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Impact of zinc application on its translocation into various plant parts of wheat and its effect on chemical composition and quality of grain

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A field experiment was conducted under All India Co-ordinated Research Project on “Micro, secondary nutrients and pollutant elements in soils and plants” during two consecutive years 2010-2011 and 2011-2012 with fallow-wheat cropping sequence on a Typic Haplustert at the Research Farm of Department of Soil Science and Agricultural Chemistry, J.N. Krishi Vishwa Vidyalaya, Jabalpur (M.P.) to study the influence of Zn application on its translocation into various plant parts of wheat and its impact on chemical composition and quality of grain. The recommended dose of N, P and K was applied at 120 N: 60 P_2O_5: 40 K_2O kg ha^{-1} in combination with Zn at 0, 1.25, 2.5, 5, 10 and 20 kg ha^{-1} as zinc sulphate. The results revealed that the application of increasing levels of Zn at 5, 10 and 20 kg ha^{-1} significantly increased the Zn concentration in root, stem, leaves and earhead of wheat over NPK fertilization alone at different growth stages of wheat. The grain and straw yields as well as harvest index increased with the increasing levels of Zn as compared to NPK alone. The maximum pooled grain yield 4.66 t ha^{-1} was observed in the treatment 20 kg Zn ha^{-1}, while the maximum pooled grain 3.88 t ha^{-1} in the control plots (100% NPK alone). The Zn, N and K contents in grain and straw of wheat significantly increased with the increasing levels of Zn at 2.5, 5, 10 and 20 kg ha^{-1}. However, the P content in both grain and straw was in decreasing order with increasing levels of Zn. Further, the quality parameters like crude and true protein, wet gluten and total carbohydrate were also increased with increasing levels of Zn as compared to NPK alone. Thus, the present studies indicated that the application of 20 kg Zn ha^{-1} with 100% NPK on wheat crop enhanced the as well as maintained the quality of produce and its chemical composition.

Key words: Zn application, translocation, chemical composition, quality, wheat, Typic Haplustert.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is an important cereal crop, source of staple food and thus the most important crop in food security prospective. India occupies second position next to China in the world with regard to area (29.90 million ha) and production (93.90 million tonnes) of wheat. It is the second most important food grain crop in India ranking next to rice (*Oryza sativa* L.) contributing about 35% of the food grain production (Agriculture Statistics at a Glance, 2012). India is now one of the major world's importers of wheat. Besides its tremendous significance, average yield is far below than developed countries (FAO, 2010), although the genetic potential of local varieties is not less than any country in the region. Nutrient deficiency is one of the important yield limiting

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Table 1. Physico-chemical properties of soil of two experimental sites.

Properties	Content	
	Site-I (2010-11)	Site-II (2011-12)
Sand (%)	25.3	25.1
Silt (%)	17.9	17.9
Clay (%)	56.7	56.8
Soil textural class	Clayey	Clayey
Soil pH (1:2.5)	7.2	7.0
Electrical conductivity (dS m^{-1})	0.30	0.24
Organic carbon (%)	0.63	0.68
Calcium carbonate (%)	2.40	3.00
Available Nitrogen (kg ha^{-1})	219.0	216.6
Available Phosphorus (kg ha^{-1})	18.9	18.2
Available Potassium (kg ha^{-1})	330.3	329.7
DTPA extractable-Zn (mg kg^{-1})	0.53	0.56

factors includes delayed sowing, high weeds infestations, water shortage at critical growth stages, intensive cultivation and imbalance and non-judicious application of fertilizers. The universal deficiency of nitrogen and phosphorus is followed by Zn deficiency. Almost 50% of the world soils used for cereal production is Zn deficient (Gibbson, 2006).

The knowledge of translocation of Zn into various plant parts of wheat at various growth stages may be useful criterion in delineating the deficiency levels of nutrients from sufficiency and toxicity levels. Nutrient content in various parts of plant can assist in evaluating the nutrient status of crops. The higher the capacity for a plant to accumulate a nutrient, the greater would be the difference in its nutrient concentration in response to varying rates of fertilizer application. Often, the concentration of micronutrients cations does not vary greatly within plants parts, however, application of nutrient(s) in question may alter the concentration of other micronutrients to some extent which may influence their critical level in the plant parts. Knowledge of Zn transport in plant is inadequate. Little is known about transport of Zn from roots to shoots and from shoots to other plant parts. Zn absorption by plants involves a number of steps (Lasat et al., 1998). First, adequate Zn bioavailability was necessary in the rhizoshpere. There are two pathways for Zn to move from the soil solution to the rhizosphere, mass flow and diffusion. 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 (Riceman and Jones, 1958). It has been claimed that the Zn transported from phloem does not occur in wheat, leaving roots starved of Zn if not supplied in root environment. However, more recent studies with wheat showed good transport of Zn from stem and leaves to developing grain, as well as from one root to another, indicating involvement of phloem transport.

Keeping this in view, the present investigation was conducted to evaluate the effect of Zn application on its translocation into various plant parts of wheat and its impact on chemical composition and quality of grain.

