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GENOTYPIC VARIATION IN ZINC EFFICIENCY (ZE) OF WHEAT GENOTYPES UNDER CULTURE SOLUTION AND FIELD CONDITIONS

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ABSTRACT

An experiment was executed to assess the relative zinc (Zn) efficiencies of advanced wheat lines in chelate-buffered hydroponic culture solutions and field conditions. Zinc efficiency was evaluated by comparing their dry matter production in a Zn-deficient medium relative to that in a Zn sufficient medium. Zinc efficiency (ZE) of 10 genotypes varied between 26.7 to 70.4% in chelate buffered nutrient solution but it was escalated from43.6 to 75.8% when grown in field. The NRL-0517 was the most efficient genotype whereas NRL-1243 was the least efficient. The Zn efficient genotypes had the capability to grab more Zn from low Zn source and translocate it in greater amount to the entire plant. The results also suggested that antagonistic effect between Zn and other elements (like P) was weaker in Zn efficient genotypes which enabled Zn to move at higher ratio from roots to shoot. Zn- inefficient genotypes had extracted lesser Zn from Zn deficient medium and ratio of its translocation was also lower with strong antagonism with other elements.

Keywords: efficiency, translocation, genotypes, hydroponic, wheat, zinc

INTRODUCTION

Zinc (Zn) deficiency is a yield limiting constraint for wheat production in several countries, such as Australia (Graham *et al*., 1992), Turkey (Cakmak *et al*., 1996a, 1999), India (Takkar *et al.,* 1989), and Pakistan (Imtiaz *et al.,* 2014). Less available Zn to roots of plant instead of lesser Zn amounts in soils is the main cause for the prevalent Zn deficiency in calcareous soils. Higher pH, high amounts of $CaCO_3$, and lower organic matter contents and lower soil moisture are the predominant causes of low availability of Zn to plant roots (Marschner, 1993) which restrict its uptake (Rengel and Wheal, 1997). Low Zn concentration in wheat grain also decreases its nutritional quality and adds to malnutrition in population, mostly in poor countries where wheat (cereal) is major staple food (Graham and Welch, 1996).The recent aggravated Zn deficiency menace in wheat is also by the regorus farming in many developing countries like Pakistan (Imtiaz *et al.,* 2010). Now the growers like to grow advanced crop varieties with high yield potential and use greater amounts of fertilizers instead of local crop

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breeds with lower nutrient fertilizers. Fair number of the new crop varieties is highly prone to Zn deficiency than the customary crop cultivars (Imtiaz *et al.,* 2006) and the increased use of fertilizers, especially phosphorus, can result in deficiency of Zn (Alloway, 2008).

Great genetic variation exists among the plant species to maintain ample growth and production in Zn stress environment and it has been characterized as Zn efficiency (Graham and Rengel, 1993). Wheat being generally less Zn efficient, variation in Zn efficiency within the genotypes has been reported, mainly in bread wheat (Shukla and Raj, 1974; Graham *et al.,* 1992; Rengel and Graham, 1995a; Cakmak *et al.,* 1996b). Mostly differences in ZE among wheat genotypes are due to variations in absorption of zinc, probabely due to the release of phytosidrophres by the roots or variations in root surface area (Cakmak *et al.,* 1994; Rengel and Wheal, 1997). Exploration of variations ZE within wheat varieties have generally been probed either in a glasshouse or growth chambers in pot or hydroponics. It is worth to compare changes if any in ZE of wheat varieties grown under field and glasshouse environment as little or no information is available on the subject. This experiment was, therefore, undertaken to study: (a) the effect of Zn activities on wheat genotypes in hydroponic system and of Zn fertilizer in a Zn-deficient calcareous soil under field conditions; (b) and to find any change in ZE of cultivars grown in both environments.

MATERIALS AND METHODS

Solution culture experiment

Chelate-buffered nutrient solution was chosen to test ten wheat genotypes (Bakhtawar-92, NRL-1006, NRL-1009, NRL-1013, NRL-1027, NRL-1028, NRL-1241, NRL-1242, NRL-1243, NRL-0517) for ZE in a greenhouse at day/night temperature of 22 and 15°C, respectively and twelve hour light period. The chelate-buffered nutrient solutions contained the activities of different as described in our previous study (Imtiaz *et al.,* 2014). Three Zn activities of 2, 10, and 40 pMas measured by GEOCHEM PC computer program were applied to the plants in the culture solutions. Sodium hypochlorite was used to sterilize the seeds and after germination in Petri dishes in an incubator at 20 $\pm$1 ^{o}C, three days old seedlings of each variety were transferred to white thermo pore sheet. These sheets were floated in stainless steel container filled with forty litres of chelate-buffered nutrient solution.

Primarily the seedling were applied in nutrient 1/2 strengths solutions of all macro and micronutrients excluding Zn and K_3 HEDTA which were applied at full strength until day 10. After that the full-strength solutions were used. Fresh nutrient solutions were applied on days 10, 15, 19, 24, 28 and 32, following transplantation with pH 6.0 $\pm$0.01. The plants were harvested on day 35 after transplantation. The plant parts (roots and shoots) were placed on tissue papers to dry and then in a forced draught oven at 70 $\pm$ 1°C for 48 hours (until constant weight).The dried samples were then digested by single acid (concentrated HNO_3) method described by Westerman, 1990. The concentrations of micronutrients were assessed by AAS (Perkin Elmer, Aanalyst 700). The ZE was determined by dry weight at 2 pM Zn^{2+} (minimum shoot dry matter) and deviding it on dry weight at 40 pM Zn^{2+} (maximum shoot dry matter) (Rengel and Graham, 1995a). The GENSTAT 5 program was used to calculate least significant difference $(LSD)_{0.05}$ the F values of the data at $P \leq 0.05$.

