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Full Length Article

Zinc Application Methods Affect its Accumulation and Allocation Pattern in Maize Grown in Solution Culture

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Abstract

Zinc (Zn) availability to plants is hampered seriously due to its immobile nature and adverse soil conditions. Nutrient management is one of the promising strategies adopted to enrich Zn in edible plant parts. Therefore, a hydroponic experiment was conducted to study Zn accumulation and allocation pattern in two maize genotypes [hybrid (Syngenta 8441) and conventional variety (Pak-Afgoi)] in response to root and foliage application of two Zn fertilizers viz. $ZnSO_4$ and Zn-EDTA. Treatments comprises; control (No Zn), solution applied $ZnSO_4.7H_2O$ @ 2 μM Zn, foliar applied $ZnSO_4.7H_2O$ @ 0.5%, solution applied Zn-EDTA @ 2 μM Zn and foliar applied Zn-EDTA @ 0.5%. Results revealed that Zn treatments significantly ($P \leq 0.05$) influenced growth rate, dry matter production and Zn accumulation in various plant parts but at variable rate. Maize hybrid (Syngenta-8441) observed more plant height, root length, root and shoot dry matter, and accumulated more Zn as compared with open pollinated variety Pak-Afgoi. This illustrated better acquisition and utilization efficiency of hybrid genotype. Moreover, all plant attributes were enhanced linearly with subsequently increase in amount of fertilization due to more availability of Zn especially in chelated form (EDTA). Among Zn treatments, solution application was more effective in plant growth and Zn enrichment than foliar application while Zn-EDTA showed better results than $ZnSO_4$. At early plant growth stage, Zn concentration in older leaves was higher but at later stage Zn concentration in young leaves was comparatively more than older leaves. On an average, Zn concentration in roots was higher followed by older leaves, young leaves and stem in both genotypes. Results suggested that differential response for plant growth, dry matter production and Zn accumulation depends on genotypic variation, Zn sources and application methods. The results depicted that the maize hybrid (Syngenta 8441) had better potential of Zn accumulation and allocation to different plant parts and the application method of Zn to the solution was found to best than the foliar application. However, further verification of results with field conditions is warranted keeping in view the soil characteristics to formulate concrete recommendations.

Keywords*:* Chelated Zn; Hybrid; Malnutrition; Sustainable productivity; *Zea mays* L.

Introduction

Zinc deficiency is an extensive nutritional limitation around the globe. It is equally important for all forms of life *i.e*., human beings, animals as well as plants. Increasing risk of Zn deficiency is of great concern because in biological systems it is vital for the proper functioning of multiple enzymes that are involved in array of metabolic processes (Hotz and Brown, 2004; Singh *et al*., 2005). During last few years, Zn deficiency, accompanied with iron (Fe) and vitamin A deficiency, has been measured as a most important risk factor to regional and global burden of many diseases. Malnutrition, including deficiencies of vitamin A and Zn, causes 45% of child deaths, resulting in 3.1 million deaths annually (Ezzati *et al*., 2002; WHO, 2002). In Pakistan, Zn deficiency has also been reported in adult women and in children below five year of age (Bhutta *et al*., 2007). Major reason of Zn deficiency in developing countries is low Zn intake because most of the people use cereal based diets having less amount of Zn. Similarly, about 50% of cereal grown soils are reported as deficient in available Zn resulting in low grain Zn concentration worldwide (Alloway, 2009). Thus, relying on such diet is leading cause of Zn deficiency in 2.7 billion people around the globe (Bouis *et al.*, 2011). Moreover, substantial loss of Zn through diarrhea is caused because of the impaired utilization of Zn due to reduced absorption capacity in intestine (Manary *et al*., 2002). The prevalence of widespread Zn deficiency in children might damage endocrine functions, DNA replication and RNA synthesis (Gibson, 2006). Therefore, an effective strategy to enhance Zn concentration in edible part of plants is urgently required.

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Maize (*Zea mays* L.) is the third most important cereal crop after wheat (*Triticum aestivum* L.) and rice (*Oryza sativa* L.) in Pakistan. During 2016-2017, area with maize production was 1.33 million ha with annual production of 6.13 million tons (GOP, 2017). In Pakistan, application of fertilizer has been limited to mainly nitrogen (N), phosphorus (P) and to some extent potassium (K). After N and P, the most deficient nutrient in alkaline calcareous soils of Pakistan is Zn (Rashid and Ryan, 2008). Moreover, maize is a Zn sensitive crop and its deficiency decreases the production of carbonic anhydrase enzyme which results in reduced photosynthetic activity (Bell and Dell, 2008). On the other hand, Zn application could increase yield and grain Zn contents (Haider *et al*., 2018a), but it is not usually applied to maize crop in Pakistan.

