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Zinc accounting for different varieties of wheat (*Triticum aestivum*) under different source and methods of application

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ABSTRACT

A field experiment was conducted during winter (*rabi*) seasons of 2013–14 and 2014–15 at ICAR–Indian Agricultural Research Institute, New Delhi to find out zinc accumulation capacity and use efficiencies of different varieties of wheat (*Triticum aestivum* L.) to zinc fertilization. The zinc concentration in different parts of wheat was found highest in grain followed by spike straw and lowest in straw. Among the tested varieties, highest Zn concentration (40.6 mg/kg) and uptake (189.2 g/ha) in grain was registered in HD 2851 and HD 2967 varieties, respectively. Zinc recovery efficiency of HD 2687 (2.5%) was registered highest among the tested varieties. Highest Zn mobilization efficiency index (ZnMEI) was recorded in HD 2967 variety. Zinc fertilization increased zinc induced nitrogen recovery efficiency (ZniNRE) of all the tested varieties to the tune of 7.4–12.7%. Application of Zn in wheat crop increased Zn concentration in grain by 7–12%. Uptake of Zn was increased 5.2–5.6% in soil + foliar application in comparison to soil application alone. The highest Zn concentration and uptake in grain, and Zn use efficiencies were recorded with the application of 1.25 kg Zn/ha through Zn-EDTA as soil application + 0.5% foliar spray at maximum tillering and booting stage.

Key words: Foliar spray, Zn–EDTA, Zn induced nitrogen recovery efficiency, Zn mobilization efficiency index

Wheat (*Triticum aestivum* L.) is the major cereal crop and source for dietary calorie intakes, proteins and micro–nutrients, mostly in the developing countries, accounting ~50% of the daily calorie intake (Cakmak 2008, Prasad 2006). In humans, Zn deficiency is the fifth major cause of diseases and mortality in the developing countries (WHO 2002). In the world population, 2.7 billion people are estimated to be Zn deficient (Muller and Krawinkel 2005). In many parts of the world, micronutrient deficiency is a more widespread problem than poor dietary quality and low energy intake (Stewart *et al*. 2010), and about 20% of deaths in children under five can be attributed to vitamin A, Zn, Fe, and/or I deficiency (Prentice *et al*. 2008). The productivity and quality of wheat depends on several factors like climate, agronomic management practices, varietal response, and soil type etc. Thus, in order to attain maximum yield potential through adopting agronomic practices for increasing yield and improvement in grain Zn concentration and quality traits, wheat is an area of research which needs immediate attention. It is expected that adoption of micronutrient dense wheat varieties will be driven by their improved agronomic properties, higher yield potential, resistance to new strains of rusts, and tolerance to climate change induced heat and drought stresses. The provision of wheat grains with higher micronutrient levels is a challenging task for wheat breeders, but one that would complement the use of supplemental fertilizers, particularly on soils inherently low in these nutrients.

Zn deficiency is prevalent in wheat growing areas both in temperate and tropical climate (Shivay *et al*. 2008). As per estimated report of Takkar (1996), ~47% Indian soils are not having enough Zn content. The major factors, i.e. high pH and $CaCO_3$ and low organic matter content are responsible for widespread Zn deficiency rather than Zn content. Available reports advocated that huge decline in wheat production due to Zn stress has been reported in several countries, viz. India, Australia and Turkey. Similarly, Zn deficiency also leads to decrease nutritional quality of wheat grain, especially in developing countries where cereals are major staple foods (Welch and Graham 1999). Compared to other cereals, wheat cultivars possess high sensitivity to Zn deficiency, and thus, application

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of Zn fertilizers is an important strategy for enhancing productivity and quality of wheat cultivars. Among Zn sources, Zn sulphate and Zn oxides forms are commonly used in developing countries. Although, Zn–EDTA supplies substantial amount of Zn to the plants without interacting with soil components, because the central metal Zn^{2+} is surrounded by chelate ligands (Karak *et al.* 2005). Foliar fertilization either through Zn sulphate or Zn–EDTA is an alternative strategy to fortify seed with Zn and also helps in improving productivity of cereals (Pooniya and Shivay 2013, Ghasal *et al.* 2015). Therefore, the present investigation was taken up to assess the effects of Zn fertilization irrespective of sources and methods on Zn concentration in different parts, uptake and zinc use efficiencies of different varieties of wheat in IGP.