MATERIALS AND METHODS

Soils and its characteristics

The present investigation is a part of an ongoing All India Co-ordinated Research Project on “Micro, secondary nutrients and pollutant elements in soils and plants”, with fallow-wheat cropping sequence during the two consecutive years 2010-2011 and 2011-2012, at two different Zn deficient sites, at the Research Farm of the Department of Soil Science and Agricultural Chemistry, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh, India. Both experimental sites (23°10'' N latitude and 79°57'' E longitude) have a semi-arid and sub-tropical climate with a characteristic feature of dry summer and cold winter. In winter season, that is, from November to February months, the temperature ranges from 4 to 33°C and the relative humidity varies from 70 to 90%. Dry and warm weather usually prevails during the months of March to June. The temperature in the month of May attains a value as high as 46°C. Monsoon season extends from mid-June to mid-September. The temperature during this period varies from 25 to 35°C and the relative humidity ranges from 70 to 80%. The total annual rainfall varies from 1000 to 1500 mm with the mean value of around 1350 mm. The length of growing period ranges from 150 to 180 days. The soil of the experimental sites falls under Vertisol and belongs to Kheri-series of fine montmorillonite, Hyperthermic family of Typic Haplusterts popularly known as “medium black soil”. The textural class of soil is clayey. The key soil properties (0 to 15 cm soil depth) are presented in Table 1.

Experimental details

The experiment was designed and conducted with different Zn levels (0, 1.25, 2.5, 5, 10 and 20 kg Zn ha^{-1}) having four replications arranged in the randomized block design. Two blocks were separated with a gap of 1.50 m, whereas individual plots (5 × 8 m) were separated with a distance of 1.25 m. The 100% NPK was

Table 2. Influence of Zn application on its translocation into various plant parts of wheat at tillering stage.

Treatment	Zn concentration (mg kg^{-1})								
	Root			Stem			Leaves		
	2010-2011	2011-2012	Pooled	2010-2011	2011-2012	Pooled	2010-2011	2011-2012	Pooled
T_1-NPK (Control)	26.75	29.00	27.88	23.33	26.14	24.73	17.63	19.51	18.57
T_2-1.25 kg Zn ha^{-1}	27.18	29.18	28.18	23.95	26.84	25.39	17.75	19.64	18.69
T_3-2.50 kg Zn ha^{-1}	27.55	30.13	28.84	24.58	27.61	26.09	18.30	20.08	19.19
T_4-5.00 kg Zn ha^{-1}	29.08	31.13	30.10	26.45	29.39	27.92	18.90	21.68	20.29
T_5-10.00 kg Zn ha^{-1}	31.23	33.43	32.33	27.60	30.71	29.16	20.65	22.84	21.74
T_6-20.00 kg Zn ha^{-1}	32.38	34.63	33.50	28.28	31.12	29.70	20.98	23.41	22.19
SEm (±)	1.08	1.15	0.74	0.91	1.03	0.64	0.72	0.78	0.50
C.D. (5 %)	3.34	3.55	2.14	2.81	3.18	1.86	2.23	2.40	1.45

SEm – Standard error of mean; C.D. – Critical difference.

commonly applied in all the treatments (Zn levels) and the recommended dose of nutrients was 120 N: 60 P_2O_5: 40 K_2O kg ha^{-1}. A basal dose of 60:60:40 N, P_2O_5, and K_2O was applied before sowing of wheat, through urea, super phosphate and muriate of potash fertilizers. Remaining 60 kg N was applied to wheat crop in two splits first half at 21 to 25 days (after the first irrigation) and the rest at 51 to 55 days after sowing. The doses of Zn @ 0, 1.25, 2.50, 5, 10 and 20 kg ha^{-1} were given through zinc sulphate fertilizer before sowing of wheat. Wheat (GW-273) was sown during 2nd to 3rd week of December 2010-2011 and 2011-2012 of rabi season with hand drill using seed rate 120 kg ha^{-1}. It is irrigated at critical phases of crop growth and as when needed. All crop management and protection measures were followed. Weed control practices were included physical method, that is, hoeing along with weedicides. Insects and diseases were kept under check following suitable control measures. Wheat crop were harvested at maturity (120 days after sowing) and yield data were recorded after threshing.

Chemical analysis of soil and plant

In present investigations, composite surface (0 to 20 cm) soil samples were collected from two different Zn deficient sites were analyzed for different basic soil properties by adopting standard laboratory procedure. The samples of various plant parts like root, stem, leaves and earhead were collected at different successive growth stages of wheat and washed thoroughly with 0.01 N HCl and then with demineralized water and dried in an oven at 60°C for analyzing Zn concentration. The chemical analysis of the plant sample was carried out by wet digesting with HNO_3:$HClO_4$ (4:1) di-acid mixture a per the procedure outlined by Jackson (1973) and to determine concentrations of different nutrients at harvest using procedure described by Jackson (1973). The Zn content in various plant parts, grain and straw was analyzed by atomic absorption spectrophotometer. The nutrients content (N, P, K and Zn) was estimated by different laboratory procedures.

