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Distribution of Zinc in Plant Parts of Wheat Varieties with Varying Zinc Sensitivity at Different Growth Stages

Deepa Rawat*, Santosh Chandra Bhatt[1], P.C. Srivastava[2] and S.P. Pachauri[3]

Department of Soil Science, College of Agriculture, GB Pant University of Agriculture and Technology, Udham Singh Nagar, Uttarakhand-263945, India

**Corresponding author*

A B S T R A C T

A pot experiment was conducted in the green house of GB Pant University of Agriculture and Technology Pantnagar, to study the percent distribution of Zn on plant parts of four wheat varieties (UP 262, UP 2628. PBW 175 and UP2554) having varying Zn sensitivity at different growth stages. The soil used for pot experiment had sandy loam texture, 7.2 pH, 0.9% organic carbon and 0.47 mg DTPA extractable Zn per kg soil. Each pot received recommended dose of 25 mg N, 11.2 mg P and 20.75 mg K kg^{-1} soil. The pretreatment imposed consisted of a factorial combination of four wheat varieties and two Zn levels (0 and 10 mg Zn kg^{-1} soil). There were two replications. Zinc was applied through a stock solution of $Zn.SO_4.7H_2O$. Among the growth stages, the maximum average total uptake of Zn was noted at D_3 (85.4 µg/plant) followed by D_4 (78.1 µg/plant) D_2 (35.6 µg/plant) and D_1 (10.6 µg/plant). Application of 10 mg Zn kg^{-1} soil increased the total average uptake of Zn per plant of wheat significantly by 31.4 percent over no application of Zn. At harvesting, the highest percent accumulation of Zn was noted in straw (55.9 %) followed by grain (32.0 %) and root (12.1 %). Among all four varieties UP 262 and PBW 175 stored more of the Zn in non-edible parts of the plant whereas higher amount of Zn was recorded in the grain of UP 2628 and UP 2554).

Keywords

Zinc, Growth stage, Plant parts, Sandy loam soil

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Introduction

Zinc deficiency in crops is the common micronutrient problem world over; therefore, zinc malnutrition has become a major health burden among the resource deprived people (Takkar *et al.,* 1990, Singh, 2011). About 50% of soils used for cereal production in the world contain low levels of plant available Zn, which reduces not only grain yields but also nutritional quality of grain (Graham and Welch, 1996).

Jiang *et al.,* (2007) showed that the final mass of Zn in the rice grain is a function of (1) Zn availability in the soil, (2) the capacity of the roots to take up Zn, (3) the Zn demand of the growing crop, and (4) the partitioning of Zn within the crop. However, a large proportion of Zn is sequestered in the vegetative parts of the above-ground crop and in the panicle structure, so that relatively little Zn accumulates in the grains, in spite of the fact that stimulating Zn uptake after flowering increased Zn mass concentration in the grains.

The supply of minerals to the developing cereal grain originates from two sources: first, as a result of direct uptake from the soil and second, from the remobilization of stored minerals in leaves as they senesce during the stage of grain filling (Uauy, 2006). Root–shoot translocation of Zn (Palmgren *et al.*, 2008), grain filling and stem–panicle transfer (Jiang *et al.*, 2008; Stomph *et al.*, 2009), as well as the direct allocation of Zn from uptake during flowering (Jiang *et al.*, 2007) need be addressed to provide better clue to the differential behaviour of different cultivars. Internal distribution and retention of Zn in different plant parts play a key role in determining grain Zn accumulation. Therefore knowledge of uptake dynamics and partitioning of Zn in different cultivars of wheat under deficient and sufficient conditions would help in devising the selection of varieties in order to overcome Zn malnutrition.