Application of fertilizers through appropriate methods is imperative for improving the efficiency of costly fertilizers (Alloway, 2008). Foliar fertilization is also a promising technique for applying micronutrients especially on environments where soil application is not suitable either due to fixation or other factors limiting the nutrient availability to plants. Foliar application of micronutrients can meet full requirements of crops and improves crop growth, grain weight and yield (Malavolta, 2006; Haider *et al*., 2018b). Crop species/varieties vary in their nutrient requirement and utilization (Maziya-Dixon *et al.*, 2000; Oikeh *et al.*, 2003). Hence the selection of those genotypes having maximum nutrient content in different plant parts is a promising approach. However, fertilization of crops to increase the mineral nutrient contents is easier.

Zinc uptake and its translocation to shoot increased with solution nutrients in cereal crops (Cakmak *et al*., 1998), which is translated into increased yield and grain Zn contents in various crops (Hoffland *et al*., 2006). Several approaches have been adopted to enrich Zn in edible plant portions like classical and molecular breeding, biotechnological tools and nutrient management (Sharma *et al.,* 2013). Soil and foliar application of Zn is an effective way of achieving Zn bio-fortification depending upon genotypes and soil characteristics (Hussain *et al.,* 2013). Therefore this study was designed to investigate the efficacy and accumulation patterns of Zn in maize, applied through different sources and application methods.

Materials and Methods

Plant Material and Experimental Setup

A hydroponic experiment was carried out in the rain protected wire house of Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad (UAF), Pakistan to investigate the effect of root zone and foliar applied Zn fertilizers ($ZnSO_4.7H_2O$ and Zn-EDTA) on Zn accumulation and distribution in various parts of two maize genotype. Seeds of maize genotypes *i.e*., Syngenta-8441 (hybrid) and Pak-Afgoi (open pollinated variety) were obtained from Department of Plant Breeding and Genetics, UAF. Seeds were surface sterilized with 3% solution of sodium hypochlorite followed by thoroughly washing with distilled water. Surface sterilized seeds were soaked overnight and were sown in polythene lined iron trays having two inches layer of acid washed riverbed sand.

The root systems of 10 days old seedlings were carefully washed with distilled water to remove sand and the uniform seedlings were transferred to 25 L plastic tubs containing Johnson nutrient solution (Johnson *et al*., 1957) as modified by Aziz *et al.* (2014). Seedlings were supported by foam plugs in the holes of polystyrene sheets fixed at the top of tubs. The composition of the full-strength nutrient solution (pH 6.5) was as follows: 5 m*M* nitrogen, 0.2 m*M* phosphorus, 3.5 m*M* potassium, 1.5 m*M* calcium, 0.5 m*M* magnesium, 2.05 m*M* sulfur, 50 μM chloride, 25 μM boron, 2 μM manganese, 0.5 μM copper, 0.5 μM molybdenum and 50 μM iron. Iron was used as Fe-EDTA.

Both maize genotypes were grown under five Zn treatments viz; control, solution applied $ZnSO_4.7H_2O$ @ 2 μM Zn, foliar applied $ZnSO_4.7H_2O$ @ 0.5% (5-6 mL per plant), solution applied Zn-EDTA @ 2 μM Zn and foliar applied Zn-EDTA @ 0.5%. Plants were arranged according to factorial arrangements following Completely Randomized Design (CRD) having three replications. The nutrient solution was replaced with fresh nutrient solution after each harvest (8 days interval) in order to ensure continuous supply of nutrients. The pH of the solution was monitored daily and maintained at 6.5 ± 0.2 using 0.1*N*HCl or 0.1*N*NaOH.