Field experiment

By the next year two Zn-efficient and two Zn-inefficient along with one medium genotype from previous year solution culture study were tested in field for ZE. Two levels of Zn (0, 5 kg ha^{-1}) were employed to assess any change in their Zn efficiency. The Split Plot design with three replications was used keeping wheat cultivars in the main plots while Zn treatments were kept in sub-plots. Before execution of experiment, Zn deficient site was selected having low available Zn by analyzing soil samples from different fields. The analysis of the selected site showed that it had 0.32 µg g^{-1} available Zn,0.57% organic matter, 7.4 µg g^{-1} Olsen P,pH 7.8 and ECe 1.8 dS m^{-1}. The recommended rates of Phosphorus (90 kg ha^{-1}) and K (60 kg ha^{-1}) were applied to the experimental area at the time of sowing whereas N (120 kg ha^{-1}) was applied in two splits I.e. one half at the time of sowing and the other half with first irrigation. Standard procedures of crop production, plant protection and the methodology of execution of experiment was same as in our previous study (Imtiaz *et al*., 2014). At physiological maturity the crop was harvested and the yield and data on yield parameters were recorded. The plant samples were collected for further analysis as described in above section.

RESULTS

Hydroponics study

Symptoms of Zn deficiency

The severity of Zn deficiency symptoms on wheat plants under hydroponic culture solution was very high compared to that grown under field. Whitish brown necrotic spots appreared on the middle parts of the leaves with reduced shoot growth. Cakmak *et al.* (1998) also noted similar symptoms in Zn deficient wheat plants. A band of dead tissue on whole leaf appeared with joining of these necrotic spots togather and ultimately leaves twisting occurred (Imtiaz *et al.,* 2014).

Shoot growth

Shoot dry matter (SDM) and root dry matter (RDM) of genotypes are presented in Figure 1 and 2. It is obvious from the data that different Zn^{2+} activities in solution had immense impact on growth of the wheat plants. Insertion of higher Zn^{2+} activities (10 pM and 40 pM) in solution enhanced the plants growth and dry matter (DM) production. Dry matter production (both SDM and RDM) was distinctly lower in the Zn deficient solutions (2 pM Zn^{2+}).The genotype NRL-0517 (later on approved as cultivar Lalma for rainfed area) produced significantly ($P \leq 0.05$) higher SDM (4.05 g/pot) at 2 pM Zn^{2+} than rest of the genotypes. Bakhtawar-92 (used as reference genotype) produced the minimum SDM (1.40 g/pot) at 2 pM Zn^{2+}. NRL-1243 produced maximum SDM (7.90g/pot) at 40 pM Zn^{2+} whereas Bakhtawar-92 produced the minimum (2.42 g/pot). There was a distinct variation in SDM production at different levels of Zn activities by each genotype under study. This variation in SDM production was exploited to determine Zn efficiency of genotypes (Genc *et al.,* 2006). As with SDM, root dry matter varied significantly ($P \leq 0.05$) among these genotypes. At 2 pM Zn^{2+}, maximum root dry matter (1.9 g/pot) was produced by NRL-0517 whereas the cultivar NRL-1009 yielded only 0.80 g/pot root dry matter. With the increase in Zn activity level in solution, root dry matter accumulation was also enhanced by the genotypes. Cultivar NRL-1243 (Zn-inefficient) has shown the maximum decrease in root dry matter at low Zn activity level of 2 pM Zn^{2+}as compared with the Zn-sufficient level (40 pM Zn^{2+}). Contrary to this, the Zn-efficient cultivars like NRL-0517 showed minimum reduction in RDM. Zinc deficiency impaired the root growth of Zn sensitive cultivars and the genotypes tend to have smaller and fibrous roots (Imtiaz *et al.,* 2014).

Zinc efficiency (%)

As described earlier that Zinc efficiency relates to the relative growth of plants under Zn deficiency stress to that growth under Zn sufficient conditions. Zinc efficiencies of various cultivars were 27 to 70 % in hydroponics study, confirming well to growth reduction by the plants (Table1). The cultivar NRL-1243 had the lower most Zn efficiency of 27%, whereas NRL-0517 was the most efficient cultivar with 70% efficiency. In this study, 3 genotypes were found Zn efficient, 3 as Zn-sensitive whereas other genotypes were assigned class of medium efficiency. These findings are in agreement to those of Kalayci *et al.* (1999).