Quality parameters

The crude protein content was determined by multiplying the nitrogen content value of grain with 5.73, which also includes non-protein nitrogen. To get true protein content, deduce the non-protein nitrogen from crude protein content and then multiplying with the factor (AOAC, 1965). Estimation of gluten content in grain was obtained by hand washing method (Payne et al., 1979). Total carbohydrate content in grain was determine by Phenol sulphuric acid method (AOAC, 1965).

Statistical analysis

The data generated from the present study were analyzed statistically and to draw suitable inference as per standard ANOVA technique described by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

The results obtained from the present investigations as well as relevant discussion based on the data pooled over two consecutive years (2010-2011 and 2011-2012) have been presented under following heads.

Translocation and distribution of Zn into various plant parts of wheat at tillering stage

The data presented in Table 2 indicates that the Zn accumulation by root, stem and leaves of wheat were found to increase by the increasing levels of Zn at tillering stage. Further, the application of 5, 10 and 20 kg Zn ha^{-1} resulted in significant increase in Zn concentration in root by 7.98, 15.96 and 20.18%, in stem by 12.88, 17.89 and 20.09% and leaves by 9.28, 17.10 and 19.52%, respectively, as compared to the application of NPK alone. However, the application of 10 and 20 kg Zn ha^{-1} were statistically at par with each other. The magnitude of Zn concentration in different plant parts was assorted as: root > stem > leaves. Zinc is taken up by root cells as Zn^{2+} and, in some plant species, also as Zn-phytosiderophore complexes. The distribution of Zn within shoots and leaves varies between plant species. Plant tissues accumulate Zn in both soluble and insoluble forms. In crop plants, much of the soluble Zn is complexed with organic compounds (White, 2012). Zn concentrations in roots, leaves and stems can be increased readily by applying Zn-fertilizers to the soil in

Table 3. Influence of Zn application on its translocation into various plant parts of wheat at flowering stage.

Treatment	Zn concentration (mg kg^{-1})											
	Root			Stem			Leaves			Earhead		
	2010-2011	2011-2012	Pooled	2010-2011	2011-2012	Pooled	2010-2011	2011-2012	Pooled	2010-2011	2011-2012	Pooled
T$_1$-NPK (Control)	23.88	24.65	24.26	22.63	22.43	22.53	14.83	17.78	16.30	28.35	28.43	28.39
T$_2$-1.25 kg Zn ha^{-1}	24.18	24.85	24.51	22.93	23.30	23.11	14.95	17.88	16.41	29.03	28.70	28.86
T$_3$-2.50 kg Zn ha^{-1}	25.78	26.70	26.24	24.33	24.53	24.43	15.75	18.33	17.04	29.33	29.65	29.49
T$_4$-5.00 kg Zn ha^{-1}	27.03	28.68	27.85	25.20	25.13	25.16	16.48	19.40	17.94	30.93	31.69	31.31
T$_5$-10.00 kg Zn ha^{-1}	27.88	29.00	28.44	26.55	26.18	26.36	17.48	20.73	19.10	32.13	33.54	32.83
T$_6$-20.00 kg Zn ha^{-1}	28.45	29.53	28.99	26.99	27.13	27.06	18.00	21.25	19.63	33.25	33.89	33.57
SEm (±)	0.97	1.00	0.66	0.89	0.87	0.59	0.57	0.67	0.42	1.04	1.12	0.73
C.D. (5 %)	2.98	3.10	1.90	2.76	2.68	1.69	1.77	2.08	1.21	3.21	3.47	2.10

SEm – Standard error of mean; C.D. – Critical difference.

plants growing on most, but not all, soils and by foliar application of Zn-fertilizers. Thus, Zn concentrations in these tissues will be limited solely by Zn toxicity (Bouis and Welch, 2010). When Zn-fertilizers are added to the soil, root tissues often exhibit higher Zn concentrations than shoot tissues, and it is likely that plant Zn accumulation and yield is limited by Zn toxicity to root cells under these conditions. Critical leaf Zn concentrations for most crop plants lie between 100 and 700 mg kg^{-1} dry matter when Zn-fertilizers are applied to the soil. Enhanced translocation of Zn from root to shoot meristems and its retranslation from senescing to growing organ under Zn supply might also contribute towards Zn efficiency in wheat. Zn is unevenly distributed within the plant. Within each organ, Zn is preferentially accumulated by specific cell types. Similar findings are enunciated by the other worker like Kumar and Qureshi (2012).

Translocation and distribution of Zn into various plant parts of wheat at flowering stage