Crop Harvesting and Plant Analysis

Plants were grown in solution culture for 40 days and harvested after 8, 16, 24, 32 and 40 days of transplanting. At each harvest, plants were washed with deionized water. Plant height and root length was measured with meter rod and then plant sample was partitioned into root, stem, older leaves and younger leaves (upper 3 leaves). After sun drying, samples were oven dried at 70°C for 72 h. After oven drying, plant dry matter's production (g plant^{-1}) was measured using digital weighing balance. Oven-dried plant samples were finely ground and a uniform portion of ground material was subjected to wet digestion using di-acid mixture (2:1; HNO_3: $HClO_4$) according to procedure described by Jones and Case (1990). Digests were then made up to 25 mL with deionized water. Zinc concentration in digested samples was determined using atomic absorption spectrometer (Solar S-100, Thermoelectron, USA) after calibrating standard solutions (Ahmad *et al.,* 2012).

Statistical Analysis

All the data regarding growth, dry matter and Zn concentration indifferent parts of maize genotypes were subjected to analysis of variance (ANOVA) using software STATISTIX 8.1® [*Analytical Software, Inc., Tallahassee, FL, USA*] while significant differences among treatment means were identified by employing Least Significant Difference (LSD) test at 5% probability level (Steel *et al.*, 1997).

Results

Plant Growth Parameters and Biomass Partitioning

Plant height of maize Syngenta 8441 and Pak-Afgoi was significantly ($P \leq 0.05$) improved by solution and foliar application of Zn fertilizers (Fig. 1a). Maize hybrid (Syngenta-8441) had comparatively more plant height compared to maize variety (Pak-Afgoi). Maximum plant height (156 cm) in maize hybrid was recorded with solution application of Zn-EDTA while control plants had minimum height. While, maximum plant height (145 cm) of open pollinated maize variety (Pak-Afgoi) was recorded by $ZnSO_4$ application (Fig. 1a).

Root length of both genotypes increased linearly with all the treatments at progressive harvests (Fig. 1b). Maximum root length (61 cm) in maize hybrid (Syngenta-8441) was recorded with solution applied $ZnSO_4$ followed by foliar applied ZnSO4, solution applied Zn-EDTA, foliar applied Zn-EDTA and control, respectively. In maize variety (Pak-Afgoi), maximum root length (49 cm) was recorded with solution applied Zn-EDTA. However, control treatment produced minimum root length at all harvests (Fig. 1b).

The effect of methods of Zn application on root and shoot dry matter of maize genotypes is presented in Fig. 1c. Zinc treatments significantly ($P \leq 0.05$) affected root and shoot dry matter production of both the tested genotypes (Table 1). Maize hybrid comparatively produced more root dry matter with solution applied Zn fertilizers than with their foliar application. Maximum root dry matter of maize hybrid was recorded with solution applied Zn-EDTA at all harvests. This is might be due to passive uptake of Zn and may increase the activity of carbonic anhydrase in growing plants. While, minimum root dry matter was noticed in control treatment. Likewise, root dry matter in maize variety was also recorded higher with solution applied Zn-EDTA followed by solution applied $ZnSO_4$ and foliar applied Zn-EDTA. Shoot dry matter production was considerably influenced in maize hybrid (Syngenta-8441) and maize variety (Pak-Afgoi) under varying Zn sources and application methods (Fig. 1 and Table 1). Overall the extent of shoot dry matter was higher in maize hybrid than conventional variety. Minimum shoot dry matter in maize hybrid was recorded in control plants while maximum in plants receiving solution applied Zn-EDTA. Shoot dry matter ranged from 1.7 to 24.0 g plant^{-1}in hybrid genotype. Similar increasing trend was noticed in conventional variety for shoot dry matter production as for maize hybrid. Shoot dry matter varied from 1.2 to 17.0 g plant^{-1} in maize variety with solution applied Zn-EDTA.

Relative shoot and root growth rate (dry matter) of maize genotypes was calculated for plants harvested after 24 and 40 days of transplanting (Table 2). As far as the comparison of relative shoot growth rate (dry matter) of two maize genotypes was concerned, Pak-Afgoi responded better than Syngenta-8441. Response of relative shoot growth rate (dry matter) of Syngenta-8441 to applied treatments at 24 DAT was maximum (2.3%) in case of foliar Zn-EDTA followed by foliar $ZnSO_4$ and least response was noted in solution applied Zn-EDTA. While at 40 DAT, relative shoot growth rate (dry matter) of Syngenta- 8441 was higher (10%) in solution applied Zn-EDTA followed by solution applied $ZnSO_4$ and least response was calculated in control. Trend of response to applied treatments for Pak-Afgoi was different where maximum response was noted with solution applied Zn-EDTA followed by solution applied $ZnSO_4$, while least response was observed for control at 24 DAT.