Nutrient concentrations

Zinc concentration and uptake

The accumulation of Zn in the shoots of various genotypes ranged between 10.5µg g^{-1} (at 2 pM Zn^{2+}) and 52.4 µg g^{-1} (at 40 pM Zn^{2+}), however, differences in Zn accumulation at 2 pM Zn^{2+} activity within the cultivars were significant (Figure 3). By and large, the Zn-inefficient cultivars (NRL-1009 and NRL-1243) have taken up lesser Zn as compared with Zn-efficient cultivars i.e.NRL-0517 and NRL-1242. Zinc concentration in Zn in-efficient genotypes at 2 pM Zn^{2+} activity varied between 10.5 to 11.2 µg g^{-1}, whereas it escalated from 17.2 to 19.5 µg g^{-1} in Zn efficient genotypes. The minimum Zn concentration of 10.2 µg g^{-1} was absorbed by NRL-1243 that was significantly ($P \leq 0.05$) lower compared to other genotypes whereas Zn accumulation by NRL-0517 was maximum (19.2 µg g^{-1}). Zinc absorption by the roots was also significantly greater with increased Zn^{2+} activities (Figure 4). Generally, higher concentrations of Zn were found in roots than shoots. Zinc inefficient genotypes (like NRL-1241) accumulated statistically similar Zn concentrations in the roots as compared with Zn-efficient varieties (NRL-0517 and NRL-1242) but translocated lesser Zn to the above ground parts (Figure 5). Insertion of Zn in the solution medium increased total Zn in the shoots and roots of genotypes (Figure 6 and Figure 7). Capacity of Zn uptake by all the genotypes was variably different because of significant interaction between cultivars and Zn activities. The minimum Zn uptake in plant shoots (Figure 6) was 15.7 µg/pot and maximum was 77.5 µg/pot at low Zn activity. Higher Zn uptake was observed in Zn-efficient genotype NRL-0517 compared to all other cultivars while NRL-1009 taken up lesser amount. These results show similarity to those obtained by Erenoglu *et al.* (1999).

Table 1. Effect of Zn activities on Zn efficiency and growth of wheat genotypes

Varieties	Efficiency (%)	Growth Reduction (%)
NRL-0517	70.4	29.6
NRL-1242	61.3	39.7
Bakhtawar-92	60.2	39.8
NRL-1027	52.8	47.2
NRL-1006	51.3	48.7
NRL-1013	51.0	49.0
NRL-1028	49.4	50.6
NRL-1241	39.7	59.7
NRL-1009	32.7	67.3
NRL-1243	26.7	73.3

Table 2. Effect of Zn application on yield (kg ha^{-1}) and ZE (%) of wheat genotypes under field conditions

Varieties	Straw Yield (kg ha^{-1})		Grain Yield (kg ha^{-1})		Efficiency (%)
	Zn (0 kg ha^{-1})	Zn (5 kg ha^{-1})	Zn (0 kg ha^{-1})	Zn (5 kg ha^{-1})	
NRL-0517 (Lalma)	7481	8074	3704 b	4889 a	75.8±3.9
NRL-1242	6815	7481	3481 bc	4667 ab	71.8±3.2
NRL-1013	8222	8593	3630 bc	5185 a	69.8±3.1
NRL-1009	6222	7556	3037 bc	5852 a	52.4±8.7
NRL-1243	7259	8000	2593c	5926 a	43.6±5.4
LSD	NS		Zn:731, V: 944, Zn*V: 788		-

Zinc translocation

Zinc translocation (Figure 5) within the plant was assessed for the genotypes under study and was found varied from genotype to genotype. The increasing levels of Zn activity significantly ($P \leq 0.05$) affected Zn translocation. It varied from 50.3 % at 2 pM Zn^{2+} to 79.2 at 40 pM Zn^{2+}. In general, Zn efficient genotypes translocated greater amount of Zn from roots to above ground parts when grown in Zn deficiency (2 pM Zn^{2+}) but Zn inefficient genotypes retained much of this nutrient in roots and transferred lesser amount to the shoot (Hart *et al.,* 1998). However, under Zn sufficient conditions, Zn inefficient genotypes translocated comparatively higher Zn toward shoots.

P concentrations and uptake

Zinc-inefficient wheat cultivar NRL-1241 accumulated maximum P concentration (1.42 g P 100 g^{-1}) in the shoot while cv. Bakhtawar-92, had the minimum P concentration of 0.65 g P 100 g^{-1} (Figure 8). With increase in Zn activities P concentrations of all the cultivars in the shoots were decreased significantly ($P \leq 0.05$). At 2 pM Zn^{2+} the average P concentration of all genotypes was 1.05 g 100 g^{-1} which decreased to 0.42 g 100 g^{-1} at 40 pM Zn^{2+} activity. Zinc X cultivar interaction) was also significant ($P≤0.05$) indicating that genotypes absorbed different quantity of P at the Zn-deficient level (Figure 8).

Various Zn activities also affected the P accumulation significantly ($P≤0.05$) in the roots (Figure 9). Roots have higher P at low Zn level (2 pM Zn^{2+}), while it generally reduced at higher Zn activities in all genotypes. As a matter of fact, roots always had higher concentrations of P than in shoots. Zn-inefficient genotypes had lower P contents (per pot) in shoots (average of 3 Zn^{2+} activities) than Zn-efficient ones. Increase in Zn activity from 2 pM to 10 pM affected the P contents of shoots significantly ($P≤0.05$) and positively but further increase to 40 pM has no significant effect (Figure 10). The same trend for P uptake in root was also observed (Figure 11).These results are in accordance to those obtained by Verma and Minhas (1987).

Field study

Deficiency symptoms and biological yield

The intensity of the deficiency symptoms in field was not as severe as in hydroponics; however stunted growth and chlorosis in the leaves were the obvious over symptoms (Brown *et al.*, 1993). Never the less these symptoms affected the biological yield (straw and grain yield) drastically. Generally, with the increase in Zn application to 5 kg ha^{-1}, the biological yield was escalated with variable reaction of cultivars under study (Alloway, 2008). Biomass production by all the genotypes was significantly affected at both levels of Zn (Table 2). As far as straw yield is concerned, the wheat genotype NRL-1013 produced 8222 kg ha^{-1} straw in control plots and the yield was escalated to 8893 kg ha^{-1} at 5 kg Zn ha^{-1}. It is pertinent to mention that straw yield did not correspond to the Zn efficiency of the genotypes.

