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Effect of Zinc Application on Distribution of Its Concentration and Dry Matter Yield in Plant Parts at Various Growth Stages in Wheat Varieties

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ABSTRACT

A pot experiment was conducted in the green house of GB Pant University of Agriculture and Technology Pantnagar, to study the effect of Zn treatment on its concentration and dry matter yield in different plant parts of four wheat varieties. The soil 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. Application of 10 mg Zn kg^{-1} soil significantly increased the average dry matter yield in plant parts. Among the varieties UP 262 recorded the highest average concentration of Zn per plant part at 30, 60 and 120 days after sowing. At the stage of harvesting the UP 2628 (1.135 g) reported the maximum average dry matter yield per plant and the lowest value was noted in UP 262 (0.844 g). The present study revealed that maximum accumulation of Zn took place in the stem at initial growth stages whereas; at later stages, higher amount was accumulated in root. The variety UP 2628 showed highest grain yield and lowest was recorded in UP262. The varieties PBW 175 and UP 2554 exhibited intermediate behaviour.

Key words: *Zinc concentration, Wheat varieties, Plant parts, Dry matter yield.*

INTRODUCTION

As Zn plays multiple roles in plant biochemical and physiological processes, even slight deficiency causes a decrease in growth, yield, and Zn content of edible plant parts. Singh[20] reported a wide spread hidden hunger of Zn in seeds and feeds which is affecting a large segment of resource deprived families whose food comes mainly from cereals grown on Zn deficient soils. It is prevalent especially, in developing nations where non-diverse diets are composed primarily of cereals that contain a low Zn concentration with only a small assimilable fraction[12].

Cultivars within a plant species differ in their ability to take up Zn, which may be caused by differences in absorption, translocation and utilization of Zn. It has been observed that the Zn translocation to the edible part is low in Zn inefficient varieties.

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Zn transport in plants takes place through both the xylem and the phloem. Following absorption by the root, Zn is rapidly transported via the xylem to the shoot. It has been claimed that the Zn transportation from phloem does not occur in wheat, leaving roots starved of Zn if not supplied in root environment. Dang *et al*[4] reported that organs of winter wheat with the highest Zn concentration differed with the change of growth centre at different growing stages. The amount of Zn accumulation in leaf blade was the highest among all the organs during early growing period, and the percentage of Zn distribution in leaf blades was higher than 50% before jointing, higher than those in other organs. In late growing period, however, the amount of Zn accumulation in grains was the highest. Pearson *et al*[16]., reported that under Zn-deficiency wheat grain was not a strong sink for Zn, but under high Zn supply; a protective barrier prevents excessive Zn accumulation in the wheat grain. In wheat, there is a xylem discontinuity at the base of the grain[21] and xylem–phloem exchange occurred in the rachis and to a lesser extent in the peduncle, lemma and palea[17]. Cakmak *et al*[3]., showed that a Zn-inefficient durum wheat cultivar exhibited Zn-deficiency symptoms earlier and more intensely than a Zn-efficient bread wheat cultivar even though the Zn tissue concentrations were similar in both lines, suggesting differential utilization of Zn in the two cultivars. The ability of some crop genotypes to tolerate low Zn availability over others is still not fully understood[6]. Vacuoles are assumed to be the major sites of metal sequestration in root cells[14]. Once Zn has entered the cytoplasm of a root cell, it might be transported into the vacuole, especially if it is present in excess of nutritional needs. Transport of metal ions into root vacuoles decreases their availability for transfer to the shoot via the xylem, resulting in the higher accumulation of Zn in roots. Zn concentration in cereals may be increased by applying Zn fertilizer to the soil or directly to the plants[2]. The appliance of Zn fertilizers may not always necessarily facilitate resolving the problem for agronomic and economic reasons[5] in developing countries. So, in view of economic as well as agronomic approach, it is constructive to exploit the genetic variability in crops and develop varieties with high Zn-use efficiency and low Zn tolerance. Such varieties should be competent enough to easily uptake and translocate Zn to shoots that result in higher yields even in Zn-deficient soils and may produce Zn-rich grains which can provide a sustainable and cost-effective solution to the Zn-malnutrition problem in developing countries. In order to achieve this, identification of the mechanisms associated with Zn efficient varieties and the phenotypic characters associated with high Zn use efficiency in a crop would help plant breeders develop varieties with high Zn use efficiency. Though the mechanisms of zinc use efficiency in crops have been thoroughly reviewed by Rengel[19] however the ability of some crop genotypes to tolerate low Zn availability over others is still not fully understood[6]. In view of these facts, an investigation was planned with the objectives to examine the pattern of Zn translocation in different plant parts and their dry matter yield under various growth stages in Zn deficient and sufficient conditions. This may provide an idea about the Zinc use efficiency of different varieties under test and the actual sink of Zn accumulation and assimilation other than grain in such varieties. The information obtained may prove to be helpful in selection, improvement and development of varieties that can combine high yield trait with high grain-Zn mass concentrations under Zn deficient situations 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 NPK 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, UP 2554) and two Zn levels (0 and 10 mg Zn kg^{-1} soil). There were two replications. Zinc was applied through a stock solution of $Zn.SO_4.7H_2O$. The 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. After harvesting, shoots and roots were separated into upper lamina, lower lamina and ear for initial four stages. While at the stage of harvesting plant parts were separated as root, shoot and grain. After proper washing and drying the plant parts were digested with diacid mixture (HNO_3:$HClO_4$, ratio 9:4) and were analysed for Zn concentration by atomic absorption spectrophotometer (GBC Avanta-M) and the content of Zn was expressed in terms of mg kg^{-1} plant tissue. The data obtained was analyzed by using 3 factorials completely randomized design.