Materials and Methods

A pot experiment was conducted in the green house of GB Pant University of Agriculture and Technology Pantnagar, District Udham Singh Nagar, Uttarakhand. A bulk surface (0-15cm) samples of Mollisol was collected from portions of E1 plot of Norman E. Borlaug Crop research Centre of the University. The soil had sandy loam texture 7.2 pH, 0.9 percent organic carbon and 0.47 mg DTPA extractable Zn per kg soil. The processed soil (4 kg) was filled in plastic pots. Each pot received recommended dose of 25 mg N, 11.2 mg P and 20.75 mg K kg^{-1} soil through urea, potassium hydrogen phosphate and potassium chloride basally in liquid form. The pretreatment imposed consisted of a factorial combination of four wheat varieties (UP 262, UP 2628. PBW 175 and UP2554) and two Zn levels (0 and 10 mg Zn kg^{-1} soil). There were two replications. Zinc was applied through a stock solution of $Zn.SO_4.7H_2O$. All Pots were watered and left for equilibration. When the soil moisture content was near field capacity, four pre-germinated rice seeds were sown in pots. The remaining amount of N (50 mg kg^{-1} soil) was applied in two splits through urea in solution at 35 and 65 days after sowing. Plants were harvested after 30, 60, 90 and 120 days of sowing. Roots were also recovered from the soil after shoot harvest at each level. To achieve this, pots containing roots were saturated with water then the whole soil mass along with roots was transferred down in a tray and passed through sieve (0.5 mm diameter opening). The roots retained on sieve were collected and washed thoroughly with stilled water. After harvesting shoot and roots were thoroughly washed sequentially, first with tap water then in dilute HCl (0.1 N) and finally in deionized water. Shoots were separated into upper lamina, upper leaf sheath, lower lamina, lower leaf sheath, stem, panicle and grains at different harvesting stages. Roots and the above mentioned shoot parts were dried at 60° C for 48 hours in an electric oven. Dry samples were then finally ground and digested with diacid mixture (HNO_3:$HClO_4$, ratio 9:4) in hot plate, the digested material was diluted with distilled water, filtered through a Watman no. 42 filter paper and transferred to plastic vials. Digested samples were analysed for Zn concentration using atomic absorption spectrophotometer (GBC Avanta-M) and the content of Zn was expressed in terms of mg kg^{-1} plant tissue.

Percent distribution of Zn within each part of a plant was calculated by the following formula:

Percent accumulation of Zn in each plant part/plant=

$$\frac{\text{Zn uptake by the plant part per plant}}{\text{Total plant uptake of Zn}} \times 100$$

Results and Discussion

Effect of Zn application on total Zn uptake (µg/plant) in wheat varieties at different growth stages

The main effect of growth stages, Zn levels, and varieties significantly influenced the total uptake of Zn in wheat plants. Among the growth stages, the maximum average total uptake of Zn was noted at D_3 (85.4 µg/plant) followed by D_4 (78.1 µg/plant) D_2 (35.6 µg/plant) and D_1 (10.6 µg/plant). Application of 10 mg Zn kg^{-1} soil increased the total average uptake of Zn per plant of wheat significantly by 31.4 percent over no application of Zn. Among wheat varieties, the highest average total Zn uptake per plant was noted in UP 262 (58.3 µg/plant) followed by UP 2628 (55.6 µg/plant), UP 2554 (50.5 µg/plant) and PBW 175 (45.4 µg/plant) however; the differences in the total average Zn uptake per plant between UP 262 and UP 2628 or UP 2628 and UP 2554 or PBW 175 and UP 2554 were statistically not significant. The interaction effect of growth stages and Zn levels significantly influenced the total uptake of Zn per plant. With application of 10 mg Zn kg^{-1} soil, the total Zn uptake per plant of wheat increased significantly by 87.4 % at $D_{1,}$ 48.5 % at D_3, 23.6% at D_2 and 27.5 % at D_4 over no Zn application. The interaction effect of growth stages and varieties also influenced the total Zn uptake per plant of wheat significantly (Table 1).