Grain yield

At physiological maturity the crop was harvested and the ZE was determined by considering the grain production at Zn deficient and Zn sufficient levels (Table 2). The Zn application in the soil grain significantly ($P≤0.05$) increased the grain production of all genotypes however, Zn-inefficient genotypes responsed conspicuously to Zn supply as compared with the Zn-efficient genotypes. The maximum economic harvests of 5926 kg ha^{-1} and 5852 kg ha^{-1} at 5 kg ha^{-1} Zn were recorded for Zn-inefficient genotypes NRL-1243 and NRL-1009 respectively, however these yields were lowered to 2593 and 3037 kg ha^{-1}, respectively without Zn application. Conversely, the lower response of Zn-efficient genotypes to Zn fertilization was perceived as of NRL-0517 and NRL-1242 produced 4889 and 4667 kg grain ha^{-1} with the application of Zn and 3704 and 3481 kg grain ha^{-1}, respectively without Zn.

Zinc efficiency (%)

Five wheat genotypes from previous hydroponics study were subjected to two levels of Zn to measure any shift in their Zn efficiency under field conditions and the impact of Zn fertilization on the yield. The results showed that the efficiency of these genotypes was escalated in the field which varied between 43.6 to 75.8% (Table 2). However, none of the genotypes shifted its class of efficiency assigned to it in hydroponics study. These findings are in line with those Cakmak *et al.* (1998) and Kalayci *et al.* (1999) who found variation and enhanced ZE of different wheat genotypes under field conditions.

Zinc concentration and Zn uptake

The results depicted that Zn concentrations in the grain was enhanced with Zn ferilization (Table 3). Higher concentrations of Zn were extracted by Zn-efficient genotypes as these genotypes hoarded significantly higher Zn in the grain at Zn deficient level. Zn-efficient cv. NRL-0517 had maximum Zn accumulation of 25.2 µg g^{-1} in the grains without any Zn fertilization, while Zn in-efficient genotype cv. NRL-1009 accumulated 19.2 µg g^{-1}. These findings confirm the former results of Jiang *et al.* (2008) that during Zn stress conditions, Zn-efficient cultivars extract more Zn than inefficient ones. Zinc uptake by different genotypes was also improved by Zn application. Cultivar NRL-1013 had significantly ($P \leq 0.05$) higher Zn uptake (99.8g ha^{-1}) in comparison with all other genotypes (Table 3) at Zn deficient level, whereas NRL-1243 accumulated the least Zn (56.0 g ha^{-1}).

Table 3. Effect of Zn application on Zn concentration and uptake by wheat genotypes under field conditions

Varieties	Zn concentration in straw (µg g^{-1})		Zn concentration in grain (µg g^{-1})		Zn uptake in straw (g ha^{-1})		Zn uptake in grain (g ha^{-1})	
	Zn (0kg ha^{-1})	Zn (5kg ha^{-1})	Zn (0kg ha^{-1})	Zn (5kg ha^{-1})	Zn (0kg ha^{-1})	Zn (5kg ha^{-1})	Zn (0kg ha^{-1})	Zn (5kg ha^{-1})
NRL-0517	6.6	8.7	25.2	34.2	66.3	83.5	93.5	167.0
NRL-1242	5.3	9.0	23.6	29.5	50.6	79.0	82.2	144.4
NRL-1013	5.9	8.1	27.5	30.8	63.4	81.0	99.8	159.7
NRL-1009	4.3	7.7	19.2	30.9	40.8	63.6	58.3	180.8
NRL-1243	4.3	6.6	21.6	24.3	43.3	60.8	56.0	144.2
$LSD_{0.05}$	Zn: 0.32, V: 29.91, Zn*V: 0.71		Zn: 0.75, V: 2.19Zn*V: 1.67		Zn: 4.66, V: 2.19, Zn*V: 10.43		Zn:10.07,V:18.30, Zn*V:22.52	

Table 4. Effect of Zn application on P concentration and uptake by wheat genotypes under field conditions

Varieties	P concentration in straw (µg g^{-1})		P concentration in grain (µg g^{-1})		P uptake in straw (kg ha^{-1})		P uptake in grain (kg ha^{-1})	
	Zn (0kg ha^{-1})	Zn (5kg ha^{-1})	Zn (0kg ha^{-1})	Zn (5kg ha^{-1})	Zn (0kg ha^{-1})	Zn (5kg ha^{-1})	Zn (0kg ha^{-1})	Zn (5kg ha^{-1})
NRL-0517 (Lalma)	0.0108	0.0100	0.048	0.0525	1.08	0.96	1.76	1.83
NRL-1242	0.0110	0.0095	0.052	0.0400	1.04	0.84	1.80	1.96
NRL-1013	0.0125	0.0105	0.053	0.0425	1.35	1.05	1.91	2.20
NRL-1009	0.0119	0.0113	0.058	0.0475	1.13	0.93	1.75	2.78
NRL-1243	0.0114	0.0100	0.060	0.0375	1.14	0.93	1.56	3.11
$LSD_{0.05}$	Zn:0.00003, V: 0.00012, Zn*V: 0.00007		Zn:0.00021, V:0.00010, Zn*V: 0.00061		Zn: 0.059NS*, V: 0.223, Zn*V: 0.1328		Zn: 0.186, V: 0.584, Zn*V: 0.416	

Phosphorus concentration and uptake

The accumulation of P in the plants varied significantly by varying the rates of Zn application (Table 4). The maximum P concentration (0.06%) at Zn deficient level was measured in the shoot of *cv*. NRL-1243 (Zn-inefficient) while P concentration was minimum (0.048%) in *cv*. NRL-0517 (Zn-efficient). The higher Zn level of 5 kg ha^{-1} antagonized P absorption significantly ($P \leq 0.05$) in the shoots. Phosphorus uptake (Table 4) in wheat grains was lower in the Zn-inefficient cultivars compared to Zn-efficient ones in the plots where Zn was not added. Zinc application had substantialy positive impact on the P contents in the shoots however, Zn-inefficient cultivars had reduced P contents in grain (Mimura *et al.,* 1996).

