	826.0	2.45	592.0
	Mean	320.0	793.0	2.25	933.0	2.64	682.0
Long duration	NW2036	379.0	878.0	2.38	988.0	2.63	748.0
	HD-2967	304.0	762.0	2.18	794.0	2.11	620.0
	K-9107	273.0	754.0	2.29	858.0	2.52	628.0
	C-306	264.0	761.0	2.37	1155.0	3.84	727.0
	K-8027	331.0	1201.0	4.14	1064.0	3.16	865.0
	HD-2733	289.0	634.0	1.64	893.0	2.60	605.0
	PBW-373	362.0	575.0	1.01	1165.0	3.46	701.0
	HD-3016	336.0	832.0	2.36	894.0	2.40	687.0
	KO-617	305.0	744.0	2.09	991.0	2.95	680.0
	BIRSA GEHUN-3	268.0	739.0	2.24	733.0	2.00	580.0
	HUW-468	356.0	984.0	2.99	1057.0	3.02	799.0
	HD-2888	450.0	842.0	1.87	933.0	2.08	741.0
	Mean	326.0	809.0	2.30	960.0	2.73	698.0
Total mean		323.0	801.0	2.27	947.0	2.68	691.0

CD at 5%: V, 0.092; Zn, 0.068 and V × Zn, 0.137. AZnR, Apparent zinc recovery.

$ZnSO_4 \cdot 7H_2O$ is significantly superior to soil application alone in increasing the total zinc uptake by wheat crop. The apparent Zn recovery is also higher with soil + foliar feeding of fertilizer Zn in wheat. Results suggest that agronomic biofortification is a practical and cost-effective measure to improve Zn content in wheat grain. This can help prevent Zn malnutrition in human beings to a considerable extent and provide health benefits.

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Cotton crop in changing climate

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Cotton is a major cash crop of global significance. It has a peculiar and inherent growth pattern with coinciding physiological growth stages. This study is based upon modelling and simulation for Hisar region. Stage-wise water stress has been quantified for three *Bt*-cotton cultivars with three sowing dates under both irrigated and non-irrigated (rainfed) conditions to assess the most sensitive stage. As per model output, it was observed that, at some stages stress value during excess years remains below 0.3 which is characterized as mild stress, in contrast with drought years where it is above 0.3, impacting potential crop productivity. Thus, rainfall impacts the productivity of cotton even in irrigated semi-arid region. Irrigation measures practiced, could partially alleviate influence of stress. Also, early sowing is found beneficial. The most water-sensitive period is ball formation and maturity stage followed by flowering stage.

Keywords: Cotton, irrigation, temperature, water.

AGAINST the backdrop of reduced cotton production in recent years, there is an urge to study and mitigate the associated stresses. Cotton is a crop with an uncertain or ambiguous growth habit and has a dynamic growth response towards the environment and management practices. Site-specific management strategies considering the soil, weather, etc. need to be considered to optimize

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