Effect of Zn application on percent distribution of Zn in different plant parts of wheat varieties at different growth stages

Percent distribution of Zn in different plant parts of wheat varieties at 30 days after sowing

The main effect of plant parts significantly influenced the percent distribution of Zn in wheat plants at 30 days after sowing whereas; the main effect of Zn levels and varieties had no statistically significant influence on the percent distribution of Zn in wheat plants at 30 days after sowing. Regarding the plant parts, percent distribution of Zn could be arranged in the following decreasing order; stem (39.4 %) > upper lamina (29.8 %) > lower lamina (18.2 %) > root (12.6 %). The interaction effect of plant parts and Zn levels significantly influenced the percent distribution of Zn in wheat plants at 30 days after sowing. Application of Zn at the rate of 10 mg Zn kg^{-1} soil increased the uptake of Zn in stem by 23.8 % in comparison to control (Table 2).

Percent distribution of Zn in different plant parts of wheat varieties at 60 days after sowing

The main effect of plant parts had significant influence on percent distribution of Zn in wheat plants at 60 days after sowing. As regards the plant parts, the highest percent distribution of Zn was noted in stem (40.0%) followed by upper lamina (17.9 %), root (17.9 %), emerging ear (16.4 %) and lower lamina (7.2 %) however; the values noted in root, ear and upper lamina did not vary from each other significantly. The main effects of Zn levels and variety failed to influence the percent distribution of Zn in wheat varieties.

The interaction effect of plant parts and Zn levels significantly influenced the percentage of Zn in wheat plants at 60 days after sowing. Application of Zn at the rate of 10 mg Zn kg^{-1} soil increased the percent distribution of Zn in stem and ear significantly by 23.8 and 12.2 percent, respectively over no application whereas; in roots it was decreased significantly by 20.8 %. The interaction effect of plant parts and varieties significantly influenced the percent distribution of Zn in wheat at 60 days after sowing. Also the interaction effect of plant parts, Zn levels and varieties significantly affected the distribution of Zn in percentage in wheat plants at 60 days after sowing (Table 3).

Percent distribution of Zn in different plant parts of wheat varieties at 90 days after sowing

The main effect of plant parts significantly influenced the percent distribution of Zn in wheat plants at 90 days after sowing whereas; the main effect of Zn levels and varieties had no significant influence on percent distribution of Zn in wheat plants at 90 days after sowing. Among the plant parts, the highest percent accumulation of Zn was noted in ear (63.4 %) followed by stem (20.0 %), root (9.9 %) > upper lamina (4.5 %) and lower lamina (2.1 %). The interaction effect of plant parts and Zn levels had significant influence on percent distribution of Zn in wheat plants at 90 days after sowing. With Zn application at the rate of 10 mg Zn^{-1} kg soil, the percent accumulation of Zn increased in stem significantly over no Zn application. The interaction effect of plant parts and varieties significantly affected the Zn distribution in wheat plants at 90 days after sowing. The interaction effect of plant parts, Zn levels and varieties significantly influenced the percent distribution of Zn in wheat plants at 90 days after sowing (Table 4).

Percent distribution of Zn in different plant parts of wheat varieties at 120 days after sowing

The main effect of plant parts had significant influence on percentage distribution of Zn in wheat plants at 120 days after sowing. As regards the plant parts, the highest percent accumulation of Zn was noted in straw (55.9 %) followed by grain (32.0 %) and root (12.1 %). The main effect of Zn levels and varieties had no significant influence on the percent distribution of Zn in wheat crop. The interaction effect of plant parts and Zn levels significantly influenced the percent distribution of Zn in wheat plants at 120 days after sowing. Zinc application at the rate of 10 mg Zn kg^{-1} soil significantly increased the percent accumulation of Zn in grain but decreased it in roots and straw. The interaction effect of plant parts and varieties significantly influenced the percent distribution of Zn in wheat plants at 120 days after sowing (Table 5).