Root to shoot ratio (dry matter) was also calculated after 8,16,24,32 and 40 days of transplanting for both maize genotypes (Table 3). Maximum root shoot ratio was recorded 0.34 with no Zn application after 24 days of transplanting; this might be due to unavailability of Zn as Zn deficiency reduces net photosynthesis. Similarly, minimum response in case of Syngenta-8441 was 0.16 with solution application of Zn-EDTA. Therefore, in case of Pak-Afgoi maximum root shoot ratio was noted 0.42 with foliar $ZnSO_4$, while minimum response was 0.20 with solution applied $ZnSO_4$.

Zinc Concentration

The data regarding root Zn concentration of maize genotypes is presented in Fig. 2. Zinc concentration in roots significantly varied ($P \leq 0.05$) between maize genotypes. Solution applied Zn-fertilizer resulted in more root Zn concentration than their foliar application in both the genotypes. Among fertilizers, solution application of Zn-EDTA resulted in higher root Zn concentration than $ZnSO_4$ in both the maize genotypes. However, minimum root Zn concentration was noticed in control treatments of both genotypes at all harvests. Maize hybrid Syngenta 8441 had higher root Zn concentration than open-pollinated maize variety Pak-Afgoi.

Both Zn fertilizers, applied with either of the methods, significantly ($p \leq 0.05$) increased Zn concentration in stem of both maize genotypes (Fig. 2 and Table 5). In both maize genotypes, relatively higher stem Zn concentration was recorded with solution application of Zn fertilizers than foliar application. Nevertheless, stem Zn concentration was not altered considerably among the harvests in all the treatments. Stem Zn concentration in maize hybrid Syngenta-8441 ranged from 14.8 μg g^{-1} in control to 45.4 μg g^{-1} in solution applied Zn-EDTA. In maize variety Pak-Afgoi, maximum stem Zn concentration of 35.4 μg g^{-1} was recorded with solution applied Zn-EDTA after 40 days of transplanting.

Table 1: Mean square values for dry matter production by various plant parts of maize genotypes as influenced by solution and foliar applied Zn

		Plant height (cm)					Root length (cm)				
Source (SOV)	DF	8 DAT	16 DAT	24 DAT	32 DAT	40 DAT	8 DAT	16 DAT	24 DAT	32 DAT	40 DAT
Treatment (T)	4	22.6^{NS}	169.6*	1158.8**	436.8**	238.1*	208.4**	96.8**	101.2**	81.6**	160.1**
Genotype (G)	1	821.6**	512.5**	90.1^{NS}	3520.8**	388.8*	252.3**	750.0**	572.1**	73.6*	418.1**
T × G	4	7.1^{NS}	14.3^{NS}	16.7^{NS}	318.6*	53.4^{NS}	210.9**	44.9**	75.6**	21.4^{NS}	47.3^{NS}
Error	20	9.667	42.067	47.730	76.670	71.267	6.133	9.100	10.600	9.900	26.900
		Shoot dry matter (g plant^{-1})					Root dry matter (g plant^{-1})				
Treatment (T)	4	0.142**	7.185**	5.745**	19.549**	55.453**	0.015**	0.196**	0.117*	1.054**	1.001**
Genotype (G)	1	3.046**	65.742**	2.629**	8.206**	109.25**	0.183**	4.026**	0.108^{NS}	0.933**	0.884**
T × G	4	0.021**	0.5445**	1.030**	1.248**	6.162**	0.002^{NS}	0.089**	0.018^{NS}	0.094^{NS}	0.291**
Error	20	0.002	0.102	0.156	0.182	1.159	0.001	0.008	0.035	0.053	0.041

NS = Non-significant ($P > 0.05$); * = Significant ($P \leq 0.05$); ** = Highly significant ($P \leq 0.01$); DF = Degree of freedom; DAT: Days after transplanting

Table 2: Effect of Zn application on root and shoot relative growth rate (RGR) of maize genotypes in solution culture