MATERIALS AND METHODS

The experiments on wheat were conducted during *rabi* season of the year 2013-14 and 2014-15 at Experimental Unit of Indian Agricultural Research Institute (IARI), New Delhi, India ($28^0$38' N latitude and $77^0$10' E longitude, 228.6 m above mean sea level). The climate of above unit is semi–arid with dry hot summers and cold winters with average annual rainfall of 650 mm, ~80% of which is received through 'South–West Monsoons' during July–September. Soils are alluvium–derived sandy clay loam (typic ustochrept) in texture with 50.2% sand, 23.2% silt and 26.6% clay. A uniformity trial on wheat was undertaken during winter season of 2012–13 to ensure uniform soil physico–chemical status in the entire field. The soil (0–30 cm layer) had pH 7.8 (1:2.5 soil and water ratio), oxidizable–SOC 0.51%, alkaline $KMnO_4$ oxidizable–N 252.8 kg/ha, 0.5 M $NaHCO_3$ extractable–P 13.1 kg/ha, and 1 N NH_4OAc extractable–K 291.2 kg/ha. The soil had 0.63 mg/kg diethylene–triamine–penta–acetate (DTPA)–extractable Zn. The critical limits of DTPA–extractable Zn for wheat grown in alluvial belt of northern India varies from 0.38 to 0.90 mg/kg soil.

The experiment was laid–out in split–plot design and replicated thrice. Wheat varieties, viz. HD 2851, HD 2687, HD 2967, PBW 343, HD 2894, HD 2932 were taken in main–plots; and five Zn fertilization treatments, viz. control (Zn_0), soil application of Zn @ 5 kg/ha through $ZnSO_4.7H_2O$, soil application of Zn @ 2.5 kg/ha through $ZnSO_4.7H_2O$ + 0.5% foliar spray of $ZnSO_4.7H_2O$ (ZnSHH) at maximum tillering (MT) and booting stages, soil application of Zn @ 2.5 kg/ha through Zn–EDTA, soil application of Zn @ 1.25 kg/ha through Zn–EDTA + 0.5% foliar spray of Zn–EDTA at MT and booting stages, respectively; foliar spray supplied 1.05 kg Zn/ha. The allocation of the treatments was done by the randomization following Fisher and Yates random number tables. The field was cultivated twice with the disc harrow followed by rotavator and a fine seed bed was obtained by giving two ploughings with a tractor drawn cultivator followed by planking. At final preparation of field, 25.8 kg P/ha through single super phosphate and 49.8 kg K/ha through muriate of potash (MOP) were uniformly broadcasted. Nitrogen (N) at the rate 120 kg/ha as prilled urea was applied in all the treatments. Nitrogen was applied through urea (46% N) into three equal splits, i.e. one–third nitrogen was applied at the time of field preparation and the remaining two–third nitrogen in two equal splits, viz. 22 and 45 days after sowing. Soil application of Zn fertilizer sources were applied as per the treatment details before sowing of wheat except in control. A seed rate of 100 kg/ha was used for sowing of wheat. The sowing was done with pora in lines 22.5 cm apart from each other. The plot size was 4.0 m × 3.0 m for each treatment. Two hand weedings were done at 30 and 60 days after sowing for removal of weeds. The high yielding tested wheat varieties were already released from IARI, New Delhi and recommended commercial cultivation by the farmers. Wheat crop was grown as per the standard recommended package of practices and was harvested in the 1^{st} fortnight of April in both the years of experimentation.

