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Full Length Research Paper

Evaluation of Wheat (Triticum aestivum L.) genotypes for enhanced productivity through identification of Zn-efficient genotypes

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The relative zinc (Zn) efficiencies of 20 wheat genotypes were determined by growing them in chelate-buffered hydroponic culture solutions. Zinc efficiency of the test genotypes were determined by comparing their growth in a Zn-deficient solution (2 pM Zn^{2+}) relative to that in a medium containing an adequate concentration of Zn (40 pM Zn^{2+}) and varied between 41to 84%. The results depicted that eight genotypes proved Zn-efficient, 4 medium and 8 inefficient ones. The SD-8006, SD-8012 and SD-669 were the most efficient wheat genotypes with the efficiency of 84, 83, and 76%, respectively; whereas, T21 and T11 were the least efficient genotypes with 41 and 42% efficiency, respectively. All the cultivars accumulated higher concentrations of iron (Fe), copper (Cu), manganese (Mn) and phosphorus (P) at deficient levels of Zn, compared with adequate Zn concentrations. The Zn-inefficient cultivars accumulated higher concentrations of these elements compared to efficient cultivars. Zinc efficiency of these genotypes under field conditions varied between 57 to 96%, which was quite higher than determined in hydroponics study. Zn-efficient genotypes produced 23% higher grain yield and more extracted Zn (38%) compared to Zn-inefficient genotypes.

Key words: Efficiency, Field study, Genotypes, Hydroponic study, Wheat, Zinc

INTRODUCTION

Zinc deficiency in cereal plants is now a well known problem that causes reduced agricultural productivity all over the world (Cakmak et al., 1999; Fageria et al., 2002). In addition, it is also a source of Zn deficiency in human especially in developing countries where diets are cereal based and poor in animal and fish products (Cakmak et al., 1999; Fageria et al., 2002). The yield losses due to Zn deficiency have been estimated as 40% or more in many Zn deficient soils (Alloway, 2008) which have drastic economic impact on the farming community and result in reduced income due to lost yield. The intensive farming always involves expensive inputs like seed, fertilizers, pesticides and water resulting in high cost of production. Owing to high cost of production and reduced yield such deficiencies grab the major income of the farmers. In countries like Pakistan, where the national exchequer is facing the burden of cost of significant shortfalls in food production, Zn deficiency has also contributed in these shortfalls.

The recent Zn deficiency problem in wheat crop is due to the intensive farming in many developing countries including Pakistan (Imtiaz et al., 2010). Now the farmers prefer to grow new, high yielding crop varieties and use relatively large amounts of fertilizers instead of local crop genotypes and low inputs of nutrients. Many of the new crop varieties are much more susceptible to Zn deficiency than the traditional crops (Imtiaz et al., 2006) and the increased use of fertilizers, especially phosphorus, can result in deficiency of Zn (Alloway, 2008). In some countries like Pakistan, India, Bangladesh, the Philippines and China, the majority of people live on cereals including wheat, rice and maize.

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There is a need to achieve maximum food production through increasing the productivity of the land by ameliorating nutritional stresses like Zn deficiency (Malakouti, 2008). Crops are generally low in Zn particularly when grown on Zn deficient soils. Around 50% of the world cereal soils are deficient in Zn (Graham and Welch, 1996) and it is estimated that one third of the world's population is at risk of Zn deficiency (Brown and Wuehler 2000) which can lead to health problems including poor immune response and impaired growth and development (Kiekens, 1995). Improving the Zn nutritional status of food crops, especially in areas where Zn deficiency in soil is widespread, is a priority for fighting malnutrition or "hidden hunger" in humans and animals.

Zinc deficiency is still a major problem with wheat, often with yields reduced by 50% as found in parts of Turkey (Malakouti, 2008) and Pakistan (Imtiaz et al., 2010). Therefore, the present study was undertaken to determine the relative Zn efficiency of some of wheat genotypes cultivated in Pakistan under hydroponic culture solution and field conditions.

MATERIAL AND METHODS

Solution culture experiment

Twenty wheat genotypes were grown in hydroponic chelate-buffered nutrient solution in a greenhouse with conditions adjusted to 22/15°C day/night temperature, at 12-h photoperiod. The seeds were surface sterilized with sodium hypochlorite (3% active chlorine v/v) (Rengel and Graham 1995a) and germinated on moist filter papers in petri dishes in a dark room at 20±1 °C. Three days after germination, four seedlings of each genotype were transplanted into two holes in white thermo pore sheet of 2 x 2 feet size. The sheet containing the seedling of all 20 genotypes was floating in polyethylene lined stainless steel (SS) container with 20 L chelate buffered nutrient solution.

The chelate-buffered nutrient solutions were the same as those used by the Rengel and Graham (1995a) and contained (in mM) Ca(NO3)2 2000, MgSO4 500, KNO3 1500, KCl 100, MES (2N-morpholinoethanesulphonic acid)-KOH 2000, NH4H2PO4 100, H3BO3 10, Na2MoO4 0.1, K3-N(Z-hydroxyethyle) ethylenedinitrilotriacetic acid (HEDTA) 25, Fe HEDTA 100, Mn HEDTA 1, Cu HEDTA 0.5, Ni HEDTA 0.1. Three concentrations of Zn i.e 0.1, 0.5, and 2.0 µM prepared from Zn HEDTA were added in hydroponic culture solution of different containers to give Zn activities of 2, 10, and 40 pM (Peco molar) to growing seedlings. These Zn activities were used to test the cultivars to get minimum and maximum at any two activities, and to calculate Zn efficiency.