The data pertaining on Zn accumulation by different plant parts of wheat are presented in Table 3 showed that the Zn concentration increased in various plant parts viz., root, stem, leaves and earhead of wheat with the increasing levels of Zn fertilization at flowering stage. The application of 2.5, 5, 10 and 20 kg Zn ha^{-1} significantly increased the Zn concentration in root by 8.12, 14.79, 17.21 and 19.47% and in stem by 8.44, 11.70, 17.04 and 20.12%, respectively, as compared to control (100% NPK alone). However, the application of 5, 10 and 20 kg Zn ha^{-1} increased Zn concentration in leaves by 10.05, 17.18 and 20.40% and in earhead by 10.29, 15.65 and 18.25%, respectively, over NPK fertilization alone. The application of 5, 10 and 20 kg Zn ha^{-1} were statistically at par with each other in increasing the Zn concentration in root and earhead while, 10 and 20 kg Zn ha^{-1} were at par in enhancing Zn accumulation in stem and leaves over control. The maximum concentration of Zn was found in earhead and lowest in leaves. The above findings suggested that during flowering stage Zn is translocated to reproductive part of the plant indicating earhead as the metabolically active region and site of maximum accumulation for Zn during flowering stage. Almost equal amount of Zn was observed in stem and root of wheat at flowering stage. This may be due to fact that Zn enters plants from the soil solution and is transported either symplastically, following uptake by root cells, or apoplastically, in regions of the root lacking a casparian band, to the stele where it enters the xylem. Xylem to phloem transfer may occur in the crown (where root meet the stem) as shown by Zn transport from one to another. Within the shoot, uptake of Zn^{+2} and Zn-complexes was by specific cell. Shoot Zn concentrations are often an order of magnitude greater than root Zn concentrations in plants that hyperaccumulated Zn, although the exact ratio depends on soil Zn phytoavailability (Broadley et al., 2007). Higher accumulation of Zn was also noted in meristematic region at base of leaves and the root tips probably because of a large Zn requirement in there rapid growing tissues. However, transport of Zn from roots could have occurred in the xylem all the way to stem or leaves, with the subsequent transfer to the phloem from downward transport to roots representing a somewhat less directly route from one part of split-root system to the other. In

Table 4. Influence of Zn application on its translocation into various plant parts of wheat at maturity stage.

Treatment	Zn concentration (mg kg^{-1})											
	Root			Stem			Leaves			Earhead		
	2010-2011	2011-2012	Pooled	2010-2011	2011-2012	Pooled	2010-2011	2011-2012	Pooled	2010-2011	2011-2012	Pooled
T_1-NPK (Control)	19.63	22.78	21.20	17.68	19.50	18.59	15.63	16.35	15.99	29.48	30.00	29.74
T_2-1.25 kg Zn ha^{-1}	19.73	22.88	21.30	17.85	19.60	18.73	16.25	16.50	16.38	30.15	30.23	30.19
T_3-2.50 kg Zn ha^{-1}	20.13	23.33	21.73	18.35	20.45	19.40	16.78	16.90	16.84	31.13	30.75	30.94
T_4-5.00 kg Zn ha^{-1}	21.13	24.40	22.76	19.19	21.05	20.12	17.78	17.75	17.76	33.70	32.90	33.30
T_5-10.00 kg Zn ha^{-1}	22.95	26.23	24.59	20.38	22.25	21.31	18.38	18.85	18.61	34.73	34.98	34.85
T_6-20.00 kg Zn ha^{-1}	23.18	26.83	25.00	21.18	23.10	22.14	18.50	19.61	19.06	35.33	35.88	35.60
SEm (±)	0.77	0.86	0.54	0.62	0.79	0.47	0.66	0.77	0.45	1.15	1.17	0.77
C.D. (5 %)	2.36	2.64	1.56	1.90	2.45	1.36	2.04	2.37	1.31	3.55	3.61	2.24

SEm – Standard error of mean; C.D. – Critical difference.

addition, due to the relative long periods, some of Zn transported from leaves to roots via phloem could have been re-translocate back to the stem and leaves in the xylem. The above results are in agreement with the result of Wu et al. (2011).

Translocation and distribution of Zn into various plant parts of wheat at maturity stage

A perusal of data presented in Table 4 showed the effect of increasing levels of Zn fertilization on Zn accumulation by root, stem, leaves and earhead of wheat at maturity stage. The Zn concentration in root increased significantly by 7.37, 15.98 and 17.92 per cent, in stem by 8.24, 14.66 and 19.10 per cent, in leaves by 11.10, 16.42 and 19.19 per cent and in earhead by 11.98, 17.19 and 19.71 per cent with the application of 5, 10 and 20 kg Zn ha^{-1}, respectively. However, the application of 10 and 20 kg Zn ha^{-1} were statistically at par with each other. Further, Zn accumulation in grain was controlled by homostatic mechanism in plant that regulates Zn absorption, translocation and loading and unloading rates of phloem sap (Hao et al., 2007). The grain Zn originated from two sources: first directly from soil and second, from the remobilization of stored Zn from leaves. In wheat, retranslocation from leaves is important for Zn allocation to the grain. The redistribution of Zn may depend on age of the plant as well as on Zn content of the source organs. The redistribution of Zn may depend on age of the plant as well as on Zn content of source. Remobilization of Zn from old leaves to younger tissues and generative organs is much greater under adequate supply of Zn. However, increasing Zn concentrations in grain, seeds and fruits requires adequate Zn mobility in the phloem and, unless Zn-fertilizers are applied directly or they have functional xylem continuity, the mobility of Zn in the phloem will limit their Zn accumulation. Moreover, the decrease in concentration of Zn at maturity stage as compared to early growth stages might be due to dilution effect on account of increased vegetative growth and consequent dry matter accumulation. Similar spool of thought was advocated by Zhao et al. (2011).