Cultivar	Treatments	Shoot RGR (mg/g/day)		Root RGR (mg/g/day)	
		24 DAT	40 DAT	24 DAT	40 DAT
Syngenta-8441	Control	97.51	53.979	104.05	19.992
	ZnSO4 (Solution)	94.44	66.329	89.62	42.781
	ZnSO4 (Foliar)	104.12	55.394	96.64	30.254
	Zn-EDTA (Solution)	93.77	72.963	95.47	35.316
	Zn-EDTA (Foliar)	106.54	60.239	99.65	29.653
Pak-Afgoi	Control	123.96	56.704	137.79	33.113
	ZnSO4 (Solution)	133.57	50.892	124.92	23.631
	ZnSO4 (Foliar)	131.26	53.493	113.48	24.984
	Zn-EDTA (Solution)	139.17	47.149	114.54	34.712
	Zn-EDTA (Foliar)	127.22	65.116	124.38	30.314
$LSD_{0.05}$(T)		7.3808	6.8311	12.442	7.981
$LSD_{0.05}$(G)		4.668	4.3204	7.869	5.0476
$LSD_{0.05}$(T × G)		10.438	9.6606	17.596	11.287

DAT: Days after transplanting

Table 3: Effect of Zn application on root shoot ratio (RSR) of maize genotypes in solution culture

Cultivar	Treatments	8 DAT	16 DAT	24 DAT	32 DAT	40 DAT
Syngenta-8441	Control	0.3067	0.2067	0.3400	0.2867	0.2000
	ZnSO4 (Solution)	0.3200	0.2200	0.2967	0.2567	0.2033
	ZnSO4 (Foliar)	0.3167	0.2067	0.2833	0.2933	0.1867
	Zn-EDTA (Solution)	0.2700	0.2033	0.2800	0.2833	0.1567
	Zn-EDTA (Foliar)	0.3200	0.2567	0.2867	0.2733	0.1767
Pak-Afgoi	Control	0.2767	0.2267	0.3467	0.2933	0.2367
	ZnSO4 (Solution)	0.3467	0.1767	0.3000	0.2433	0.1967
	ZnSO4 (Foliar)	0.4233	0.2300	0.3233	0.2967	0.2000
	Zn-EDTA (Solution)	0.3733	0.1833	0.2500	0.2667	0.2033
	Zn-EDTA (Foliar)	0.3567	0.1967	0.3433	0.2733	0.1967
$LSD_{0.05}$(T)		0.0279	0.0211	0.0392	0.0298	0.0181
$LSD_{0.05}$(G)		0.0441	0.0133	0.0248	0.0189	0.0115
$LSD_{0.05}$(T × G)		0.0624	0.0298	0.0555	0.0422	0.0256

DAT: Days after transplanting

A significant main and interactive effect of maize genotypes and Zn treatments was observed for Zn concentration in young leaves (Fig. 2 and Table 5). Zinc concentration in young leaves of maize hybrid Syngenta-8441 was higher than that of conventional maize variety Pak-Afgoi. Highest Zn concentration in young leaves of all harvests was recorded in solution applied Zn-EDTA followed by foliar applied Zn-EDTA, foliar applied $ZnSO_4$ and solution applied $ZnSO_4$ in both the genotypes. Control plants of maize hybrid Syngenta-8441and conventional variety Pak-Afgoi had minimum average Zn concentration in young leaves, 19.8 and 16.6 μg g^{-1}, respectively, while maximum, 39.0 and 33.8 μg g^{-1} respectively, was recorded with solution applied Zn-EDTA.

Maize hybrid had maximum Zn concentration in older leaves (three-fold) at 2nd harvest with foliar applied Zn-EDTA as compared to control followed by foliar applied $ZnSO_4$(Fig. 2 and Table 5). Averaged over all the harvests, maximum Zn concentration in older leaves of maize variety Pak-Afgoi was recorded with solution applied Zn-EDTA. Therefore, Zn concentration in older leaves of maize variety was higher (40.7 μg g^{-1}) with solution applied Zn-EDTA than other treatments after 40 days of transplanting.