The experiment was set up in a completely randomized design with factorially arranged treatments (20 cultivars with 3 Zn treatments and 4 plants per treatment) with three replications. The plants were initially grown in nutrient solutions containing half strength (50% of concentrations shown in recipe) of all macro- and micronutrients, except for Zn, MES (2(N-Morpholino) ethanesulphonic acid) and K_3 HEDTA (N-(2-hydroxyethyl) ethylenedinitrilotriacetic acid) which were at full strength until day 10, after which the full-strength (concentrations as shown in recipe) solutions were used. The nutrient solutions were replaced with fresh mixtures on days 10, 15, 19, 23 and 27 following transplantation.

The pH values of the solutions were adjusted to 6.0 + 0.01 with 0.1 M HCl or 0.1 M KOH as required. Harvesting of the plants was carried out on day 30 after transplantation. Plants were removed from the pots and separated into root and shoot samples, which were gently washed in three lots of deionized water, followed by a final rinse in double-deionized water. The tissue samples were then air dried on paper towels and later dried in a forced draught oven at 80 ±1 °C for 48 h (until constant weight). The oven-dried samples were finely ground in a Tema mill using acid-washed stainless steel pots and balls. A wet digestion method using concentrated HNO_3 was used for digesting the plant samples (Westerman, 1990), and the concentrations of micronutrients were determined by AAS (NOVA-400, Analytic Gena).

Zinc efficiency was calculated from dry weight at 2 pM Zn^{2+} (minimum shoot dry matter)/dry weight at 40 pM Zn^{2+} (maximum shoot dry matter) expressed in percent (Rengel and Graham, 1995a). The Zn-efficiency classes were constructed by finding the median values of the trait under consideration (an average between data for genotypes ranked 10 and 11) and creating a medium-efficiency interval as median ± S.E. of the genotype effect. Genotypes with data falling above or below that medium interval were classed as Zn efficient or Zn inefficient, respectively. The data were analyzed by analysis of variance using routines of the GENSTAT 5 program. The least significant difference $(LSD)_{0.05}$ was calculated only when the F value was significant at $P \leq 0.05$.

Field

Ten genotypes used in the solution culture study (4 Zn-efficient, 1 medium, 5 Zn-inefficient) were tested at two levels of Zn (0, 5 kg ha^{-1}) under field conditions. Prior to initiation of experiment, soil samples were collected from different fields and analyzed for available Zn so as to select Zn deficient site. The available Zn in experimental site was 0.35 µg g^{-1}. The soil also contained 0.72% organic matter, 7.2 µg g^{-1} Olsen P having pH 8.0 and ECe 1.3 dSm^{-1}. Phosphorus at a rate of 90 kg P ha^{-1} was applied in basal to the entire experimental site at the time of sowing; whereas, N (120 kg ha^{-1}) was applied at the time of sowing (half) and the remaining half during first irrigation (Zadoks stage 22). Agronomic activities like hoeing and weeding were carried out on regular interval

Table: 1 Effect of Zn activities on plant height, number of tillers and DM accumulation in chelate-buffered nutrient solution

Cultivars	Plant Height (cm)		Number of tillers		Shoot DM (g/pot)		Root DM (g/pot)	
	-Zn (2pM)	+Zn (40pM)	-Zn (2pM)	+Zn (40pM)	-Zn (2pM)	+Zn (40pM)	-Zn (2pM)	+Zn (40pM)
Pak -81	45	64	6	7	3.80	7.17	1.85	1.87
SD-668	46	65	7	10	4.87	6.74	2.20	2.80
SD-669	48	67	6	8	5.88	7.78	1.81	1.93
SD- 670	42	64	5	8	5.65	8.15	1.90	2.09
SD-1200/19/1	41	61	5	7	3.74	6.25	2.29	1.88
SD-1200/51	45	65	6	8	3.84	6.32	1.82	1.60
SD-4047/1	46	62	6	9	4.97	7.46	1.87	1.89
SD-4085/3	47	66	6	8	7.13	9.85	2.53	2.66
SD-8006	51	67	7	9	7.20	8.53	2.38	2.05
SD-8012	49	71	5	8	5.13	6.15	2.76	1.43
T1	42	62	5	8	4.10	6.87	2.14	2.33
T9	43	62	8	14	4.73	7.27	2.36	2.31
T10	42	61	8	11	4.50	6.40	2.78	2.07
T11	38	60	4	9	2.98	7.10	2.67	2.05
T17	46	66	5	8	4.52	8.32	2.14	2.49
T19	39	58	8	14	5.21	10.15	3.25	2.39
T20	39	59	8	14	5.26	10.73	3.18	3.05
T21	37	58	7	13	3.41	8.23	3.26	2.30
T23	46	64	7	11	7.39	13.57	2.30	2.86
T25	41	60	8	15	6.35	13.06	2.44	3.06
LSD *(P≤0.05)*								
Cultivars	1.65		2.66		0.72		0.49	
Zn activities	1.32		2.12		0.56		0.39	
Cultivars x Zn	2.77		4.46		1.21		0.83	

as and when required till maturity. To harvest good crop 5 irrigations were also applied. At maturity, dry matter and grain yield was recorded and plant samples were collected for further analysis. Zn efficiency was calculated as described by Rengel and Graham (1995a). Five plants were selected at random from each treatment and were mixed to make a composite sample.