RESULTS AND DISCUSSION

The main effect of plant parts had statistically significant effect on the average concentration of Zn in wheat plant parts at all four growth stages. The highest average concentration of Zn was reported in stem (68.5 mg Zn kg^{-1}) at 30 and in root at 60 (48.6 mg Zn kg^{-1}), 90 (45.71 mg Zn kg^{-1}) and 120 (59.0 mg Zn kg^{-1}) days after sowing. The data on Zn concentration in different plant parts in wheat varieties indicated that at 30 days after sowing (Table:1) the highest Zn concentration was found in stem followed by root, lower lamina and upper lamina. The higher concentration of Zn in lower lamina than in upper lamina at the initial stage suggested the poor translocation of Zn from older to younger leaves. Under low Zn conditions, Zn is not usually effectively mobilized from the older leaves, phloem mobility of Zn is fairly low. This has been suggested as reason for Zn deficiency symptoms appearing primarily on young leaves[13]. However, a recent study in wheat has suggested that under certain conditions, Zn might move readily through the phloem[8]. Unlike the initial stage (30 days after sowing), stem had the least average concentration of Zn than upper and lower lamina at 60 and 90 days after sowing indicating higher translocation and accumulation of Zn towards leaf blades at later stages because translocation of Zn from leaves contributed more to total Zn allocated to cereal grains than concurrent Zn uptake during grain filling. The average Zn concentration of roots in UP 262 was the highest at 30, 60 and 90 days after sowing as the plants sensitive to Zn deficiency accumulated excess Zn in root vacuoles to supply more Zn to the shoot[15]. The main effect of Zn levels had statistically significant influence on the average concentration of Zn in plant parts of wheat at 30, 60 and 90 days after sowing and the application of 10 mg Zn kg^{-1} soil increased the average concentration of Zn in plant parts of wheat by 42.3%, 21.5% and 21.8% over no application of Zn at 30, 60 and 90 days after transplanting, respectively. The highest increase in average Zn concentration was noted in UP 2628 under Zn application as compared to no application of Zn whereas in case of UP 262 the increase was much lower in magnitude. The plants required the highest amount of Zn during initial stage and more of the Zn was translocated to the shoot to meet the requirements of rapid growth of the plant. At this stage the increase in the average Zn concentration with Zn application was the highest in PBW 175 whereas the lowest increase in the average Zn concentration was recorded in UP 2628. The Zn inefficient variety; UP 262, was observed with the highest average Zn concentration at 30 days after sowing followed by UP 2554 whereas PBW 175 and comparatively Zn tolerant UP 2628 had lower concentration of Zn in comparison to UP 262 suggesting that Zn efficient variety had lower requirement of Zn at initial stage as compared to Zn inefficient genotypes. In a greenhouse experiment, Kumar and Qureshi[11] (2012) also recorded that the Zn content in wheat leaves, stem and roots at 60 days after sowing significantly increased with increased levels of Zn in soil. Ranjbar and Bahmaniar[18] reported that the concentration of Zn in flag leaves and grains of wheat had been increased by Zn application. Dang *et al*[4]., observed that the concentration of Zn in various above-ground organs of wheat was 9.5 to 112.5 mg kg^{-1} at different growing stages. The order of different plant tissues with respect to Zn content was leaf blades > spikes > leaf sheaths > stems showing the net absorption and transportation of Zn as well as their contribution to Zn accumulation in grains. The main effect of varieties had statistically significant influence on average concentration of Zn in plant parts of wheat at all the growth stages except at 90 days after sowing. Among wheat varieties UP 262 recorded the highest average concentration of Zn per plant part at 30 (55.7 mg Zn kg^{-1}), 60 (39.2 mg Zn kg^{-1}) and 120 (43.0 mg Zn kg^{-1}) days after sowing. Moreover, it is quite apparent from the study that the Zn concentration in grain in UP 2628 was at par with that of UP 262 but the overall grain uptake of Zn was the highest in UP 2628 followed by UP 2554 owing to the