Yield and harvest index

The grain and straw yields as well as harvest index increased with the increasing levels of Zn as compared to NPK alone (Table 5). Zn fertilization @ 10 kg ha^{-1} enhanced both grain and straw yields significantly by 19.19 and 14.26%, respectively, as compared to control. However, the application of 20 kg Zn ha^{-1} also significant increased grain and straw yields by 20.15 and 14.26%, respectively, over control but statistically at par with 10 kg Zn ha^{-1}. Further, the harvest index was also increased, though non-significantly with the increasing levels of Zn as compare to control. This was perhaps due to abundant supply of Zn nutrition and balanced NPK, which increased the protoplasmic constituents, accelerates the process of cell division and elongation, photosynthesis processes, respiration, nitrogen metabolism-protein synthesis, other biochemical and physiological activates. This in

Table 5. Effect of Zn application on grain and straw yields and harvest index.

Treatment	Yield								
	Grain (t ha^{-1})			Straw (t ha^{-1})			Harvest index (%)		
	2010-2011	2011-2012	Pooled	2010-2011	2011-2012	Pooled	2010-2011	2011-2012	Pooled
T_1-NPK (Control)	3.75	4.00	3.88	4.60	4.93	4.76	45.01	44.92	44.97
T_2-1.25 kg Zn ha^{-1}	3.80	4.06	3.93	4.66	4.96	4.81	45.01	44.95	44.98
T_3-2.50 kg Zn ha^{-1}	3.89	4.19	4.04	4.73	5.04	4.88	45.06	45.24	45.15
T_4-5.00 kg Zn ha^{-1}	3.98	4.49	4.24	4.80	5.37	5.09	45.36	45.37	45.37
T_5-10.00 kg Zn ha^{-1}	4.48	4.77	4.62	5.28	5.56	5.42	45.97	46.41	46.19
T_6-20.00 kg Zn ha^{-1}	4.52	4.79	4.66	5.29	5.59	5.44	46.02	46.12	46.07
SEm (±)	0.23	0.24	0.16	0.29	0.29	0.19	0.84	0.93	0.59
C.D. (5 %)	0.70	0.74	0.45	NS	NS	0.56	NS	NS	NS

SEm – Standard error of mean; C.D. – Critical difference; NS – Non-significant.

turn increased the values of all growth and yield attributing parameters, which finally reflected both in increased grain and straw yields as well as harvest index. Our results are in line with Ram et al. (2012) which showed that the soil application of Zn had economical and long-term effects on enhanced crop production on Zn deficient soils.

Nutrients content in grain and straw of wheat

Zn content in grain and straw

A perusal of data presented in Table 6 indicates that the application of Zn at 1.25, 2.5, 5, 10 and 20 kg ha^{-1} significantly increased the Zn content in grain by 10.22, 22.22, 38.49, 54.01 and 72.84%, respectively, over control. However, the Zn content in straw increased significantly with the application of 10 and 20 kg Zn ha^{-1} by 22.37 and 28.48%, respectively, over control but both Zn levels were statistically at par with each other. The magnitude of increase in Zn concentration in grain and straw of wheat was found to be higher over control. The application of increasing levels of Zn enhanced the availability of Zn in crops. Generally, when the rate of plant growth exceeds the rate of uptake of a particular nutrient, the concentration of that nutrient in the tissue decreases or it is diluted in the plant tissue. Crops fertilized with Zn improved the nutritional environment of rhizosphere and consequently in plant system, which caused higher metabolic and photosynthesis activity in plant resulted in greater uptake of Zn by crops, higher dry matter production, which led to higher total Zn uptake by crops. The present findings support the results of Kanwal et al. (2010).

N content in grain and straw

The increasing levels of Zn enhanced N content in grain and straw as compared to application of NPK alone. The data presented in Table 6 revealed that the application of Zn at 2.5, 5, 10 and 20 kg ha^{-1} significantly increased the N content in grain by 10.59, 18.34, 21.89 and 23.03%, respectively, over control. However, the application of 5, 10 and 20 kg Zn ha^{-1} were statistically at par with each other. The N content in straw also increased significantly with the application of 5, 10 and 20 kg Zn ha^{-1} by 10.79, 16.90 and 20.77%, respectively, over control but 10 and 20 kg Zn ha^{-1} were statistically at par with each other. Increases in N content in both grain and straw of wheat with the application of various increasing Zn levels could be attributed to synergistic effect between N and Zn. This might be partially attributed to the favourable effect of Zn application to form vegetative plant material which in turn increases N content in grain and straw. It is also inferred that plants are not able to survive without adequate or sufficient Zn because it is essential for synthesis of DNA and RNA and to metabolizing carbohydrates, lipids and proteins production. They attributed an increase in the dry weight of the airborne organs to increase in N uptake (Abbas et al., 2009).

P content in grain and straw

The data shown in Table 6 indicates that P content in both grain and straw was in decreasing order with increasing levels of Zn at 1.25, 2.5, 5, 10 and 20 kg ha^{-1}. It might be due to antagonistic effect of Zn on P absorption. Zn was found to inhabit the translocation of P from roots to the tops. Zn has the ability to control the rate of P-absorption by roots possibly through some functional association in the cell membrane. It interferes directly with P-metabolism, decreasing the amount of P absorbed by roots and transported to tops. The decrease in concentration of P in grain and straw with the increasing levels of Zn may be attributed due to antagonistic relationship between Zn and P. Excess of Zn (high tissue Zn concentrations) causes a decrease in the

Table 6. Effect of Zn application on chemical composition of wheat.