These plants were then separated in grains and stalks and oven dried at 80 ±1 °C. The oven-dried samples were finely ground in a Tema mill using acid-washed stainless steel pots and balls. Single acid (concentrated HNO_3) wet digestion method was used for digesting the plant samples (Westerman, 1990), and the concentrations of micronutrients were determined by AAS (NOVA-400, Analytic Gena).

RESULTS

Hydroponic Culture Study

Zinc deficiency symptoms

The symptoms of Zn deficiency under hydroponic culture solution were more severe, with a symptom of whitish-brown necrotic spots on the middle parts of the leaves occurred after reduction in shoot elongation. In earlier study, Cakmak et al. (1998) also reported similar symptoms on (wheat). In the advanced stages of deficiency, these necrotic spots joined to form a strip of dead cells along the entire leaf, causing twisting on the leaves in line with Imtiaz et al.,(2006). In acute cases of deficiency (Zn-inefficient cultivars), the death of affected leaves was also noted. However, the time of appearance and severity of Zn-deficiency symptoms varied among the cultivars used in the study.

Shoot Growth

Shoot dry matter (DM) and growth parameters of crop are presented in Table 1. The yield parameters like plant height and number of tiller (only from hydroponic culture solution study) increased significantly ($P \leq 0.05$) with each increment of Zn^{2+} activity. It is obvious from the data that the cultivars ranked as Zn efficient had taller plants at 2pM Zn^{2+} compared to Zn inefficient ones whereas, Zn inefficient genotypes have significantly ($P \leq 0.05$) higher number of tillers per plant at sufficient Zn level (40pM Zn^{2+}).

Three different levels of Zn^{2+} activity in solution had a significant effect on the growth of the wheat plants. In the hydroponic culture solutions with higher Zn^{2+} activities, the plants showed enhanced growth and dry matter (DM) production. In the Zn deficient solutions (2 pM Zn^{2+}), shoot dry matter production was distinctly lower

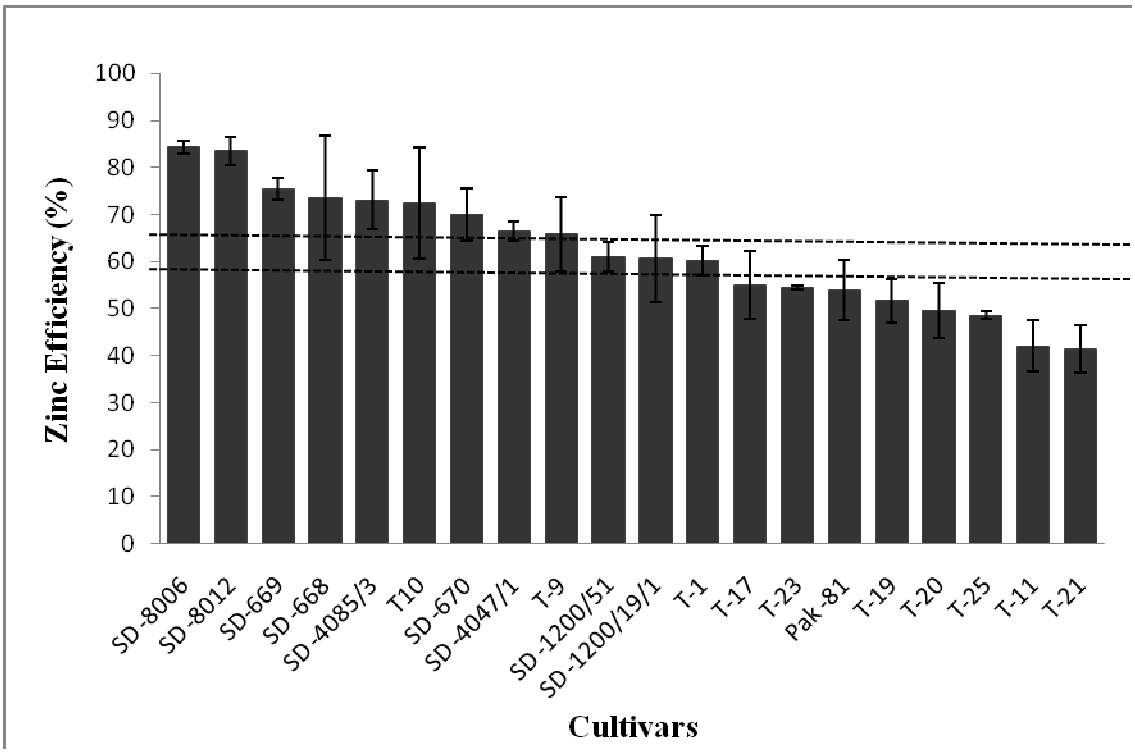

Figure 1: Zinc efficiency (%) of different genotypes grown in chelate-buffered nutrient solution

(Table1). The lowest shoot dry weight (2.98 g/pot) at 2 pM Zn^{2+} was recorded for genotype T-11 which was significantly lower than all other genotypes. The genotype T-23 accumulated maximum DM of 7.39 g/pot at 2 pM and at this level of activity cv. SD-8006 also had higher DM which was 7.20 g/pot. At Zn sufficient levels, the genotypes later classified as Zn inefficient have produced significantly (P≤ 0.05) higher dry matter. Large variations in dry matter production at the Zn-deficient level (2 pM Zn^{2+}) were observed within the cultivars, which may be due to variations in the severity of Zn-deficiency symptoms and depressed photosynthesis (Imtiaz et al., 2006).