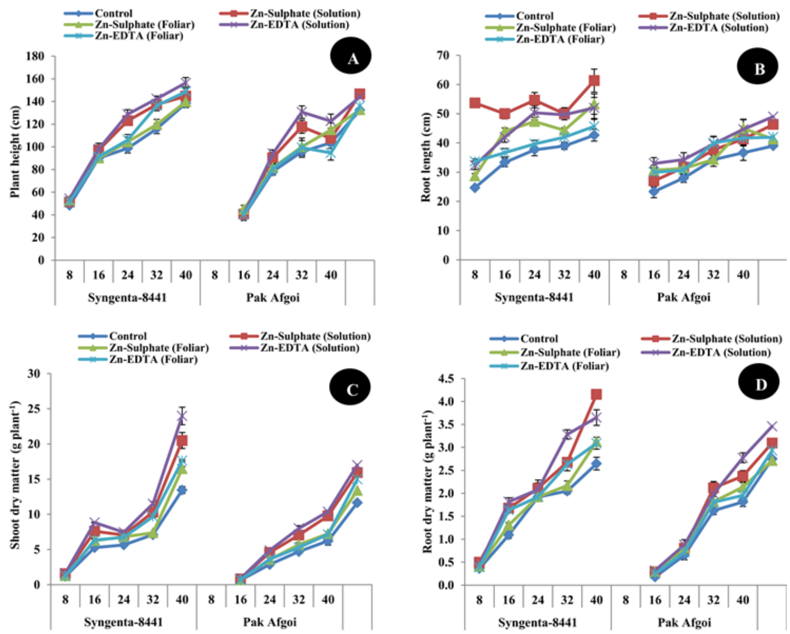

Fig. 1: Influence of solution and foliar applied various sources of Zn on different parameters of maize hybrid (Syngenta-8441) and maize variety (Pak-Afgoi). *A:* plant height, *B:* root length, *C:* shoot dry matter, and *D:* root dry matter

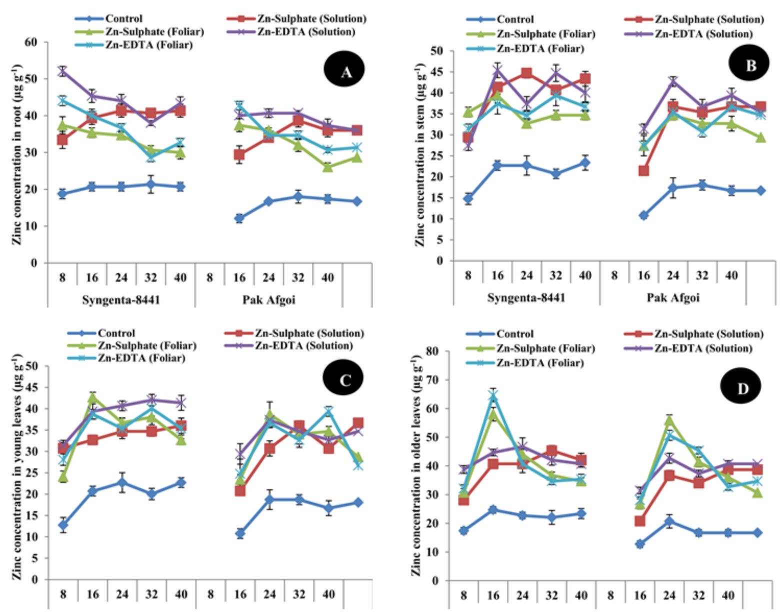

Fig. 2: Influence of solution and foliar applied various sources of Zn on Zn concentration in different plant tissues of maize hybrid (Syngenta-8441) and maize variety (Pak-Afgoi). *A:* zinc concentration in root, *B:* stem, *C:* young leaves, and *D:* older leaves

Zinc Accumulation

Zinc accumulation by root and shoot of maize genotypes was significantly ($P \leq 0.05$) influenced at all harvests by the application of Zn fertilizers (Table 4). Zinc accumulation increased root and shoot of both genotypes with subsequent increase in time of harvests. Generally, maize hybrid Syngena-8441 accumulated more Zn with all the treatments than maize variety Pak-Afgoi. Maximum root Zn accumulation (23.47 μg plant^{-1}) in maize hybrid after 8 DAT was recorded with solution applied Zn-EDTA while foliar applied Zn-EDTA, solution and foliar applied $ZnSO_4$ showed statistically similar results. At final harvest, *i.e.*, 40 DAT, solution applied $ZnSO_4$ resulted in highest root Zn accumulation (171. 94 μg plant^{-1}) which was at per with solution applied Zn-EDTA (157.74 μg plant^{-1}).