DISCUSSION

Wheat genotypes under investigation showed considerable genotypic variation in tolerance to Zn deficiency. Tolerance to Zn deficiency primarily rely on the calculated ZE by considering the growth of whole shoot (in hydroponics) and economic harvest (under field). To assess the genotypic differences in tolerance to Zn sensitivity, dry weight-based ZE has been mostly used (Rengel and Graham, 1995a; Cakmak *et al*., 1997; Khan *et al.,* 1998; Torun *et al*., 2000; Rengel and Römheld, 2000) and other nutrient deficiencies have also been estimated by such calculations as well (Fageria and Baligar, 1999; Gourley *et al*., 1994). The blatant severity and degree of visual of Zn deficiency symptoms was totally different on the plants of solution culture and field. Severe necrotic spots were visible on plants in hydroponic culture solution compared to those under field conditions. The common symptoms visible in the plants of both hydroponic and field conditions were the reduction in shoot length and leaf size (Pearson and Rengel, 1997; Cakmak *et al.,* 1997), appearance of whitish brown spots (in .hydroponic culture solution) (Imtiaz *et al*., 2006) and chlorotic and chlorophyll lacked leaves (field) (Brown *et al.,* 1993). The ZE calculated from shoot dry matter of various genotypes varied between 26.7 to 70.4% in hydroponic culture solution study. However, under field conditions ZE was escalated and varied between 43.6 to 75.8%.

In some of the cultivars dry matter production was greatly reduced by the severe leaf symptoms and the cultivars had a lower Zn efficiency. The lowest ZE calculated was for genotype NRL-1243 (26.7%) whereas NRL-0517 had the highest calculated ZE of 70.4%. The variation in ZE of different cultivars coincided with severity of deficiency symptoms in these cultivars (Imtiaz *et al*., 2014). Five of the above mentioned cultivars (two Zn-efficient, one medium and two Zn inefficient) were examined in field to measure any shift in their ZE or impact of Zn fertilization on economic harvest. There was no change in their ZE ranking assigned to them in hydroponics study except that ZE of these genotypes was enhanced in the field. The increase in ZE in field might be due to soil matrix which is of complex nature. Various mechanisms of ZE operate in the soil with low available Zn than in a Zn-deficient nutrient solution. The possible mechanisms could be the higher Zn transport by mycorrhizae (Dong *et al*., 1995) and Zn chelation through root exudates (Oburger *et al.*, 2014) which may be lacking in hydroponic system. Low intensity of Zn deficiency symptoms in field also suggests better Zn availability to the plants under field conditions.