Treatment	Zn (mg kg^{-1})			N (%)			P (%)			K (%)		
	2010-2011	2011-2012	Pooled	2010-2011	2011-2012	Pooled	2010-2011	2011-2012	Pooled	2010-2011	2011-2012	Pooled
Nutrients content in grain												
T_1-NPK (Control)	20.76	22.23	21.49	1.67	1.85	1.76	0.32	0.31	0.31	0.51	0.54	0.52
T_2-1.25 kg Zn ha^{-1}	22.36	25.02	23.69	1.73	1.93	1.83	0.31	0.31	0.31	0.51	0.55	0.53
T_3-2.50 kg Zn ha^{-1}	24.58	27.96	26.27	1.83	2.06	1.95	0.31	0.30	0.30	0.52	0.56	0.54
T_4-5.00 kg Zn ha^{-1}	27.62	31.92	29.77	1.97	2.20	2.08	0.30	0.29	0.29	0.53	0.58	0.55
T_5-10.00 kg Zn ha^{-1}	30.89	35.32	33.10	2.02	2.27	2.14	0.28	0.27	0.27	0.55	0.61	0.58
T_6-20.00 kg Zn ha^{-1}	34.81	39.49	37.15	2.03	2.30	2.16	0.26	0.25	0.26	0.58	0.62	0.60
SEm (±)	0.96	1.07	0.71	0.07	0.07	0.05	0.01	0.01	0.01	0.02	0.02	0.01
C.D. (5 %)	2.96	3.35	2.06	0.21	0.23	0.14	NS	NS	NS	0.06	0.07	0.04
Nutrients content in straw												
T_1-NPK (Control)	8.99	9.43	9.21	0.57	0.66	0.61	0.095	0.088	0.091	0.74	0.78	0.76
T_2-1.25 kg Zn ha^{-1}	9.24	9.77	9.50	0.58	0.67	0.63	0.095	0.085	0.090	0.75	0.79	0.77
T_3-2.50 kg Zn ha^{-1}	9.54	10.12	9.83	0.60	0.69	0.65	0.093	0.083	0.088	0.76	0.81	0.78
T_4-5.00 kg Zn ha^{-1}	10.19	11.06	10.63	0.63	0.73	0.68	0.093	0.080	0.086	0.77	0.82	0.80
T_5-10.00 kg Zn ha^{-1}	10.94	11.60	11.27	0.66	0.77	0.72	0.090	0.078	0.084	0.80	0.85	0.83
T_6-20.00 kg Zn ha^{-1}	11.42	12.24	11.83	0.69	0.80	0.74	0.088	0.075	0.081	0.83	0.87	0.85
SEm (±)	0.38	0.40	0.63	0.02	0.03	0.02	0.003	0.003	0.002	0.03	0.03	0.02
C.D. (5 %)	1.17	1.24	1.81	0.07	0.08	0.05	NS	NS	NS	0.09	0.09	0.05

SEm – Standard error of mean; C.D. – Critical difference; NS – Non-significant.

expression of P transporter genes in plant roots. The origin of this interaction whether due to dilution effects in higher Zn rate applied did not affect absorption of P in the roots but partially reduced the translocation of P from roots to the tops. Zn application in Zn-deficient soil reduced root P uptake and grain deposition of P and thus grain phytate concentrations. Consequently, phytate:Zn ratios showed dramatic decreases by Zn application (Alam et al., 2000). Moreover the P content in grain was much higher than in straw. This might be due to the fact that absorbed P is translocated and utilized more for the formation of certain P-compound in grain, which leads to the apparent depletion in straw. The results stand in agreement those of Kumar and Yadav (2005).

K content in grain and straw

A perusal of data in Tables 6 showed that the increasing levels of Zn increased K content in grain as well as straw of wheat as compared to control. It is also revealed that the K content was higher by straw than by grain of wheat. The application of various increasing levels of Zn as compared to NPK fertilization alone, while the application of 10 and 20 kg Zn ha^{-1} significantly increased K content from 9.06 to 11.86%, respectively, in straw but both levels of Zn were statistically at par with each other. This might be due to: (1) synergetic interaction between Zn and K, (2) many zinc dependent enzymes that are involved in carbohydrate metabolism in general and in leaves in particular, (3) impairment of K in stomata regulation, (4) phloem export of photosynthetase from source, the leaves, into sink organs and (5) maintained water balanced within the soil-plant-atmosphere continuum. Zn

Table 7. Effect of Zn application on quality of wheat grain.