Plant samples were collected at different growth stages and 10 days before of harvesting and dried in hot air oven at 60±2 ºC for 6 hr. The oven dried samples were sieved by passing through 40 mesh sieve in a Macro–Wiley Mill. From each replication 0.5 g dry matter samples at different growth stages of wheat, straw, spike straw and grain samples were taken for chemical analysis to determine the Zn concentration in wheat varieties. The Zn content in dry matter was determined by wet–digestion (di–acid digestion) procedure described by Prasad *et al.* (2006) using Atomic Absorption Spectrophotometry (AAS). The Zn content was expressed as mg/kg. The Zn uptake was computed by multiplying with respective Zn concentration with different parts of plant and was expressed as Zn uptake in g/ha.

The estimated values of partial factor productivity (PFP), agronomic efficiency (AE), recovery efficiency (RE), physiological efficiency (PE) and Zn harvest index (ZnHI) of applied Zn were computed using the following expressions as suggested by Fageria and Baligar (2003), Dobermann (2005), Pooniya and Shivay (2013).

$$PFP = Y_t / Zn_a$$
$$AE = (Y_t - Y_{Ac})/Zn_a$$
$$RE = [(U_{Zn} - U_{Ac})/Zn_a] \times 100$$
$$PE = (Y_t - Y_{Ac}) / (U_{Zn} - U_{Ac})$$
$$ZnHI = GU_{Zn}/ U_{Zn}$$

where, Y_t and U_{Zn} refer to the grain yield (kg/ha) and total Zn uptake (g/ha), respectively of diffèrent wheat varieties in Zn applied plots; Y_{AC} and U_{AC} refer to the grain yield (kg/ha) and total Zn uptake (g/ha), respectively of wheat in control (Zn_0) plots; Zn_a refers to the Zn applied (kg/ha); GU_{Zn} refers to Zn uptake (g/ha) in grain.

Zn mobilization efficiency index (ZnMEI): The Zn mobilization efficiency index (ZnMEI) was calculated as the equation given below (Srivastava *et al*. 1999):

$$ZnMEI = \frac{\text{Zn concentration in wheat grain (mg/kg)}}{\text{Zn concentration in wheat straw (mg/kg)}}$$

Zn induced nitrogen recovery efficiency (ZniNRE): The Zn induced nitrogen recovery efficiency (ZniNRE) was calculated as following the equation proposed by Prasad and Shivay (2015):

$$\text{ZniNRE} = \frac{\text{[N uptake (kg/ha) in Zn treatment– N uptake (kg/ha) in control plots (Zn}_0\text{)]}}{\text{N applied (kg/ha)}}$$

The data obtained from study for two years were analyzed statistically using the F–test, as per the procedure given by Gomez and Gomez (1984). LSD values at P = 0.05 were used to determine the significance of difference between treatment means. Interactions if found significant were discussed.

RESULTS AND DISCUSSION

Zinc concentration and uptake

Higher concentration of Zn was observed during initial stage of crop growth and decreased subsequently with increase in the crop growth stages (Table 1). The Zn concentrations in different parts of wheat was registered in order of grain > spike straw > straw. The Zn concentrations was highest in the grain of HD 2851 variety. However, uptake of Zn was highest in HD 2967 variety which was at par with HD 2851, PBW 343 and HD 2894 varieties (Table 2). Among the tested varieties of wheat, 54-78% higher Zn concentration was found in grain as compared to straw. The higher Zn concentration in wheat grain than straw showed that Zn is easily mobilized to sink, i.e. grain. Similar findings have been reported by Prasad *et al.* (2012). Significant variation in different varieties regarding to Zn concentrations might be due to differential capability of varieties to acquire and utilized nutrient from the soil. Significant differences in micronutrient concentrations in different varieties was also reported by Narwal *et al.* (2012), Shekhari *et al.* (2015) and Nawaz *et al.* (2015).