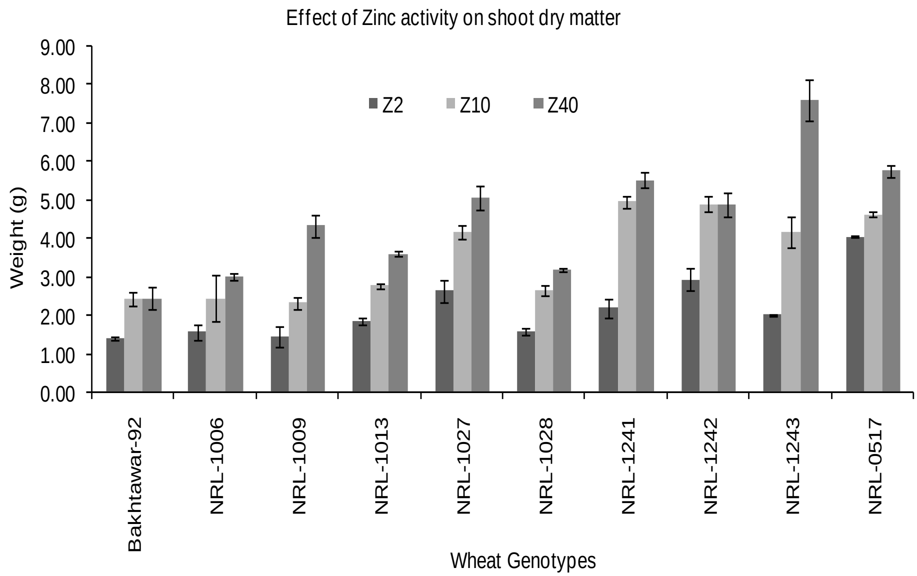

Figure 1. Effect of Zn activities on shoot dry matter of wheat genotypes

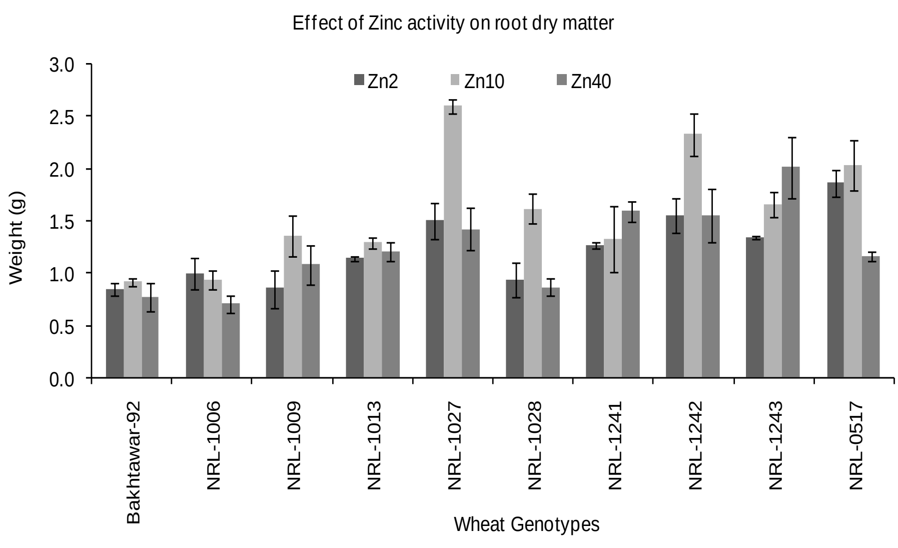

Figure 2. Effect of Zn activities on root dry matter of wheat genotypes

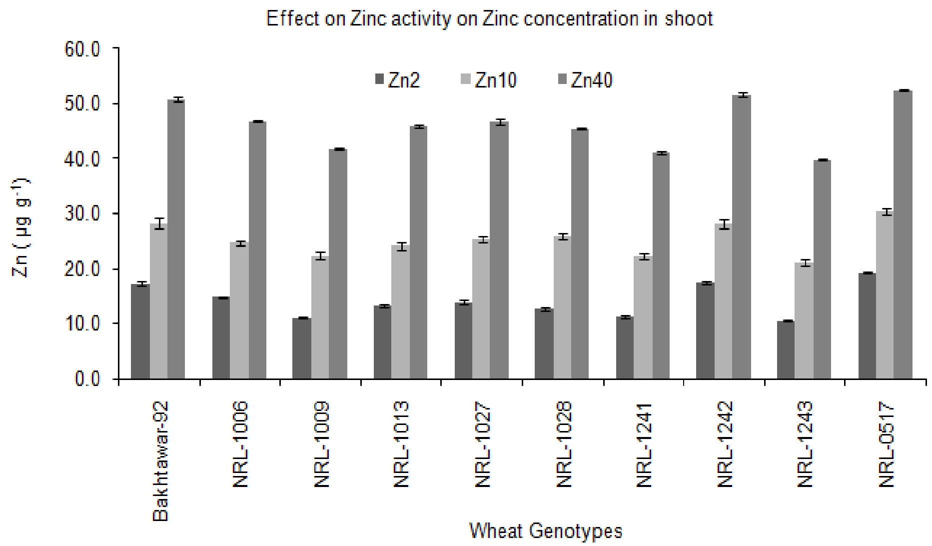

Figure 3. Effect of Zn activities on Zn concentration in shoot of wheat genotypes