Table.1 Effect of Zn application on total uptake per plant (µg/plant) in wheat varieties at different growth stages

Varieties	**D1**			**D2**			**D3**			**D4**			**Mean of plant part**		
	Zn0	**Zn 10**	**Mean**	**Zn0**	**Zn 10**	**Mean**	**Zn0**	**Zn 10**	**Mean**	**Zn0**	**Zn10**	**Mean**	**Zn0**	**Zn 10**	**Mean**
UP 262	9.8	17.4	13.6	41.0	38.3	39.7	85.9	134.0	109.9	55.5	84.2	69.9	48.0	68.1	58.1
UP2628	6.3	10.2	8.2	28.4	41.4	34.9	71.4	82.7	77.0	92.5	111.8	102.2	49.7	61.5	55.6
PBW175	5.9	11.1	8.5	28.3	36.9	32.6	49.0	85.4	67.2	63.7	82.9	73.3	36.7	54.1	45.4
UP2554	7.6	16.8	12.2	29.7	40.8	35.3	68.6	106.2	87.4	62.9	71.2	67.0	42.2	58.8	50.5
Mean	7.4	13.9	10.6	31.9	39.4	35.6	68.7	102.1	85.4	68.7	87.6	78.1	44.2	60.7	52.45
		D		Zn		V		D× Zn		Zn×V		D×V	D×Zn×V		
Sem±		2.4		1.7		2.5		3.5		4.9		3.5	7.0		
CD(p≤0.05)		7.1		5.0		7.1		10.0		NS		10.0	NS		

Table.2 Effect of Zn application on percent distribution of Zinc in different plant parts of wheat at 30 days after sowing

Varieties	Root			Stem			Lower lamina			Upper lamina			Mean of plant part		
	Zn0	**Zn10**	**Mean**	**Zn0**	**Zn10**	**Mean**	**Zn0**	**Zn10**	**Mean**	**Zn0**	**Zn10**	**Mean**	**Zn0**	**Zn10**	**Mean**
UP 262	25.8	10.1	18.0	35.0	47.8	41.4	16.0	16.7	16.4	23.2	25.4	24.3	25.0	25.0	25.0
UP2628	8.4	10.9	9.7	40.5	41.0	40.7	22.3	18.1	20.2	28.8	29.9	29.4	25.0	25.0	25.0
PBW175	11.6	8.8	10.2	40.4	43.3	41.9	21.3	14.6	17.9	26.7	33.2	30.0	25.0	25.0	25.0
UP2554	14.0	11.1	12.6	25.0	42.3	33.7	22.4	13.8	18.1	38.6	32.8	35.7	25.0	25.0	25.0
Mean	15.0	10.2	12.6	35.2	43.6	39.4	20.5	15.8	18.2	29.3	30.3	29.8	25.0	25.0	25.0
	PP		Zn		V		PP×Zn		Zn×V		PP×V		PP×Zn×V		
SEm±	1.3		0.9		1.3		1.8		2.6		1.8		3.6		
CD(p≤0.05)	3.7		NS		NS		5.2		NS		5.2		NS		

Table.3 Effect of Zn application on percent distribution of Zinc in different plant parts of wheat at 60 days after sowing

Varieties	Root			Stem			Lower lamina			Upper lamina			Ear			Mean of plant part		
	Z0	**Z10**	**Mean**	**Zn0**	**Zn10**	**Mean**	**Zn0**	**Zn10**	**Mean**	**Zn0**	**Zn10**	**Mean**	**Zn0**	**Zn10**	**Mean**	**Zn0**	**Z10**	**Mean**
UP 262	17.1	15.3	16.2	39.3	42.0	40.7	8.9	8.0	8.5	13.2	17.8	15.5	18.9	16.7	17.8	19.5	20.0	19.7
UP2628	20.7	16.8	18.8	41.7	48.8	45.2	6.6	7.7	7.1	21.6	15.5	18.6	6.5	11.1	8.8	19.4	20.0	19.7
PBW175	19.6	17.2	18.4	29.3	41.2	35.3	7.6	6.2	6.9	18.6	20.9	19.8	26.2	14.9	20.6	20.3	20.1	20.2
UP2554	22.7	14.0	18.4	32.6	44.9	38.8	8.3	4.4	6.3	24.1	11.5	17.8	10.3	26.6	18.4	19.6	20.3	19.9
Mean	20.0	15.8	17.9	35.7	44.2	40.0	7.8	6.6	7.2	19.4	16.4	17.9	15.5	17.3	16.4	19.7	20.1	19.9
		PP		Zn		V			PP×Zn			Zn×V			PP×V			PP×Zn×V
SEm±		1.0		0.6		0.9			1.4			2.0			1.3			2.8
CD (p≤0.05)		2.8		NS		NS			4.0			NS			3.6			8.1