Zn fertilization significantly increased Zn concentration at different crop growth stages and in different parts of wheat. Between two tested sources of zinc, the highest Zn concentration was found in Zn-EDTA. Soil + foliar application of Zn were found superior over soil application alone. The highest Zn concentration was found with application of 1.25 kg Zn/ha through Zn-EDTA as soil application + 0.5% foliar spray at maximum tillering and

Table 1 Zn concentration at different crop growth stages and in different parts of wheat at harvest as influenced by varieties and Zn fertilization (mean of 2 years)

Treatment	Zn concentration (mg/kg dry matter)					
	30 DAS	60 DAS	90 DAS	Straw	Grain	Spike straw
Varieties						
HD 2851	123.7	73.1	61.4	25.1	40.6	42.3
HD 2687	108.5	74.4	58.4	23.8	38.1	20.9
HD 2967	114.6	76.4	56.3	21.8	38.7	32.4
PBW 343	103.9	69.1	62.7	24.4	38.0	20.9
HD 2894	109.8	71.5	63.5	24.7	38.0	24.0
HD 2932	128.5	64.6	61.8	22.8	35.8	20.2
SEm±	1.07	0.46	0.94	0.37	0.45	0.335
CD (P=0.05)	3.365	1.445	2.95	1.165	1.42	1.065
Zinc fertilization						
Control (no Zn)	112.20	68.40	57.45	22.20	35.35	26.05
5.0 kg Zn/ha through $ZnSO_4.7H_2O$ as SA	115.95	72.30	60.85	23.80	37.95	26.75
2.5 kg Zn/ha through $ZnSO_4.7H_2O$ as SA + 0.5% foliar spray at MT and booting stage	113.90	72.35	61.70	24.10	39.40	27.10
2.5 kg Zn/ha through Zn-EDTA as SA	117.30	72.10	61.05	24.15	38.45	26.95
1.25 kg Zn/ha through Zn-EDTA as SA + 0.5 % foliar spray at MT and booting stage	114.65	72.35	62.15	24.45	39.85	27.30
SEm±	1.53	0.42	0.82	0.29	0.43	0.37
CD (P=0.05)	4.36	1.19	2.325	0.825	1.22	1.035

SA, Soil application; MT, Maximum tillering

Table 2 Zn uptake by different parts of wheat as influenced by varieties and Zn fertilization (mean of 2 years)

Treatment	Zn uptake (g/ha)			
	Straw	Grain	Spike straw	Total uptake
Varieties				
HD 2851	136.5	186.2	43.6	366.3
HD 2687	126.4	164.6	41.4	332.4
HD 2967	107.9	189.2	74.7	371.9
PBW 343	141.3	176.3	43.0	360.5
HD 2894	153.8	174.2	34.3	362.2
HD 2932	149.2	161.7	25.9	336.7
SEm±	7.495	5.59	2.94	9.185
CD (P=0.05)	23.625	17.615	9.265	28.95
Zinc fertilization				
Control (no Zn)	125.60	149.15	36.20	310.90
5.0 kg Zn/ha through $ZnSO_4.7H_2O$ as SA	131.55	175.40	45.85	352.75
2.5 kg Zn/ha through $ZnSO_4.7H_2O$ as SA + 0.5% foliar spray at MT and booting stage	139.75	185.60	47.30	372.60
2.5 kg Zn/ha through Zn-EDTA as SA	137.85	178.25	43.90	359.90
1.25 kg Zn/ha through Zn-EDTA as SA + 0.5 % foliar spray at MT and booting stage	144.55	188.30	45.75	378.60
SEm±	4.645	3.150	2.855	4.765
CD (P=0.05)	13.205	8.965	8.105	13.555