higher production of dry matter in these varieties in comparison to UP 262 and PBW 175. The interaction effect of plant parts and Zn levels significantly affected the average concentration of Zn in wheat at 30 and 120 days after sowing. At 30 days after sowing, the highest increase among the plant parts due to Zn application was noted in lower lamina (54.4%) while the lowest increase was reported in root (30.3%). At 120 days after sowing, application of Zn brought the maximum increase of 28.6% in grain. Interaction effect of Zn levels and varieties had statistically significant influence on average concentration of Zn per plant parts in wheat at 30 and 120 days after sowing. At 30 days after sowing, the variety PBW 175 recorded the maximum increase (65.9%) in the average Zn concentration per plant with application of 10 mg Zn kg^{-1} soil over no Zn application whereas, the lowest increase was noted in UP 2628 (24.7%). At 120 days after sowing, application of Zn increased the average Zn concentration most prominently in UP 2554 (15.6%) followed by UP 262 (12.7%) over no application of Zn. The interaction effect of plant parts and varieties significantly affected the average concentration of Zn in wheat plants at all four growth stages. The interaction effect of plant parts, Zn levels and varieties had statistically significant influence on average Zn concentration of wheat plants at all growth stages except at 60 days after sowing. With no application of Zn, the average Zn concentration in grain ranged from 34.1 mg Zn kg^{-1} to 40.4 mg Zn kg^{-1} whereas, with 10 mg Zn kg^{-1} soil, the average concentration of Zn in wheat varieties ranged from 36.0 mg Zn kg^{-1} to 45.6 mg Zn kg^{-1}. The ability of a plant to tolerate limited amounts of available Zn included higher root uptake, more efficient biochemical utilization of Zn, and enhanced Zn translocation within the plant[7]. As indicated by the data presented in table 5 of dry matter yield at the harvesting stage (120 days after sowing), the effect of Zn fertilization did not exhibit any significant variation in the average Zn concentration of wheat plant but in the individual plant parts the average Zn concentration increased in straw and grain with 10 mg Zn kg^{-1} soil by 9.8 and 28.6 percent over no Zn application, respectively however; a decrease of 11.1 percent was noted in root. Since Zn plays an important role in plant biochemical and physiological processes, even slight deficiency could cause a decrease in growth, yield and Zn content of edible plant part. Kalayci *et al*[10]., opined that the Zn mass concentration in grains could be increased by 1.5 to 3.5 fold in wheat by Zn fertilization. With Zn application the lower lamina recorded the maximum increase in average Zn concentration and indicated poor translocation of Zn from it.

As regards the dry matter yield at the harvesting stage, the average grain weight was the highest in UP 2628 and the least value was noted for UP 262. The grain weight noted for UP 2554 was at par with those of UP 2628 and in PBW 175 the value recorded for grain weight was close to UP 262 showing its lower capacity of grain production under Zn deficient conditions. According to Jiang and Huang[9], the yield components in wheat increased as the influence of Zn on the amount of chlorophyll and the concentration of abscisic acid, increased chlorophyll content increased the yield through the increase in photosynthesis. Apart from grain, the dry matter yield of straw was also highest in UP 2628. In a field experiment conducted by Bendary *et al*[1]., to investigate the response of nine local hexaploid wheat cultivars to Zn application and to assess the effect of wheat genotypes on Zn efficiency, the grain dry weight of Zn efficient cultivar Gemmieza-7 was the highest while Zn-inefficient Sahel-1 had the lowest dry weight of grains, under Zn-deficient conditions. At 120 days after sowing, the effect of Zn levels had no significant effect on dry matter yield in wheat plants. Similar results were recorded by Regel and Graham[5] who noted that the relative production of root and shoot dry matter did not differ significantly under Zn deficient- as compared to Zn sufficient- condition for two genotypes Durati wheat and Warigal which were varying in Zn sensitivity.