Root Growth

Root DM yields varied significantly (P≤0.05) between the wheat cultivars. At 2 pM Zn^{2+}, T-21 that produced maximum root dry matter of 3.26 g/pot while the cultivar SD-669 had the lowest root dry matter (1.81 g/pot). As the level of Zn activity in the solution increased, root DM production of cultivars also increased. Zn-inefficient cultivars such as T-11, T-20 and T-21 showed the largest reduction in root dry matter in Zn-deficient solutions (2 pM Zn^{2+}) compared to the Zn-sufficient level (40 pM Zn^{2+}). In contrast, the Zn-efficient cultivars SD-8006, SD-8012 and SD-669 showed only a slight or no reduction in the root dry matter. Root growth of inefficient cultivars was impaired by Zn deficiency, and the roots of these cultivars appeared smaller and more fibrous than those of efficient cultivars. These results are in line with those of Rengel and Graham (1995a).

Zinc efficiency (%)

Zinc efficiencies in different genotypes varied between 41to 84% in hydroponic culture solution study which correspond with the severity of Zn deficiency symptoms (Figure 1). The genotype T-21 showed the lowest Zn efficiency of 41%, while SD-8006 had 84% Zn efficiency which was the maximum. Out of 20 genotypes tested in solution culture, nine genotypes were identified as Zn efficient, and eight as Zn-inefficient while the rest of genotypes were medium in efficiency.

Nutrient Concentrations

Zinc concentration

Zinc concentrations in the shoots of the different cultivars varied between 7.7 µg g^{-1} (at 2 pM Zn^{2+}) and 70.8 µg g^{-1} (at 40 pM Zn^{2+}), however, considerable variation was more observed in Zn concentrations at 2 pM Zn^{2+} activity. Generally, the Zn-inefficient cultivars had lower Zn concentrations than the Zn-efficient ones (Table-2).

Table 2: Concentration of elements in shoot of wheat as affected by various Zn activities in chelate-buffered nutrient solution

Cultivars	Zn Concentration µg g^{-1}		Zn Uptake µg/pot		Fe Concentration µg g^{-1}		Cu Concentration µg g^{-1}		Mn Concentration µg g^{-1}		P Concentration µg g^{-1}	
	-Zn (2pM)	+Zn (40pM)	-Zn (2pM)	+Zn (40pM)	-Zn (2pM)	+Zn (40pM)	-Zn (2pM)	+Zn (40pM)	-Zn (2pM)	+Zn (40pM)	-Zn (2pM)	+Zn (40pM)
Pak -81	9.4	35.8	35.8	257.0	295.5	310.4	35.0	21.1	124.0	109.8	0.39	0.16
SD-668	15.9	36.0	78.1	242.4	310.0	251.8	36.8	22.0	121.0	106.5	0.35	0.20
SD-669	13.4	39.9	78.6	310.6	284.5	264.3	32.1	21.3	141.7	104.6	0.46	0.28
SD- 670	10.5	36.3	59.5	296.2	294.2	337.2	35.8	22.8	128.3	109.5	0.34	0.19
SD-1200/19/1	7.6	39.9	28.3	249.2	334.8	347.5	32.0	20.7	124.3	113.7	0.45	0.19
SD-1200/51	10.9	43.4	41.9	274.3	338.0	289.4	35.2	24.1	130.3	107.3	0.43	0.22
SD-4047/1	9.7	36.5	48.2	272.4	316.8	329.2	31.5	22.9	137.3	102.9	0.40	0.21
SD-4085/3	10.9	43.4	77.9	427.6	285.7	287.4	37.6	24.8	140.0	102.3	0.41	0.31
SD-8006	13.3	36.0	95.5	307.3	320.9	343.8	37.5	24.8	147.0	104.4	0.32	0.25
SD-8012	14.0	69.2	71.9	425.8	315.3	235.6	37.7	23.5	149.3	109.1	0.36	0.21
T1	10.7	70.8	43.9	486.4	356.8	357.7	34.0	21.5	149.0	103.9	0.44	0.14
T9	9.7	35.7	45.8	259.3	334.4	320.0	32.3	21.6	121.0	100.4	0.34	0.29
T10	12.7	36.2	56.9	231.4	265.2	249.7	33.4	21.2	120.7	107.8	0.34	0.29
T11	8.8	33.2	26.2	235.4	264.4	370.5	37.3	22.4	110.7	99.5	0.45	0.26
T17	8.8	33.2	39.8	276.1	282.7	357.3	34.6	23.3	121.0	98.5	0.34	0.28
T19	10.7	38.8	55.6	393.4	266.5	344.3	34.6	22.5	133.7	101.6	0.32	0.17
T20	8.6	35.6	45.1	382.3	289.1	299.6	35.4	24.4	107.3	108.0	0.35	0.16
T21	9.4	37.1	27.9	305.6	314.5	293.7	33.9	21.5	165.3	101.8	0.56	0.27
T23	14.3	57.6	94.6	781.8	275.3	239.6	33.4	24.9	114.3	99.1	0.53	0.29
T25	7.7	36.8	48.7	481.1	266.2	303.7	34.5	23.6	122.7	100.1	0.42	0.24
LSD (*P≤0.05*)												
Cultivars	1.12		23.84		22.53		2.08		6.60		0.076	
Zn activities	0.89		18.98		17.94		1.66		5.25		0.061	
Cultivars x Zn	1.88		39.94		37.75		3.49		11.05		0.128	

Zinc concentration in Zn inefficient genotypes at 2 pM Zn^{2+} activity ranged between 7.7 to 10.7 µg g^{-1}, whereas it varied up to 14.0 to 15.9 µg g^{-1} in Zn efficient genotypes. The genotype T-25 has accumulated 7.7 µg g^{-1} Zn which was significantly (P≤0.05) lower than all genotypes whereas SD-688 has accumulated the highest Zn concentration of 15.9 µg g^{-1}.