Table 4: Effect of Zn application on root and shoot Zn content (μg plant^{-1}) of maize genotypes in solution culture

Treatments	8 DAT		16 DAT		24 DAT		32 DAT		40 DAT	
	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot
(A) Syngenta-8441										
Control	6.81 c	17.37 d	22.81 d	118.40 c	39.74 c	128.42 d	43.69 c	148.47 e	55.02 c	310.71 d
ZnSO4 (Solution)	16.66 b	46.15 b	66.21 b	295.27 b	86.99 a	287.15 ab	109.06 a	413.95 b	171.94 a	852.60 b
ZnSO4 (Foliar)	15.37 b	40.50 c	46.38 c	275.98 b	66.68 b	252.47 bc	66.58 b	266.74 d	93.98 b	565.03 c
Zn-EDTA (Solution)	23.47 a	50.94 a	82.25 a	384.19 a	91.13 a	304.95 a	124.97 a	496.86 a	157.74 a	964.69 a
Zn-EDTA (Foliar)	17.19 b	37.39 c	65.38 b	269.47 b	70.39 b	246.80 c	75.51 b	371.85 c	101.35 b	636.15 c
$LSD_{0.05}$	3.19	3.99	11.81	34.13	11.32	40.27	16.36	41.81	21.01	89.19
(B) Pak-Afgoi										
Control	2.18 c	7.25 c	10.88 c	53.36 c	29.19 c	84.56 d	31.35 c	103.58 d	46.09 c	197.96 d
ZnSO4 (Solution)	8.60 b	17.57 b	27.46 b	155.48 b	82.16 a	248.41 b	85.92 a	345.88 b	111.66 a	590.11 a
ZnSO4 (Foliar)	11.15 ab	18.07 b	29.49 ab	142.06 b	58.25 b	201.23 c	55.80 b	248.83 c	77.97 b	395.53 c
Zn-EDTA (Solution)	12.83 a	26.67 a	35.59 a	196.62 a	80.80 a	288.84 a	103.61 a	391.75 a	124.38 a	618.12 a
Zn-EDTA (Foliar)	10.56 ab	18.45 b	24.86 b	142.53 b	62.61 b	185.43 c	59.74 b	259.58 c	92.03 b	493.98 b
$LSD_{0.05}$	3.39	2.31	6.19	32.43	9.49	26.81	20.48	39.35	16.55	54.13

Treatment means sharing same letter(s) in the same column indicates non-significant differences at $P \leq 0.05$. DAT: Days after transplanting

Table 5: Mean square values for Zn concentration in various plant parts of maize genotypes as influenced by solution and foliar applied Zn

		Zinc concentration in root (μg g^{-1})					Zinc concentration in stem (μg g^{-1})				
Source (SOV)	DF	8 DAT	16 DAT	24 DAT	32 DAT	40 DAT	8 DAT	16 DAT	24 DAT	32 DAT	40 DAT
Treatment (T)	4	892.5**	504.6**	485.1**	363.6**	430.9**	341.7**	490.6**	336.5**	504.7**	371.4**
Genotype (G)	1	172.6**	104.5**	53.3*	43.2*	112.1**	119.9**	112.1**	104.5**	97.2**	192.5**
T × G	4	34.1*	9.5^{NS}	0.3^{NS}	43.2^{NS}	10.1^{NS}	36.0**	3.1^{NS}	20.9*	2.5^{NS}	5.5^{NS}
Error	20	9.6	9.9	4.5	6.4	6.3	4.3	7.1	7.6	6.7	7.4
		Zinc concentration in young leaves (μg g^{-1})					Zinc concentration in older leaves (μg g^{-1})				
Treatment (T)	4	298.9**	429.7**	277.1**	433.8**	286.1**	338.8**	1257.7**	589.9**	505.0**	424.1**
Genotype (G)	1	97.1**	43.2*	58.8*	128.1**	163.2**	223.9**	202.8**	119.6**	76.8**	64.5**
T × G	4	20.5*	1.2^{NS}	10.8^{NS}	15.1^{NS}	18.3*	4.5^{NS}	37.8**	43.6*	10.5^{NS}	10.9^{NS}
Error	20	5.3	9.1	10.4	7.1	6.9	5.1	7.1	12.7	6.9	6.4

NS = Non-significant ($P > 0.05$); * = Significant ($P \leq 0.05$); ** = Highly significant ($P \leq 0.01$); DF = Degree of freedom; DAT: Days after transplanting

Root Zn accumulation by conventional variety (Pak-Afgoi) ranged from 2.18 to 124.38 μg plant^{-1}. However, shoot Zn accumulation in maize conventional variety with highest values of 618.12 μg plant^{-1}was recorded with solution applied Zn-EDTA, while other Zn treatments *i.e.*, foliar applied Zn-EDTA, solution and foliar applied $ZnSO_4$ illustrated statistically non-significant variation irrespective of control treatment.