Table 1: Effect of Zn application on Zn concentration (mg Zn kg^{-1}) 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	61.7	65.4	63.6	61.9	93.2	77.5	35.6	53.9	44.7	31.0	42.9	36.9	47.5	63.8	55.7
UP2628	33.2	55.5	44.4	66.0	69.6	67.8	28.2	35.8	32.0	27.4	32.1	29.7	38.7	48.2	43.4
PBW175	39.4	51.8	45.6	44.6	76.3	60.4	25.7	51.0	38.3	24.5	43.4	33.9	33.5	55.6	44.6
UP2554	51.5	69.5	60.5	51.2	85.6	68.4	39.3	57.9	48.6	31.1	44.3	37.7	43.2	64.3	53.8
Mean	46.5	60.5	53.5	55.9	81.1	68.5	32.2	49.6	40.9	28.5	40.7	34.6	40.7	58.0	49.4

	PP	Zn	V	PP×Zn	Zn×V	PP×V	PP×Zn×V
SEm±	0.7	0.5	0.7	0.9	1.3	0.9	1.9
CD (p≤0.05)	1.9	1.3	1.9	2.7	3.8	2.7	5.4

PP= Plant parts, Zn= Zinc, V= varieties, Zn0= 0 mg Zn/kg soil, Zn10= 10 mg Zn/kg soil

Table 2: Effect of Zn application on Zn concentration (mg Zn kg^{-1}) in different plant parts of wheat at 60 days after sowing

Varieties	Root			Stem			Lower lamina			Upper lamina			Emerging 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	56.1	57.7	56.9	30.0	33.4	31.7	38.8	43.8	41.3	31.7	36.2	34.0	31.7	32.3	32.0	37.7	40.7	39.2
UP2628	40.7	56.7	48.7	25.2	41.2	33.2	21.0	32.6	26.8	25.3	30.9	28.1	43.5	46.2	44.8	31.1	41.5	36.3
PBW175	42.8	47.2	45.0	15.7	26.0	20.9	22.2	27.3	24.7	25.7	31.4	28.5	30.5	36.1	33.3	27.4	33.6	30.5
UP2554	41.7	45.9	43.8	19.4	37.9	28.7	18.2	28.0	23.1	31.3	32.1	31.7	31.8	34.5	33.1	28.5	35.7	32.1
Mean	45.3	51.9	48.6	22.6	34.6	28.6	25.0	32.9	29.0	28.5	32.7	30.6	34.4	37.2	35.8	31.2	37.9	34.5

	PP	Zn	V	PP×Zn	Zn×V	PP×V	PP×Zn×V
SEm±	1.6	1.0	1.5	2.3	3.3	2.1	4.6
CD (p≤0.05)	4.7	3.0	4.2	NS	NS	5.9	NS

PP= Plant parts, Zn= Zinc, V= varieties, Zn0= 0 mg Zn/kg soil, Zn10= 10 mg Zn/kg soil

Table 3: Effect of Zn application on Zn concentration (mg Zn kg^{-1}) in different plant parts of wheat at 90 days after sowing

Varieties	Root			Stem			Lower Lamina			Upper lamina			Ear			Mean of plant parts		
	Z0	Z10	Mean	Zn0	Zn10	Mean	Zn0	Zn10	Mean	Zn0	Zn10	Mean	Zn0	Zn10	Mean	Zn0	Z10	Mean
UP 262	37.70	43.28	40.49	15.35	28.63	21.99	35.90	38.75	37.33	24.98	26.80	25.89	46.65	45.50	46.08	32.12	36.59	34.35
UP2628	56.70	64.85	60.78	9.73	17.30	13.51	23.80	36.95	30.38	22.70	24.83	23.76	33.10	35.28	34.19	29.21	35.84	32.52
PBW175	37.15	42.80	39.98	6.43	12.88	9.65	25.15	25.35	25.25	16.90	20.40	18.65	25.83	37.65	31.74	22.29	27.82	25.05
UP2554	45.93	37.25	41.59	12.45	21.55	17.00	32.60	46.15	39.38	27.48	32.68	30.08	25.60	45.80	35.70	28.81	36.69	32.75
Mean	44.37	47.04	45.71	10.99	20.09	15.54	29.36	36.80	33.08	23.01	26.18	24.59	32.79	41.06	36.93	28.11	34.23	31.17