Zinc concentrations in the roots were also higher with elevated Zn^{2+} activities. Generally, roots had higher Zn concentrations than shoots. Zinc-inefficient cultivars such as T-17, T-19 and T-25 accumulated either similar or greater amounts of Zn in the roots compared with Zn-efficient varieties such as SD-8006 and SD-669 but translocated smaller amounts to the shoot.

Concentration of Cu, Fe, Mn and P

The concentrations Fe, Mn, and Cu in shoots of all the genotypes at the Zn-deficient level (2 pM Zn^{2+}) varied significantly (P≤0.05). In contrary to previous study (Imtiaz et. al. 2006) cultivars showed significantly (P≤0.05) higher concentrations of Fe at low Zn^{2+} activity than at sufficient Zn^{2+} activity. However, there was no significant (P≤0.05) difference in Fe concentration between Zn efficient and inefficient genotypes at low Zn^{2+} activity (2 pM Zn^{2+}) which might be due to different genetic material and difference in Zn concentrations at that particular level. Some of the Zn-inefficient genotypes have higher Fe concentration at low activity while some of the Zn efficient genotypes have higher concentration than Zn inefficient ones. However, genotypes

medium in Zn efficiency have higher Fe concentration than other two categories. Iron, Mn, Cu and P concentrations in the shoots of the Zn¬ sufficient plants were signifi¬cantly (P≤0.05) lowered at higher Zn activities and Zn-deficient plants had higher Mn, Cu and P concentrations (Table-3). Similar observations were reported by Rengel et al., (1998) while studying uptake of zinc and iron by wheat genotypes differing in tolerance to zinc deficiency and indicating the strong antagonism between these elements. Iron, Mn, Cu and P concentrations in the roots of different cultivars were also significantly affected (P≤0.05) by the levels of Zn activity, and significant (P≤0.05) differences were observed between the cultivars. With few exceptions (T-11, T-19 and T21), most of the Zn-inefficient cultivars generally had lower concen¬trations of the micronutrients in their roots than the Zn-efficient ones.

Zinc uptake

Total contents of Zn (uptake) also varied significantly (P=0.05) from cultivar to cultivar. Zinc application increased Zn uptake by the cultivars. A significant interaction between cultivars and Zn showed that all cultivars differed in Zn uptake at both levels of Zn application. The uptake of Zn in plant shoots (Table-2) varied between 26.2 µg/pot and 95.5 µg/pot at Zn deficient level. The genotype SD-8006 took up more Zn than all other cultivars whereas T-11 accumulated the least.

Field Study

Deficiency Symptoms and Biological Yield

Under field conditions, apart from stunted growth, the plants also showed chlorosis (Brown et al., 1993) which affected the biological yield drastically. In general, the biological yield increased with increasing Zn level up to 5 kg ha^{-1} however, response of different genotypes was variable (Alloway, 2008). A significant variation in biomass production was recorded among the genotyped at both levels of Zn (Table-4). The wheat genotype SD-4085 produced the highest biological yield of 19.5 t ha^{-1} with application of 5 kg Zn ha^{-1}, which was significantly (P=0.05) higher than the rest of the genotypes. The same genotype (SD-4085) gave 16.67 t ha^{-1} biological yield when not applied with Zn (control) and this yield was significantly (P=0.05) lower than other genotypes under study. Similarly, the wheat genotype T-20 produced the minimum biological mass of 10.67 t ha^{-1} at Zn deficient level which was escalated to 14.67 t ha^{-1} with the application of 5 kg Zn ha^{-1}. Zinc inefficient genotypes were generally more responsive to Zn application as compared Zn efficient ones (Table-1 and 4).

Grain Yield

The crop was harvested at maturity and the Zn efficiency was calculated on the basis of grain production at Zn deficient and Zn sufficient levels (Table-4). The grain yield of the genotypes was significantly (P=0.05) increased by the application of Zn (Imtiaz et al., 2010), however, the response of Zn-inefficient genotypes to the application of Zn was very conspicuous as compared to the Zn-efficient ones. The Zn-inefficient genotypes T-21 and T-11 produced the highest grain harvest of 6.3 t ha^{-1} and 6.4 t ha^{-1} at 5 kg ha^{-1} Zn level however, the yield of these genotypes reduced to 3.6 and 4.6 t ha^{-1} when grown without Zn. On the other hand, the Zn-efficient genotypes were less responsive to Zn application as the grain harvest of SD-8006 and SD-8012 was 5.6 and 5.2 t ha^{-1} with the application of Zn. The grain yield of these genotypes recorded without Zn was 5.3 t ha^{-1} and 5.0 t ha^{-1}.