Table.4 Effect of Zn application on percent distribution of Zinc in different plant parts of wheat at 90 days after sowing

Varieties	Root			Stem			Lower lamina			Upper lamina			Ear			Mean of plant part		
	Z0	Z10	Mean	Zn0	Zn10	Mean	Zn0	Zn10	Mean	Zn0	Zn10	Mean	Zn0	Zn10	Mean	Zn0	Z10	Mean
UP 262	5.2	6.2	5.7	20.5	29.1	24.8	2.3	1.9	2.1	4.6	4.2	4.4	67.9	59.4	63.7	20.1	20.2	20.2
UP2628	11.1	15.0	13.0	17.4	26.2	21.8	2.8	2.8	2.8	5.5	4.4	5.0	63.3	51.3	57.3	20.0	19.9	20.0
PBW175	12.3	8.6	10.4	12.3	17.9	15.1	1.3	1.7	1.5	3.3	4.1	3.7	70.6	67.5	69.0	19.9	20.0	20.0
UP2554	14.5	6.6	10.6	20.6	15.8	18.2	2.2	1.8	2.0	6.4	3.8	5.1	56.0	71.6	63.8	19.9	19.9	19.9
Mean	10.8	9.1	9.9	17.7	22.3	20.0	2.1	2.1	2.1	4.9	4.1	4.5	64.4	62.4	63.4	20.0	20.0	20.0
		PP		Zn		V			PP×Zn			Zn×V			PP×V			PP×Zn×V
SEm±		0.8		0.5		0.7			1.1			1.6			1.0			2.2
CD(p≤0.05)		2.3		NS		NS			3.2			NS			2.9			6.4

Table.5 Effect of Zn application on percent distribution of Zinc in different plant parts of wheat at 120 days after sowing

Varieties	Root			Straw			Grain			Mean of plant part		
	Z0	Z10	Mean	Zn0	Zn10	Mean	Zn0	Z10	Mean	Zn0	Z10	Mean
UP 262	12.8	10.1	11.5	69.2	63.4	66.3	18.0	26.6	22.3	33.3	33.3	33.3
UP2628	12.5	6.6	9.5	48.5	46.2	47.3	39.0	47.2	43.1	33.3	33.3	33.3
PBW175	16.1	8.4	12.2	68.5	61.5	65.0	15.4	30.1	22.8	33.3	33.3	33.3
UP2554	18.9	11.8	15.4	50.0	39.9	45.0	31.1	48.3	39.7	33.3	33.3	33.3
Mean	15.1	9.2	12.1	59.0	52.7	55.9	25.9	38.0	32.0	33.3	33.3	33.3
	PP		Zn	V		PP×Zn		Zn×V		PP×V		PP×Zn×V
SEm±	1.6		1.3	1.9		2.3		3.3		2.7		4.6
CD (p≤0.05)	4.7		3.8	5.4		6.6		9.3		7.6		13.2

Effect of Zn application on total Zn uptake (µg/plant) in wheat varieties at different growth stages

