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Effect of Exogenous Zinc Supply on Photosynthetic Rate, Chlorophyll Content and Some Growth Parameters in Different Wheat Genotypes

K. BHARTI[1], N. PANDEY[2], D. SHANKHDHAR[1], P.C. SRIVASTAVA[3] and S.C. SHANKHDHAR[1]*

[1]Department of Plant Physiology, College of Basic Sciences and Humanities,
[2]Department of Entomology, College of Agriculture,
[3]Department of Soil Science, College of Agriculture
G. B. Pant University of Agriculture & Technology, Pantnagar, U.S. Nagar. 263145, Uttarakhand, India

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A two-year field experiment was conducted to study the effect of three zinc levels 0, 20 kg $ZnSO_4$ ha^{-1} and 20 kg $ZnSO_4$ ha^{-1} + foliar spray of 0.5% $ZnSO_4$ solution on plant height, leaf area, shoot biomass, photosynthetic rate and chlorophyll content in different wheat genotypes. Increasing zinc levels was found to be beneficial in improving growth and physiological aspects of genotypes. Soil application + foliar spray proved to be the best application in improving all the parameters. Zinc application brought about a maximum increment limit of 41.8% in plant height, 101.8% in leaf area, 86% in shoot biomass and 51.1% in photosynthetic rate irrespective of stages and year of study. A variation was found to occur among genotypes in showing responses towards zinc application and PBW 550 was found to be more responsive.

Keywords: photosynthetic rate, chlorophyll content, leaf area, shoot biomass, plant height

Introduction

Zinc is a micronutrient involved in an array of vital functions strictly suggesting its essentiality in growth and development. For instance, it is predicted to be a cofactor in over 300 enzymes (Coleman 1998). It forms a structural part in many proteins including very important ones as Zn-finger DNA binding proteins (Rhodes and Klug 1993). Evidently a host of biochemical and physiological processes indispensably require zinc including photosynthesis, the most exploitative phenomenon in the whole plant system and cornerstone in forming the structure of plants and providing energy to drive other plant processes by assimilating carbon. Zinc is a cofactor of important photosynthetic enzymes such as carbonic anhydrase, Rubisco and fructose-1,6-bisphosphate (Ohki 1976). However, if optimum concentrations are not met, it emanates in a multitude of consequences such as malfunctioning of the related enzymes, damage to membranes, lipids, proteins and chlorophyll causing disturbances in metabolic pathways and several physiological disor-

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* Corresponding author; E-mail: shankhdhar.sc@rediffmail.com

ders eventually leading to stunted growth in plants. It is well understood that growth and development of plants are required to be essentially proper in order to prevent any reproductive incapability. Poor growth and development of plants tends to threaten the productivity of plants and raises a concern for crop plants in particular. Unfortunately zinc deficiency has been speculated as one of the widespread micronutrient deficiencies in soil and plants (Cakmak 2002). It is mainly due to decreased solubility of zinc and its low content in soil. About 50% of the soil used for cereal production in the world has been reported to contain a low level of plant available zinc due to soil features such as pH, calcium carbonate content, clay content etc. (Graham and Welch 1996; Cakmak 2011). India along with Pakistan, China, Iran and Turkey are the major regions with Zn deficient soils. This is a major concern for grain yield and nutritional quality. Not to mention the fact that zinc inadequacy in soil results in low zinc content in grains of cereal crop (Shankhdhar and Pant 2003) and therefore a zinc culminated growth would partition more zinc in them. Increasing zinc concentration of edible parts is crucial since approximately 33% of the world's human population consume diets deficient in zinc (Hotz and Brown 2004). Zinc is estimated to be a prosthetic group of some 3000 proteins in human beings and is equally essential as in plants. Zinc deficiency remains a cause of somewhat 450,000 deaths in children every year around the world (Cakmak et al. 2010). Zinc deficiency directed complications include impairments in growth, immune system, learning ability, increased risk of infections, and may even be DNA damage. Wheat a widely and preferentially consumed cereal crop in human diets is an incipient of zinc deficiency to an extent that the problem has emerged as one of the fundamental restrictions in its growth. India being the second largest producer of wheat in the world requires an all time insight into the problem. Zinc fertilization research stands unique in this perspective capable of bringing skyrocketing changes. As mentioned above there are several soil associated problems it is essential to deduce the tendency of foliar zinc application. Thus this paper aims at evaluating the potential of soil zinc fertilization at 20 kg $ZnSO_4$ ha^{-1} with and without foliar application of 0.5% solution of $ZnSO_4$ in improving physiological and different growth parameters of wheat. Also, it is necessary to exploit the genotypic variation to select those genotypes that are more responsive to zinc application in exhibiting improved growth.