Zinc efficiency (%)

Ten wheat genotypes (classified as Zn efficient, and Zn-inefficient in hydroponics study) were tested under field condition to assess any change in their Zn efficiency or in their response to Zn fertilization. The efficiency of these genotypes was enhanced under field as compared to the hydroponics conditions which varied between 57.4 to 96.1% (Table-5). However, these genotypes maintained their ranking of Zn efficiency assigned to them in hydroponics study. These results are similar to those Cakmak et al. (1998) and Rengel and Graham (1995 a) who found variation in Zn efficiency of different wheat genotypes.

Zinc Concentration

The results of the study revealed that Zn concentrations increased in the grain with application of Zn to the soil (Table-5). Zinc efficient genotypes had accumulated significantly higher concentrations of Zn in the grain at Zn deficient level as compared with Zn inefficient genotypes. Maximum Zn accumulation of 16.61 µg g^{-1} was recorded in the grains of Zn-efficient cv. SD-4085 at no Zn application, while the same was only 8.21 µg g^{-1} for T-20, a Zn inefficient genotype. These results are in agreement with earlier report of Cakmak et al. (1998) under Zn deficiency conditions, Zn-efficient cultivars accumulated more Zn than inefficient cultivars.

Zinc uptake

Total contents of Zn (uptake) also varied significantly (P=0.05) from cultivar to cultivar. Zinc application also

Table 3: Concentration of elements in root of wheat as affected by various Zn activities in chelate-buffered nutrient solution

Cultivars	Zn Concentration µg g^{-1}		Zn Uptake µg/pot		Fe Concentration µg g^{-1}		Cu Concentration µg g^{-1}		Mn Concentration µg g^{-1}		P Concentration µg g^{-1}	
	-Zn (2pM)	+Zn (40pM)	-Zn (2pM)	+Zn (40pM)	-Zn (2pM)	+Zn (40pM)	-Zn (2pM)	+Zn (40pM)	-Zn (2pM)	+Zn (40pM)	-Zn (2pM)	+Zn (40pM)
Pak -81	16.5	37.4	30.5	70.9	303.0	419.7	174.9	105.3	124.0	178.3	0.88	0.78
SD-668	19.6	37.9	43.0	105.6	317.0	304.0	184.0	110.0	121.0	178.0	0.96	0.75
SD-669	15.8	51.1	29.6	98.7	402.0	304.0	160.7	106.3	141.7	187.7	0.78	0.79
SD- 670	20.1	64.2	38.0	134.9	359.3	404.3	179.0	114.0	128.3	160.7	0.84	0.66
SD-1200/19/1	18.1	62.6	41.2	118.2	381.7	392.0	160.0	103.7	124.3	177.3	0.89	0.72
SD-1200/51	12.3	42.9	22.6	68.7	397.0	388.0	176.0	120.7	130.3	180.3	0.95	0.80
SD-4047/1	17.0	46.4	30.7	87.2	402.3	372.7	157.7	114.7	137.3	183.0	0.97	0.78
SD-4085/3	17.6	42.7	44.4	113.1	409.3	310.7	188.0	124.0	140.0	190.3	0.87	0.75
SD-8006	14.4	37.6	34.0	77.3	422.3	417.3	187.7	124.0	147.0	177.7	0.77	0.77
SD-8012	13.4	44.9	36.9	63.9	380.7	393.3	188.3	117.7	149.3	158.0	0.77	0.85
T1	12.9	43.7	27.6	101.7	393.0	378.0	170.0	107.7	149.0	160.3	0.85	0.91
T9	13.3	42.0	31.4	96.9	379.0	317.3	161.3	108.0	121.0	195.7	0.85	0.76
T10	16.0	42.1	44.4	86.8	379.3	373.3	167.0	106.0	120.7	174.3	0.84	0.77
T11	16.6	36.1	44.1	73.4	372.7	377.7	186.7	112.0	110.7	187.3	0.80	0.53
T17	13.0	60.4	28.3	150.1	370.7	343.3	173.0	116.7	121.0	189.0	0.93	1.00
T19	15.1	66.3	49.3	157.0	405.7	386.0	173.0	112.7	133.7	177.0	0.90	0.81
T20	12.3	54.9	39.2	168.1	387.3	347.7	177.0	122.0	107.3	158.0	0.89	0.81
T21	12.9	68.0	29.0	155.4	392.3	323.7	169.3	107.3	165.3	137.7	0.88	0.47
T23	17.5	45.5	40.2	129.9	404.3	295.7	167.0	124.7	114.3	174.7	0.87	0.72
T25	19.2	42.0	46.7	127.6	391.3	311.0	172.7	118.0	122.7	159.0	0.88	0.76
LSD (*P≤0.05*)												
Cultivars	1.73		17.17		6.40		0.79		13.74		0.121	
Zn activities	1.38		13.67		5.09		0.63		10.94		0.096	
Cultivars x Zn	2.89		28.76		10.72		1.32		23.02		0.202	

Table 4. Biological and grain yield of different wheat genotypes as affected by Zn

Variety	Biological yield t ha^{-1}		Grain yield t ha^{-1}	
	Zn-0	Zn-5 kg ha^{-1}	Zn-0	Zn-5 kg ha^{-1}
SD-8006	12.3	14.7	5.3	5.6
SD-8012	11.0	13.5	5.	5.2
SD-4085	16.7	19.5	4.9	5.4
T-10	11.3	14.0	5.1	5.6
Pak-81	11.8	14.3	4.9	5.3
SD-1200/51	13.5	15.3	4.9	5.5
T-19	10.7	14.7	4.8	5.5
T-20	11.7	17.0	5.1	6.0

Table 4 Cont.