SA, Soil application; MT, Maximum tillering booting stages followed by with 2.5 kg Zn/ha through $ZnSO_4.7H_2O$ as soil application + 0.5% foliar spray at maximum tillering and booting stage. Application of Zn in wheat crop increased Zn concentration in grain by 7-12%. Uptake of Zn was increased 5.2-5.6% in soil + foliar application in comparison to soil application alone. The highest uptake of Zn was registered with application of 1.25 kg Zn/ha through Zn-EDTA as soil application + 0.5% foliar spray at maximum tillering and booting stages which was 21.78% higher over control (no Zn). Higher Zn concentration in soil + foliar applied Zn might be due to foliar applied Zn was more easily absorbed by the leaves of the plant and translocated to reproductive parts, hence accumulation was more as compared to soil application alone. Similar results were also reported by Mathpal *et al.* (2015), Shivay *et al.* (2015), Ghasal *et al.* (2015). More concentration of Zn and uptake of micronutrients in chelated-Zn applied plots were also reported by Singh (2013).

Zinc use efficiencies

It is discernable from (Table 3 and 4) that partial factor productivity (PFP) and agronomic efficiency (AE) varied among different varieties of wheat and the highest were registered in HD 2967 followed by PBW 343. Higher PFP and AE in HD 2967 and PBW 343 might be due to higher growth and grain yields in these varieties. The highest recovery was recorded in HD 2687 (2.5%) followed by PBW 343 (2.3%) varieties. Crop recovery efficiency improved with Zn fertilization and higher values were observed in Zn-EDTA treated plots in comparison to $ZnSO_4.7H_2O$ treated plots. Higher crop recovery efficiency was recorded in soil + foliar application of Zn in comparison to soil application alone. Contrary to this, physiological efficiency (PE) was observed higher in soil application treatments of Zn fertilization. Among different Zn fertilization treatments, Zn harvest index was found non-significant. Highest Zn mobilization efficiency index (ZnMEI) was recorded in HD 2967 variety and least in HD 2894 variety. ZnMEI was found at par among different Zn fertilization treatments although numerically higher values were recorded in Zn applied as soil + foliar treatments. Differences in recovery efficiency and ZnMEI of tested varieties might be due to variation in genetic makeup of different varieties which resulted in differential capacity of wheat varieties to absorb, assimilate and translocation of nutrients from soil (Narwal *et al*. 2012).

Zn fertilization significantly improved Zn induced nitrogen recovery efficiency (ZniNRE) over control in all the tested varieties of wheat and the highest ZniNRE was observed in HD 2687 (12.7%) and HD 2967 (11.6%) varieties. ZniNRE was found higher where Zn-EDTA was used as a source as compared to $ZnSO_4.7H_2O$. The highest ZniNRE was recorded with application of 1.25 kg Zn/ha through Zn-EDTA as soil application + 0.5% foliar spray at maximum tillering and booting stages followed by 2.5 kg Zn/ha through $ZnSO_4.7H_2O$ as soil application of 0.5% foliar spray at maximum tillering and booting stages.

Table 3 Agronomic efficiency, recovery efficiency and physiological efficiency of applied zinc in wheat as influenced by varieties and Zn fertilization (mean of 2 years)

Treatment	Grain yield (tonnes/ha)	Agronomic efficiency (kg grain increased/kg Zn applied)	Recovery efficiency (%)	Physiological efficiency (kg grain increased/kg Zn uptake)
Varieties				
HD 2851	4.59	163.6	1.9	9745.9
HD 2687	4.31	165.0	2.5	10257.9
HD 2967	4.89	184.7	2.2	9567.5
PBW 343	4.62	177.3	2.3	11820.7
HD 2894	4.58	139.7	1.7	6367.0
HD 2932	4.50	148.3	1.7	9160.7
SEm±	0.11	1.58	0.02	360.18
CD (P=0.05)	0.30	4.97	0.06	1134.96
Zinc fertilization				
Control (no Zn)	4.22			
5.0 kg Zn/ha through $ZnSO_4.7H_2O$ as SA	4.62	79.80	0.84	10410.15
2.5 kg Zn/ha through $ZnSO_4.7H_2O$ as SA + 0.5% foliar spray at MT and booting stage	4.70	134.30	1.74	8403.60
2.5 kg Zn/ha through Zn-EDTA as SA	4.63	164.35	1.96	11683.95
1.25 kg Zn/ha through Zn-EDTA as SA + 0.5 % foliar spray at MT and booting stage	4.73	273.90	3.66	7448.70
SEm±	0.06	1.170	0.01	294.430
CD (P=0.05)	0.11	3.325	0.04	837.215