Treatment	Quality parameters											
	Crude protein (%)			**True protein (%)**			**Wet gluten (%)**			**Total carbohydrate (%)**		
	2010-2011	**2011-2012**	**Pooled**	**2010-2011**	**2011-2012**	**Pooled**	**2010-2011**	**2011-2012**	**Pooled**	**2010-2011**	**2011-2012**	**Pooled**
T_1-NPK (Control)	9.50	10.55	10.02	8.88	9.35	9.12	9.58	10.52	10.05	58.19	61.83	60.01
T_2-1.25 kg Zn ha^{-1}	9.83	11.00	10.42	9.10	9.71	9.41	9.77	10.82	10.30	60.23	62.08	61.15
T_3-2.50 kg Zn ha^{-1}	10.43	11.74	11.09	9.50	10.22	9.86	10.33	11.52	10.93	63.92	64.83	64.37
T_4-5.00 kg Zn ha^{-1}	11.21	12.51	11.86	10.05	10.66	10.36	11.23	12.54	11.89	65.81	65.40	65.60
T_5-10.00 kg Zn ha^{-1}	11.50	12.94	12.22	10.54	11.47	11.00	11.57	12.80	12.19	68.45	69.95	69.20
T_6-20.00 kg Zn ha^{-1}	11.59	13.08	12.33	10.67	11.76	11.21	11.76	12.97	12.37	69.29	71.45	70.37
SEm (±)	0.38	0.42	0.27	0.36	0.38	0.25	0.41	0.47	0.30	2.26	2.22	1.50
C.D. (5 %)	1.17	1.31	0.78	1.11	1.18	0.72	1.28	1.46	0.86	6.97	6.86	4.35

SEm – Standard error of mean; C.D. – Critical difference.

sufficiency is associated with marked increases in K efflux from roots and shoots into growth medium. Zn also facilitates the movement of K in the guard cells of the stomata (Ali et al., 2011).

Effect of Zn application on quality parameters of wheat grain

Results of the present study on the effect of various Zn levels on quality of wheat viz., crude protein, true protein, wet gluten and total carbohydrate content in wheat grain are presented in Table 7.

Crude protein content

It is observed from the data presented in Table 7 that the crude protein in wheat grain was markedly increased by the application of increasing Zn levels. The application of Zn at 2.5, 5, 10 and 20 kg ha^{-1} significantly increased crude protein content in wheat grains by 10.59, 18.34, 21.89 and 23.03% over control. This might be due to that application of Zn increased N-metabolism, which enhanced accumulation of amino acids and drastically increased the rate of protein synthesis and consequently, protein content in grain. Zn application in soil enhanced the Zn concentration in the plant which associated with RNA and ribosome induction the result of which accelerates protein synthesis (Sonune et al., 2001). The results are in consonance with the findings of Mishra (2012).

True protein content

The data presented in Table 7 revealed that the true protein (deduced non-protein nitrogen from crude protein) in wheat grain increased with the increasing Zn levels. The application of Zn at 2.5, 5, 10 and 20 kg ha^{-1} significantly increased true protein content in wheat grains by 8.17, 13.63, 20.71 and 22.98% as compared to control plot. This could be due to increased conversion of N to protein compounds and the build-up of free amino acids and amides in the plant with Zn application (Kharub and Gupta, 2003). These conditions are an evidence for the importance of Zn in protein synthesis and its production in grain. The present results are in conformity with those reported by Pable et al. (2010).

Wet gluten content

The data showed that the increasing levels of Zn increased wet gluten content of wheat grain (Table 7). The wet gluten content in wheat grains was found to increase significantly with the application of Zn at 2.5, 5, 10 and 20 kg ha^{-1} by 8.75, 18.30, 21.30 and 23.08% as compared to application of NPK alone. Improvement in wet gluten content in wheat grain may be due to the role of Zn in maintaining balanced plant physiological growth. Even though Zn is present in small amount, it activates about 70 enzymes in plant and it is essential to synthesis of DNA and RNA and metabolizing lipid and proteins (Knapowski et al., 2008). The increase in protein synthesis and its production also accelerates the gluten content because it is one fraction of protein itself (Akay, 2011).

Total carbohydrate content

A perusal of data presented in Table 7 indicate that the increasing levels of Zn showed positive response in enhancing the total carbohydrate content of wheat grain. The application of Zn at 2.5, 5, 10 and 20 kg ha^{-1} significantly increased total carbohydrate content in wheat grains by 7.27, 9.32, 15.32 and 17.26% over NPK fertilization alone. This may be due to direct involvement of Zn in carbonic anhydrase, photosynthesis enzymatic activates and formation of chlorophyll. Presence of Zn probably increases sucrose synthase activity and starch formation. It also favours synthesis of starch, by activating ADP-glucose pyrophosphorylase and impaired in conversion of starch to glucose and sucrose, thus increased total carbohydrate in grain (El-Tohamy and El-Greadly, 2007).

Conclusion

It may be concluded that the increasing levels of Zn at 5, 10 and 20 kg ha^{-1} increased the Zn concentration in root, stem, leaves and earhead of wheat. The grain and straw yields as well as harvest index was also increased with the increasing levels of Zn. Furthermore, the application of 20 kg Zn ha^{-1} with 100% NPK on wheat crop maintained the quality of produce and its chemical composition.

REFERENCES

Abbas G, Khan MQ, Jamil M, Tahir M, Hussain F (2009). Nutrient uptake, growth and yield of wheat (Triticum aestivum) as affected by zinc application rates. Int. J. Agric. Biol. 11:389-396.