	PP	Zn	V	PP×Zn	Zn×V	PP×V	PP×Zn×V
SEm±	1.2	0.7	1.0	1.7	2.3	1.5	3.3
CD (p≤0.05)	3.3	2.1	NS	NS	NS	4.2	9.5

PP= Plant parts, Zn= Zinc, V= varieties, Zn0= 0 mg Zn/kg soil, Zn10= 10 mg Zn/kg soil

Table 4: Effect of Zn application on Zn concentration (mg Zn kg^{-1}) 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	65.4	68.1	66.7	22.4	23.5	22.9	33.6	45.2	39.4	40.4	45.6	43.0
UP2628	59.0	48.6	53.8	20.9	25.7	23.3	37.2	39.4	38.3	39.0	37.9	38.5
PBW175	71.9	46.4	59.1	23.8	25.5	24.6	23.7	36.1	29.9	39.8	36.0	37.9
UP2554	53.7	59.2	56.4	18.2	19.1	18.7	30.3	39.8	35.1	34.1	39.4	36.7
Mean	62.5	55.5	59.0	21.3	23.4	22.4	31.2	40.1	35.7	38.3	39.7	39.0

	PP	Zn	V	PP×Zn	Zn×V	PP×V	PP×Zn×V
SEm±	0.8	0.6	0.9	1.1	1.5	1.2	2.1
CD (p≤0.05)	2.2	NS	2.5	3.1	4.3	3.5	6.1

PP= Plant parts, Zn= Zinc, V= varieties, Zn0= 0 mg Zn/kg soil, Zn10= 10 mg Zn/kg soil

Table 5: Effect of Zn application on dry matter yield (g) of 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	0.109	0.121	0.115	1.738	2.311	2.024	0.295	0.490	0.393	0.714	0.974	0.844
UP2628	0.193	0.148	0.170	2.154	2.018	2.086	0.954	1.343	1.148	1.100	1.169	1.135
PBW175	0.142	0.150	0.146	1.836	2.006	1.921	0.416	0.692	0.554	0.798	0.949	0.874
UP2554	0.222	0.142	0.182	1.744	1.486	1.615	0.636	0.864	0.750	0.867	0.831	0.849
Mean	0.167	0.140	0.153	1.868	1.955	1.912	0.575	0.847	0.711	0.870	0.981	0.925

	PP	Zn	V	PP×Zn	Zn×V	PP×V	PP×Zn×V
SEm±	0.05	0.04	0.06	0.07	0.10	0.08	0.15
CD (p≤0.05)	0.15	NS	0.17	NS	NS	0.24	NS

PP= Plant parts, Zn= Zinc, V= varieties, Zn0= 0 mg Zn/kg soil, Zn10= 10 mg Zn/kg soil

CONCLUSION

The highest average concentration of Zn was reported in stem at 30 and in root at 60, 90, and 120 days after sowing suggesting the constrained translocation of Zn from root to above ground potion of wheat at later stages of plant growth. Application of 10 mg Zn kg^{-1} soil significantly increased the average concentration of Zn in different plant parts of wheat. Among the wheat varieties of varying Zn sensitivity, UP 2628 gave highest grain yield and lowest value was recorded in UP 262; however, the straw yield in both the varieties was statistically at par. The study suggested that the Zn efficient variety UP 2628 had better assimilation efficiency of Zn for yield production and uptake capacity of Zn in grain. While UP 262 exhibited lower efficiency for biochemical utilization of Zn to enhance the grain yields. The varieties UP 2554 and PBW 175 showed intermediate behaviour. The pattern of Zn concentration distribution and yield in these varieties could be utilized for development of more efficient varieties of wheat by improving the mechanism of translocation of Zn from lower portions of plant to the grain to enhance the enrichment of this important micronutrient in the diet of vast population of countries where cereals are used as staple food.

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