Discussion

Plant growth was significantly influenced by application of Zn in maize genotypes. The response of plant growth showed gradual increase with nutrients application (Engels *et al*., 2012). Hybrid genotype Syngenta-8441 had comparatively more plant height and longer roots than conventional variety Pak-Afgoi with solution application of Zn. This may attributes genotypic variation of crop species to their tolerance to low Zn availability in soil. Kaya *et al*. (2002) reported that increase in plant height with Zn addition might be attributed to increased inter-nodal distance. Likewise, El-Badawy and Mehasen (2011), Badshah and Ayub (2013) showed a significant increase in plant height with the foliar application of Zn. Similarly, hybrid genotype produced comparatively more dry matter with solution applied Zn fertilizers as compared with foliar application. Several authors stated an increase in dry matter production of various crops by Zn application to root medium (Randall and Bouma, 1973; Cakmak *et al*., 1998; Alvarez and Rico, 2003; Hoffland *et al*., 2006). Increase in maize dry matter production in response to Zn application might be due enhanced protein synthesis and greater activity of carbonic anhydrase enzyme in growing plants (Mandal *et al.,* 2000; Lisuma *et al.,* 2006). Variation in shoot dry matter on Zn application to rooting medium between the genotypes is attributed to their differential Zn acquisition, translocation and utilization efficiencies (Hoffland *et al.,* 2006).

The differential response of Zn application was observed in Zn concentration and accumulation by various plant parts. Root and stem Zn concentration was more with solution application of Zn-EDTA in maize genotypes. Ozkutlu *et al.* (2006) reported increase in shoot Zn concentration in response to Zn addition to plants. Therefore, increase in Zn uptake probably were either due to the passive uptake of higher solution concentration of Zn-EDTA or high concentration of EDTA physiologically damaging the plant roots and in turn leading to indiscriminate Zn-EDTA uptake (Bremner and Mulvaney, 1982). Therefore, the application of chelated Zn in spray is not much effective in this study. Moreover, author state that the efficiency of foliar application is higher than ground fertilization (Malavolta, 2006). In this study, Zn uptake by roots was higher showing similarities with the results of De Vasconcelos *et al*. (2011). Regarding the form of application, Zn concentrations in stems showed a similar response. These results are in agreements with De Vasconcelos *et al*. (2011) who reported that the application of Zn enhanced stem Zn concentration in maize. Zn concentration in maize plants ranged from 25-150 mg kg^{-1} for shoots, depending on the soil aeration and soil temperature, moisture in the root zone as well as the genetic material (Malavolta, 2006). Moreover, Zn concentration in young leaves was increased more with solution applied Zn-EDTA. This increase was might be because of long term availability of Zn. Bremner and Mulvaney (1982) also reported similar findings. Moreover, Zn concentration in older leaves was increased with foliar applied Zn-EDTA. Foliar spray applications in the early growth stages resulted in greater absorption of Zn than those applied at later growth stages (Gupta and Cutcliffe, 1978). The results are similar with study of Aref (2011) which concluded that Zinc spraying increased Zn concentration in the leaf but adding Zn to the soil had no significant effect on it. These results indicate that Zn uptake in maize is more efficient when foliar applied but in this study solution applied Zn illustrated better results than foliar application because of minimum interactions and more availability to plants. Korndörfer *et al.* (1995) reported that Zn content in the maize leaf increased with Zn application rates to soil. Therefore, the application of foliar Zn to early growth stages perform more effectively than on later stages.

For differential Zn requirement, genotypic variation in maize genotypes could serve as initial step for those plant breeders whose objective is to increase mineral contents of staple food crops through plant breeding and genetics. In the past, breeding programs not put main focus on the improvement of micronutrient concentration in staple food crops (Graham *et al*., 1999; Kanwal *et al*., 2010).

Conclusion

The results indicated that hybrid maize cultivar (Syngenta 8441) accumulate and translocate more Zn in different plant parts as compared to synthetic variety (Pak-Afgoi). It is also concluded that both maize hybrid and synthetic variety are more responsive to solution Zn application as compared to its foliar application.

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