Agriculture Statistics At a Glance (2012). Agricultural Statistics Division. Directorate of Economics and Statistics. Department of Agriculture and Co-operation, Ministry of Agriculture, Govt, of India, New Delhi.

Akay A (2011). Effect of zinc fertilizer applications on yield and element contents of some registered chickpeas varieties. Afr. J. Biotech. 10:13090-13096.

Alam SM, Iqbal Z, Latif A (2000). Effect of P and Zn application by fertigation on P use efficiency and yield of wheat. Trop. Agric. Res. Exten. 3:115-119.

Ali S, Said A, Saeed B, Ahmad I, Ali K (2011). Response of yield and yield components of wheat towards foliar spray of nitrogen, potassium and zinc. ARPN J. Agric. Biol. Sci. 5: 23-25.

AOAC (1965). Official methods of analysis of the association of official agricultural chemists. 10th Ed. 744.

Bouis HE, Welch RM (2010). Biofortification–a sustainable agricultural strategy for reducing micronutrient malnutrition in the global South. Crop Sci. 50:20-32.

El-Tohamy WA, El-Greadly NHM (2007). Physiological responses, growth, yield and quality of snap beans in response to foliar application of yeast, vitamin -E and zinc under sandy soil conditions. Aust. J. Basic and Appl. Sci. 1: 294-299.

.

FAO (2010). Scaling soil nutrient balances: Enabling meso-level applications for African realities fertilizer and plant nutrition bulletin 15 Rome.

Gibbson RS (2006). Zinc: The missing link in combating micronutrient malnutrition in developing countries. Proceedings of the Nutrition Society, University of East Anglia, Norwich, June 28 - July 1, 2005.

Gomez KA, Gomez AA (1984). Statistical Procedures for Agricultural Research. John Wiely and Sons, New York, P. 680.

Hao HL, Wei YZ, Yang XE, Feng Y, Wu CY (2007). Effects of different nitrogen fertilizer levels on Fe, Mn, Cu and Zn concentrations in shoot and grain quality in rice (*Oryza sativa*). Rice Sci. 14:289-294.

Jackson ML (1973). Soil chemical analysis Prentice Hall of India Ltd. New Delhi. pp. 219-221.

Kanwal S, Rahmatullah, Ranjha AM, Ahmad R (2010). Zinc partitioning in maize grain after soil fertilization with zinc sulfate. Intern. J. Agric. Biol. 2:299-302.

Kharub AS, Gupta SP (2003). Quality traits in durum and aestivum wheat genotypes as influenced by zinc application. Indian J. Agric. Res. 37:48-51.

Knapowski T, Ralcewicz M, Barczak B, Kozera W (2008). Effect of nitrogen and zinc fertilizing on bread-making quality of spring triticale cultivated in Notec valley. Polish J. Environ. Stud. 18:227-233

Kumar M, Qureshi FM (2012). Dynamics of zinc fractions, availability to wheat and residual effect on succeeding maize in Inceptisols. J. Agric. Sci. 4:236-245.

Kumar V, Yadav GV (2005). Effect of P, K, S and Zn in Alluvial soil under rice-wheat cropping sequence. Napana J. Sci. 4:8-14.

Lasat MM, Baker AJM, Kochian LV (1998). Altered zinc compartmentation in the root symplasm and stimulated zinc absorption into the leaf as mechanisms involved in zinc hyperaccumulation in Thlaspi caerulescens. Plant Physiol. 118: 875-883.

Mishra LK (2012). Effect of phosphorus and zinc fertilization on biochemical composition of wheat. The Bioscan 7:445-449.

Pable D, Patil DB, Deshmukh PW (2010). Effect of sulphur and zinc on yield and quality of soybean in Vertisol. Asian J. Soil Sci. 5(2):315-317.

Payne PI, Corfield KG, Blackman JA (1979). Identification of a high molecular weight subunit of gluten in whose presence correlates with bread making quality in wheat of related pedigree. Theo. Appl. Gene 55:153-159.

Ram A, Pannu RK, Prasad D (2012). Effect of management practices on growth, yield and quality of late sown wheat. Indian J. Agron. 57:92-95.

Riceman DS, Jones GB (1958). Distribution of zinc in subterranean clover (*Trifolium subterraneum* L.) grown to maturity in a culture solution containing zinc labeled with the radioactive isotope Zn. Aust. J. Agric, Res. 9:730-744.

Sonune BA, Naphade PS, Kankal DS (2001). Effect of zinc and sulphur on protein and oil content of soybean. Agric. Sci. Digest 21:259-260.

White PJ (2012). Heavy metal toxicity in plants, in Plant Stress Physiology, ed. S. Shabala (Wallingford:CABI), (in press).

Wu C, Feng Y, Shohag MJI, Lu L, Wei Y, Gao C, Yang X (2011). Characterization of zinc uptake, translocation, and accumulation into developing grains and young leaves of high Zn-density rice genotype. Biomed. Biotech. 12:408-418.

Zhao A, Lu X, Chen Z, Tian X, Yang X (2011). Zinc fertilization methods on zinc absorption and translocation in wheat. J. Agric. Sci. 3:28-35.