T-11	12.2	17.0	4.6	6.4
T-21	11.3	17.0	3.6	6.3
LSD (*P≤0.05*)				
Cultivars	1278		398	
Zn levels	571		178	
Cultivars x Zn	1807		563	

Table5: Effect of Zn application on Zn efficiency and Zn contents in wheat genotypes under field conditions

Variety	Zn Efficiency (%)	Zinc Concentration		Zinc uptake	
		Zn-0	Zn-5 kg ha^{-1}	Zn-0	Zn-5 kg ha^{-1}
SD-8006	95±0.47	12.8	52.3	67.6	291.2
SD-8012	96±0.17	16.6	53.5	83.1	277.9
SD-4085	91±3.75	11.5	32.2	55.8	173.1
T-10	92±3.08	16.3	41.1	83.8	230.4
Pak-81	92±3.63	12.1	31.6	58.7	168.6
SD-1200/51	91±2.90	12.9	65.9	64.2	360.2
T-19	88±1.98	13.3	54.4	64.7	301.3
T-20	85±2.24	8.2	29.7	42.1	178.3
T-11	72±4.77	9.7	25.2	44.5	161.2
T-21	57±1.09	8.9	27.7	32.0	173.5
LSD (*P≤0.05*)					
Cultivars		2.81		20.10	
Zn activities		1.25		8.99	
Cultivars x Zn	--	3.97		28.44	

increased Zn uptake by the cultivars. The genotype T-10 took up significantly (P=0.05) higher Zn content (83.83 g ha^{-1}) compared to all other cultivars (Table-5), whereas T-21 accumulated the least (32.02 g ha^{-1}). The genotype which assimilated the maximum Zn from soil at Zn deficient level was T-10 in contrast to SD-8006 which took up maximum Zn in hydroponic culture solution study (Table-2). The least accumulators of Zn in both studies were also different. The results are in agreement to those reported by Graham et al. (1997) and Imtiaz et al. (2006).

Discussion

The degree of severity of overt symptoms of Zn deficiency on plants under field and hydroponic culture solution conditions was different. The symptoms were more severe onn plants in hydroponic culture solution compared to those under field conditions. The first and common symptom in both cases was a reduction in shoot elongation and leaf size (Pearson and Rengel, 1997; Cakmak et al., 1997). The development of whitish brown necrotic patches on the middle part of the leaves was also characteristic of Zn deficiency in plants grown in hydroponic culture solution (Imtiaz et al., 2006). Although, the symptoms were not as severe as in hydroponic culture solution, the older leaves became chlorotic and lacked chlorophyll (Brown et al., 1993). Zn efficiency in different cultivars varied between 41 to 84% when calculated from shoot dry matter obtained from hydroponic culture solution study.

The cultivars with severe leaf symptoms showed a greater dry matter reduction and had a lower Zn efficiency. The genotype T-21 showed the lowest Zn efficiency (41%) whereas SD-8006 had the highest Zn efficiency of 84% (Table-5). The intensity of appearance of deficiency symptoms on these genotypes was coinciding with efficiency ranking later assigned to them. These results are similar to those of Cakmak et al. (1998) and Rengel and Graham (1995a).

Ten wheat genotypes (classified as Zn efficient and Zn-inefficient in hydroponics study) were tested under field condition to assess any change in their Zn efficiency or in their response to Zn fertilization. The efficiency of these genotypes was enhanced under field condition compared to the hydroponics conditions which varied between 57 to 96%. Although, these genotypes maintained their ranking of Zn efficiency assigned to them in hydroponics study, there was a little shift in efficiency of Zn efficient genotypes as in field study the genotypes SD-8012 was the most Zn efficient while in hydroponic culture solution the SD-8006 was the most Zn efficient one. The possible reason for enhanced Zn efficiency in field could be the complex nature of the soil. Different mechanisms of Zn efficiency operate in a Zn-deficient soil than in a Zn-deficient nutrient solution.

The wheat cv. Excalibur was the most Zn-efficient genotype of those tested by Graham and Rengel (1993)

Table 6: ANOVA for genotype into Zn activities interaction of different parameters for hydroponic and field study

Parameter	Df	EMS	F-value	P-Value
Shoot				
Plant height	38	9.46	3.3714	0.0000
Number of tillers	38	7.267	2.5299	0.0001
DM	38	0.536	4.6893	0.0000
Zn concentration	38	198.268	1.289	0.0000
Zn uptake	38	583.965	36.5045	0.0000
Fe concentration	38	521.533	5.9936	0.0000
Cu concentration	38	4.445	11.1555	0.0000
Mn concentration	38	44.730	9.6988	0.0000
P concentration	38	0.006	1.876	0.0056
Root				
DM	38	0.253	1.4679	0.0612
Zn concentration	38	3.070	39.4650	0.0000
Zn uptake	38	302.664	906.188	2.9940
Fe concentration	38	42.033	102.5511	0.0000
Cu concentration	38	0.640	92.5422	0.0000
Mn concentration	38	193.987	4.0647	0.0000
P concentration	38	0.015	1.2038	0.2241
Field Study				
Biological yield	9	1194737	2.42	0.0279
Grain yield	9	116090	7.94	0.0000
Zn concentration	9	0.55094	1.08	0.3986

in a Zn-deficient soil but was found to be the least Zn-efficient in chelate-buffered nutrient solution studies in our earlier study (Imtiaz et al., 2006). In a Zn-deficient soil, the cv. Excalibur has the ability to produce a greater number of roots of smaller diameter (<0.3 mm) (smaller roots have greater surface to volume ratio) than cultivars shown to be Zn-inefficient (Graham and Rengel, 1993). This would allow exploration of a larger volume of soil and hence more efficient scavenging of the small amounts of immobile Zn ions by the cv. Excalibur rendering it Zn efficient which was not possible in solution. The same difference may have existed in our present study for enhancement in Zn efficiency in soil compared to hydroponic culture solution.