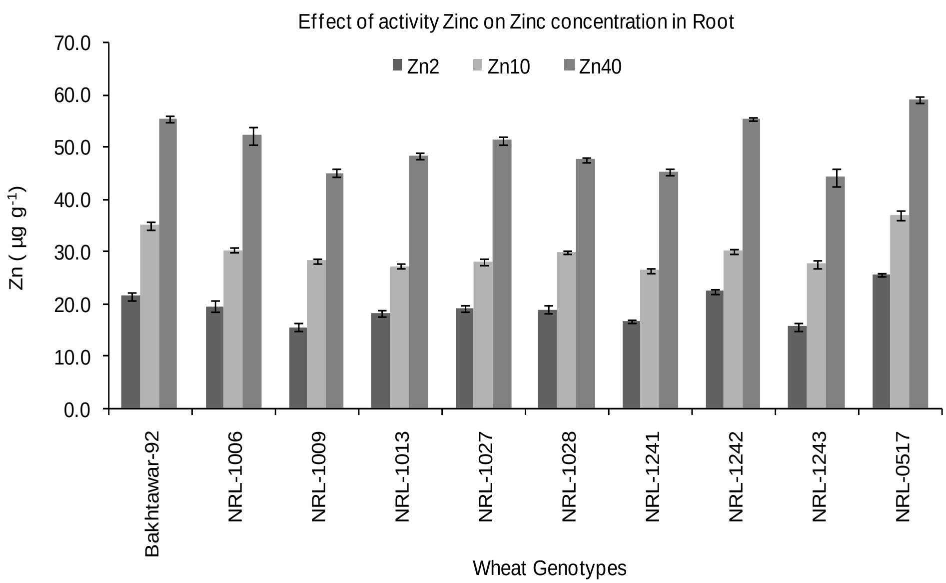

Figure 4 Effect of Zn activities on Zn concentration in root of wheat genotypes

Figure 5. Effect of Zn activities on Zn translocation ratio

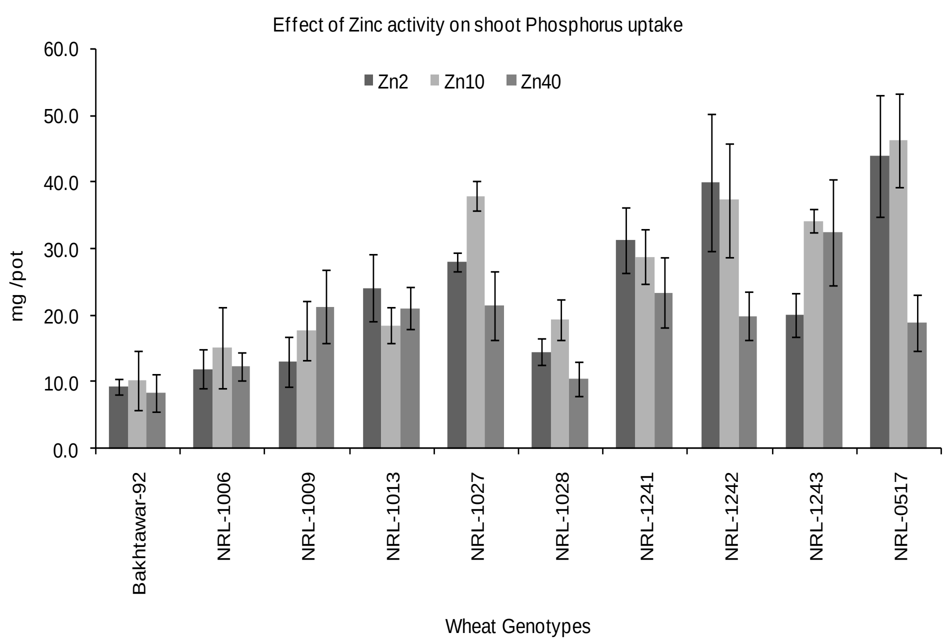

Figure 6. Effect of Zn activities on Zn uptake in shoot of wheat genotypes

Figure 7. Effect of Zn activities on Zn uptake in root of wheat genotypes

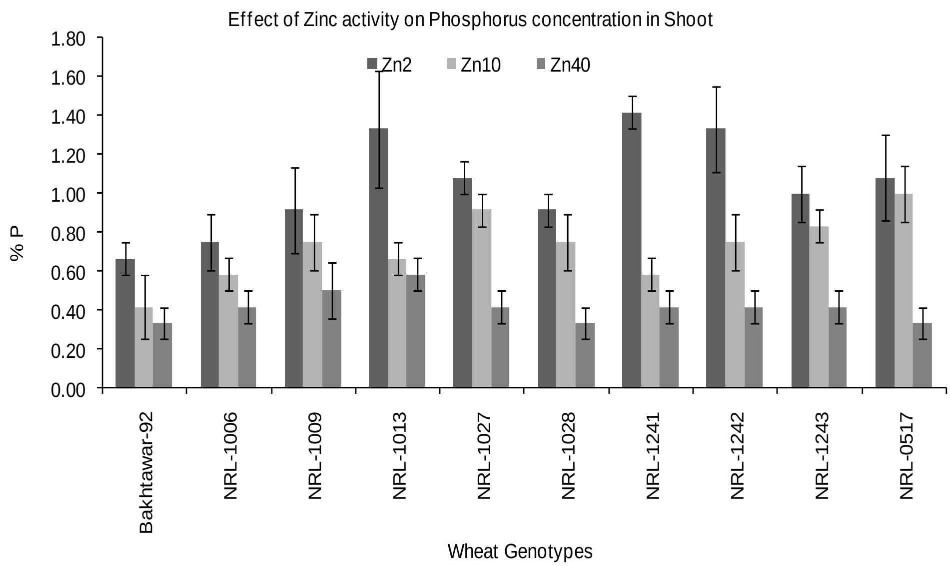

Figure 8. Effect of Zn activities on P concentration in shoot of wheat genotypes

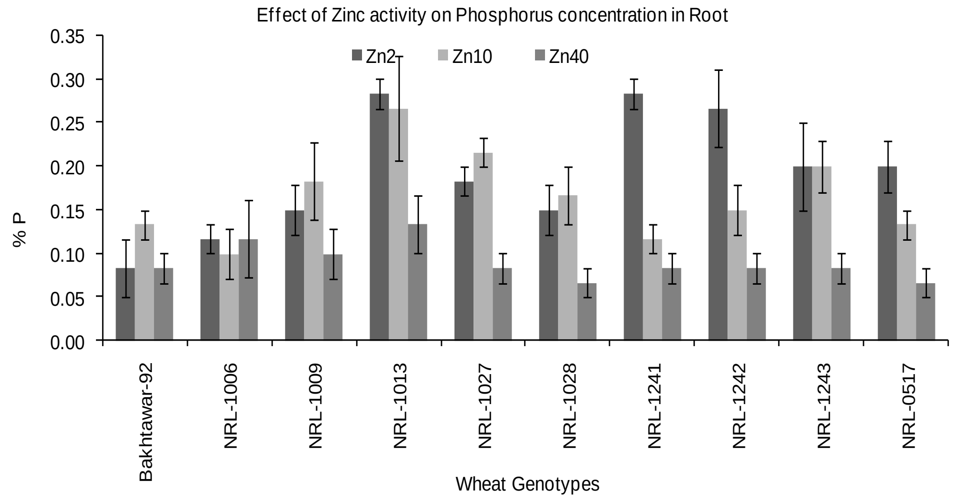

Figure 9. Effect of Zn activities on P concentration in root of wheat genotypes

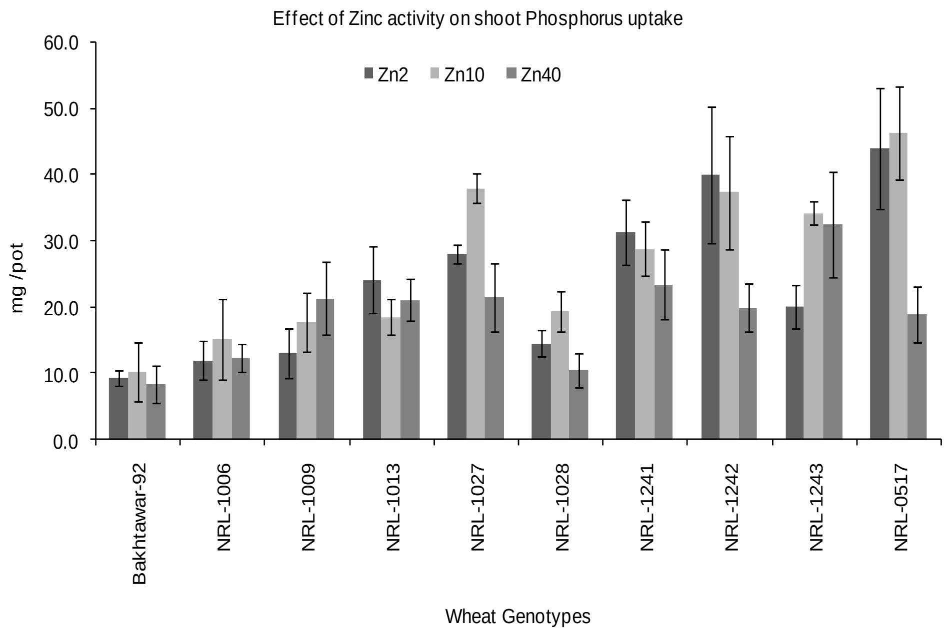

Figure 10. Effect of Zn activities on P uptake in shoot of wheat genotypes

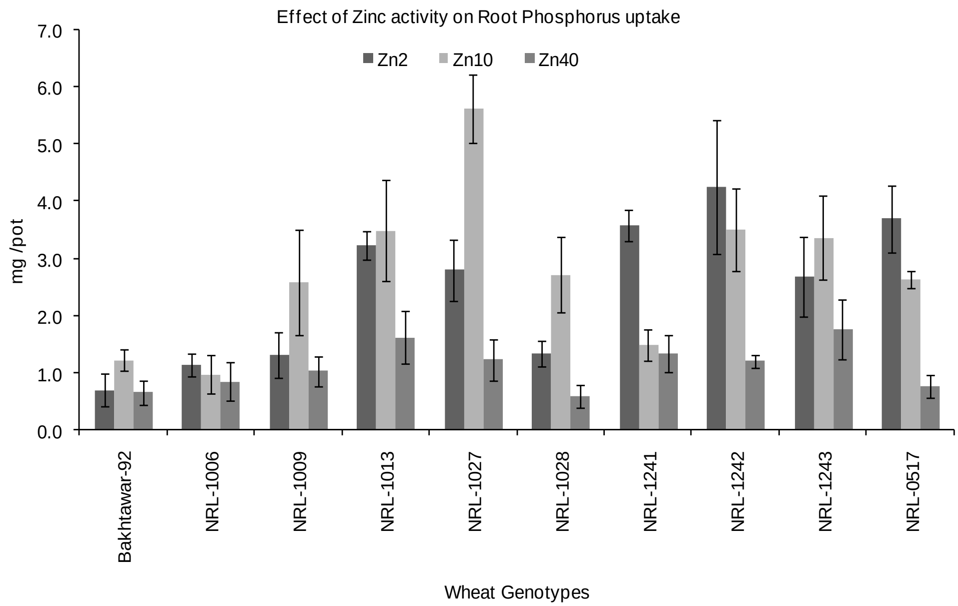

Figure 11. Effect of Zn activities on P uptake in root of wheat genotypes

It appears that the expression of escalated ZE in cereals is linked with higher capability of Zn uptake (Cakmak *et al.,* 1998). The capability of genotypes to accumulate and translocate more Zn to the above ground parts at higher rates in stress condition is therefore crucial trait for determining the mien of ZE. The translocation ratio also depicts that Zn-efficient genotypes like cv. Bakhtawar-90 and NRL-0517 have translocated higher amounts of Zn to the shoots as compared with Zn inefficient ones. Zinc efficient genotypes managed to translocate higher Zn to shoot by weaker antagonism between Zn and other nutrients particularly P. However, there was a strong antagonism among Zn and other nutrients (Webb and Loneragan, 1990) that hindered the translocation of Zn from root to shoot in Zn inefficient genotypes. It seems that efficient genotypes have evolved some mechanisms that helped the plant in taking up higher quantities of Zn and then made its free movement possible in the entire plant without any hindrance. These mechanisms might be obsolete or operating at lesser intensity in inefficient genotypes (Graham and Rengel, 1993).

CONCLUSION

The identification and development of Zn-efficient crop genotypes is imperative for the countries like Pakistan where 37% population is Zn deficient. Cultivation of Zn efficient genotypes like NRL-0517 can improve Zn status in daily diet and alleviate Zn malnutrition. Soil application of Zn can further improve the quality of wheat aiding to increase the yield and Zn contents of staple food of Pakistan. The technique of solution culture proved to be reliable tool for quick screening of wheat genotypes for their zinc efficiency.

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