SA, Soil application; MT, Maximum tillering

Table 4 PFP, Zn harvest index, ZnMEI and ZniNRE of applied zinc in wheat as influenced by varieties and Zn fertilization (Mean of 2 years)

Treatment	PFP (kg grain/kg Zn)	Zn harvest index (%)	ZnMEI	ZniNRE (%)
Varieties				
HD 2851	1662.1	50.8	1.6	9.2
HD 2687	1565.5	49.9	1.6	12.7
HD 2967	1770.1	50.9	1.8	11.6
PBW 343	1687.9	49.0	1.6	10.2
HD 2894	1668.3	48.2	1.5	7.8
HD 2932	1632.4	48.2	1.6	7.4
SEm±	39.36	1.07	0.035	3.15
CD (P=0.05)	124.02	3.38	0.11	9.915
Zinc fertilization				
Control (no Zn)		48.20	1.61	
5.0 kg Zn/ha through $ZnSO_4.7H_2O$ as SA	924.70	49.90	1.61	8.98
2.5 kg Zn/ha through $ZnSO_4.7H_2O$ as SA + 0.5% foliar spray at MT and booting stage	1324.40	49.85	1.65	13.56
2.5 kg Zn/ha through Zn-EDTA as SA	1853.60	49.60	1.60	10.78
1.25 kg Zn/ha through Zn-EDTA as SA + 0.5 % foliar spray at MT and booting stage	2554.75	49.80	1.64	15.83
SEm±	22.290	0.835	0.03	1.525
CD (P=0.05)	63.375	NS	NS	4.345

SA, Soil application; MT, Maximum tillering; PFP, Partial factor productivity; ZnMEI, Zn mobilization efficiency index; ZniNRE, Zn induced nitrogen recovery efficiency.

Increase in ZniNRE might be due to higher growth and biomass production with the Zn application as higher Zn is available to plants and resulted in higher grain yield as compared to control (no Zn). Increase in grain yield with the application of Zn resulted into higher uptake of N and thereby higher recovery of N from soil. The highest PFP, AE, RE, ZnHI, ZnMEI and ZniNRE were recorded with application of 1.25 kg Zn/ha through Zn-EDTA as soil application + 0.5% foliar spray at maximum tillering and booting stages. Application of EDTA-chelated Zn remained available to crop plants for longer time than $ZnSO_4.7H_2O$; owing to less transformation of EDTA chelated Zn into unavailable forms and application of Zn as foliar spray was efficiently absorbed by leaves and increased biomass production of plant which ultimately led to higher grain yield and better Zn use efficiencies. Increase in Zn use efficiencies with the Zn application was reported by Muthukuraraja and Sriramchandrasekharan (2012), Pooniya and Shivay (2012) and Singh (2013).

This study clearly demonstrates that among Zn sources, Zn-EDTA with two foliar spray of 0.5% solution is the most efficient strategy for improving Zn concentration in different parts, uptake and ZnUEs of the wheat. Among the tested varieties of wheat HD 2851 and HD 2967 are the promising varieties for accumulating higher Zn concentration in grain. Overall, Zn applications through Zn-EDTA increased the Zn concentration and uptake in wheat varieties, helped to improve the grain quality by ensuring the proper supply of Zn which permitted the greater accumulation of Zn in grain.

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