It seems very likely that the expression of high Zn efficiency in cereals is associated with an enhanced uptake capacity (Zn contents) for Zn (Cakmak et al. 1998). The capacity of cultivars to absorb and translocate Zn to the shoot at higher rates under a deficient supply of Zn is therefore an important trait determining expression of Zn efficiency. It is also pertinent to note that dilution of Zn in Zn efficient was a very key factor which reduces the Zn concentration in plant (Rengel and Graham, 1995b) especially at Zn deficient level Table 6.

CONCLUSION

It evident from this study that the chelate-buffered nutrient technique used for screening of wheat genotypes for Zn efficiency is a reliable as the results from this technique are similar to those obtained from field cultivation. Zinc inefficient genotypes were more responsive to application of Zn and their grain yield was increased manifold as compared to Zn efficient one. The growers may apply 5 kg Zn ha^{-1} at the time of sowing if they are unaware of Zn efficiency of cultivar so that they can get better yield and quality of produce.

REFERENCES

Alloway BJ (2008). Zinc in soil and crop nutrition. www.2008_IZA_IFA_ZincInSoils.pdf.

Brown KH, Wuehler SE (2000). Zinc and human health: Results of recent trials and implications for program interventions and research. The Micronutrient

Initiative/International Development Research Centre, Ottawa.

Brown PH, Cakmak I, Zhang Q (1993). Forms and function of zinc in plants. In Zinc in soils and plants. (Ed.) R. D. Robson. Kluwer Academic Publisher, Dordecht. pp107-117.

Cakmak I, Kalayci MH, Ekiz, Braun HJ, Kiline Y, Yilmaz A (1999). Zinc deficiency as a practical problem in plant and human nutrition in Turkey. A NATO-science for stability project. Field Crops Research, 60:175-188.

Cakmak I, Öztürk L, Eker S, Torun B, Kalfa, HI, Yilmaz A (1997). Concentration of Zn and Activity of Copper/Zinc Superoxide Dimutase in the leaves of Rye and Wheat Cultivars Differing in Sensitivity to Zinc Deficiency. J. Plant Physiol. 151:91-95.

Cakmak I, Torun B, Erenoglu B, Öztürk L, Marschner H, Kalayci M, Ekiz H, Yilmaz A (1998). Morphological and physiological differences in the response of cereals to zinc deficiency. Euphytica 100:349-357.

Fageria NK, Baligar VC, Clark RB (2002). Micronutrients in crop production. Advances in Agronomy 77: 185–268.

Gao X, Kuyper TW, Zou C, Zhang F, Hoffland E (2007). Mycorrhizal responsiveness of aerobic rice genotpes is negatively correlated with their zinc uptake. Plant and Soil, 290:283-291.

Graham RD, Welch RM (1996). Breeding for the staple food crops with high micronutrient density. Agricultural Strategies for Micronutrients, Working Paper No.3. IFPRI, Washington, DC.

Graham RD, Senadhira D, Monosterio IO (1997). A strategy for breeding staple-food with high micronutrient density. Soil Scie. Plant Nutr. 43:1153-1157.
Imtiaz M, Alloway BJ, Khan P, Memon MY, Siddiqui SH, Aslam M, Shah KH (2006). Zinc deficiency in selected cultivars of wheat and barley as tested in solution culture. Comm.Soil Sci. & Plant Anal., 23(11-12): 1703-1721.
Imtiaz M, Rashid A, Khan P, Memon MY, Aslam M (2010). The role of micronutrients in crop production and human health. Pak. J. Bot., 42(4): 2565-2578.
Kiekens L (1995) Zinc In Heavy Metals in Soils (Ed.) B. J. Alloway Blackie Academic and Professional, London.
Malakouti MJ (2008). The effect of micronutrients in ensuring efficient use of macronutrients. Turk. J. Agric. For., 32: 215-220.
Pearson JN, Rengel Z (1997). Genotypic differences in the production and partitioning of carbohydrates between shoot and roots of wheat grown under zinc or manganese deficiency. Annals of Bot.80:803-808.
Rengel Z, Graham RD (1995). Wheat genotypes differ in Zn efficiency when grown in chelate-buffered nutrient solution. I. growth. Plant and Soil 176:307-316.
Rengel Z, Graham RD (1995). Wheat genotypes differ in Zn efficiency when grown in chelate-buffered nutrient solution. II. Nutrient uptake. Plant and Soil 176:317-324.
Rengel Z, RÖmheld V, Marschner H (1998). Uptake of zinc and iron by wheat genotypes differing in tolerance to zinc deficiency. Physiologia Plantarum, 152:433–438.
Westerman RL (1990). Soil Testing and Plant analysis (Ed). Soil Sci. Soc. Am. Inc. Madison, Wisconsin, USA