Zinc uptake is the most important parameter statistically explaining the variation in Zn efficiency among the wheat genotypes (Hajiboland and Salehi, 2006). The data regarding uptake of Zn per plant showed that the Zn uptake was the highest in stem at 30 and 60 days after sowing whereas, at 90 days after sowing the highest uptake was recorded in ear followed by stem suggesting that at vegetative stage most of the Zn in above ground part of plant was accumulated in stem. The Zn uptake in upper lamina was recorded to be greater than lower lamina at 30 and 60 days after sowing whereas at the succeeding stage (i.e 90 days after sowing) the Zn uptake did not vary significantly for upper and lower lamina. Dang *et al.*, (2010) also observed that accumulation of Zn in leaf blade was the highest among all the organs during early growing period similar to the results of our investigation. In late growing period, however, accumulation of Zn in grain was the highest. Application of 10 mg Zn kg^{-1} soil increased the average uptake of Zn in plant parts of wheat by 87.4 %, 26.1 %, 48.6 % and 27.5 % at 30, 60, 90 and 120 days after sowing. A comparison among the uptake of Zn in root at different growth stages revealed that Zn uptake in root was lower than all the above ground parts of plant at 30 days after sowing. The higher requirement of nutrient resulted in higher translocation of Zn to the shoot part at initial stage of plant growth in order to meet higher rate of growth. Thus, the early growing period from emergence to double ridge stage was one of the important periods of Zn absorption. In a field experiment, Dang *et al.*, (2010) also recorded that the highest Zn concentration in aboveground organs of winter wheat occurred before double ridge stage, and declined sharply thereafter. At double ridge stage, the percentage of Zn accumulation in wheat plant reached 30-40% of the total accumulation. As regards the varieties, Zn uptake was the highest in UP 262 at 30 and 90 days after sowing whereas, at the termination of crop UP 2628 recorded the maximum uptake, also the Zn uptake in grain was found to be the highest in UP 2628 and the Zn uptake in grain in other three varieties did not differ from each other significantly. Though at 30 and 90 days after sowing the Zn uptake in UP 2628 and PBW 175 did not vary from each other but the uptake at harvesting stage was the maximum in UP 2628. Under Zn deficiency, Zn uptake could be better related to Zn efficiency because Zn-efficient genotypes possibly have greater Zn uptake capacity under Zn deficiency. Enhancements in Zn uptake rate by roots and Zn utilization at the cellular level have been shown as important mechanisms affecting expression of high Zn efficiency in wheat (Rengel and Wheal, 1997).

Effect of Zn application on percent distribution of Zn in different plant parts of wheat varieties at different growth stages

Similar to the trend observed in Zn uptake per plant, the percent accumulation of Zn was the highest in stem at 30 and 60 days after sowing whereas, at 90 days after sowing the highest percentage of Zn was recorded in ear followed by stem however at harvest; the highest amount of Zn was accumulated in straw. Dang *et al.*, (2010) also reported that Zn was mainly distributed in leaf blade and sheath before anthesis, especially in leaf blade, where the distribution percentage was above 50% before jointing, much higher than those in other plant parts. The percentage rapidly declined after booting and decreased to 13.6% at maturity. Similar to these observations, average percent accumulation of Zn in plant parts of wheat was found to be 25 percent (mean of all plant parts) at initial plant growth stage (30 d) which reduced at D_2 and D_3 in the present study. At 90 days after sowing the percent accumulation of Zn was higher in lower lamina as compared to upper lamina because Zn is moderately mobile in plant due to which most of the Zn was mobilized from lower part of the plants to the upper parts. In wheat, Zn reaches the developing wheat grain via the phloem (Pearson and Rengel, 1995). Before Zn is loaded into the developing grain, the xylem bundles face discontinuity (Zee and O'Brien, 1970) and the xylem-phloem exchange occurs in the rachis and to a lesser extent in the peduncle, lemma and palea (Pearson and Rengel, 1995)b. In Zn inefficient varieties, the relatively lower capacity of loading Zn to the phloem in comparison to Zn efficient genotypes might be a limiting step.

It is concluded from these findings that among all four varieties UP 262 and PBW 175 stored more of the Zn in non-edible parts of the plant. Out of total Zn accumulation in aboveground plant parts, less than half of the percent accumulation of Zn was present in grains of these varieties. On the other hand, UP 2628 and UP 2554 were capable of producing the grains with higher percent accumulation of Zn as compared to UP 262 and PBW 175.

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