Materials and Methods

A two-year field study was conducted at the Norman E. Borlaug Crop Research Centre, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Udham Singh Nagar (Uttarakhand), India during the winter–summer season of 2009–2010 and 2010–2011. Geographically, the site lies in Tarai plains about 30 km southwards of foothills of Shivalik range of the Himalayas at 29° N latitude, 79° 29' E longitude and at an altitude of 243.8 meter above the mean sea level. The experimental plot (typic haplndoll) had a loam texture, 7.0 pH, 0.278 dSm^{-1} E.C. at 25º C, 10.3 g organic C kg^{-1} and 0.42 mg DTPA extractable Zn mg kg^{-1} soil. The field experiment was laid out in split plot design. Ten wheat genotypes, namely UP 262, UP 2338, UP 2382, UP 2572, UP 2554, UP 2584, PBW 343, PBW 550, PBW 175 and PBW 590, were used for the given experiment. Three treatments were given, namely 0 kg $ZnSO_4$ ha^{-1} (Zn_0 or T_1), 20 kg $ZnSO_4$ ha^{-1}) (Zn_{20} or T_2) and 20 kg $ZnSO_4$ ha^{-1} along with foliar spray of 0.5% solution of $ZnSO_4$ ($Zn_{20 + F}$ or T_3). Foliar spray was given at maximum tillering and one week after flowering. Each treatment was replicated thrice. All the growth and physiological parameters were recorded at three growth stages, i.e maximum tillering (S1), flowering (S2) and grain filling (S3). Data regarding plant height was recorded from five plants from each plot. To record data on leaf area, shoot biomass, chlorophyll content three plants were randomly selected from each plot. Leaf area was measured with leaf area meter, LICOR LI-3000A, USA. Photosynthetic rate (P_N) was measured with the instrument Infra Red Gas Analyser, TPS-2 Portable Photosynthesis Systems, USA. Chlorophyll content was measured according to the method described by Hiscox and Israelstam (1979). The statistical analysis of data for all the parameters was carried out with analysis of variance for split plot design. The means were tested at $P > 0.05$ using a STPR software designed at Department of Mathematics, Statistics and Computer Science, CBSH, G.B. Pant Univ. of Agri. & Tech, Pantnagar, India.

Results

Photosynthetic rate (PN)

The data regarding photosynthetic rate (P_N) predicted its significant dependence on the different regimes of zinc. It exhibited an increasing pattern on zinc supplementation for majority of genotypes increasing more rapidly on applying $Zn_{20 + F}$. As an average of all genotypes Zn_{20} enhanced P_N by 7.7% at S1, 10.6% at S2, 3.9% at S3 in 2009–2010 and 14.9% at S1, 10.0% at S2, 8.9% at S3 in 2010–2011 while Zn_{20+F} brought about a considerable increment of 28.4% at S1, 17.1% at S2, 7.6% at S3 in 2009–2010 and 27% at S1, 11.4% at S2, 22.8% at S3 in 2010–2011. P_N was observed to fasten by as much as 51.1% in 2009–2010 and 41.9% in 2010–2011 on zinc application [Table 1 (A)].

Chlorophyll a, chlorophyll b and total chlorophyll content

Evaluating the data relating to chlorophyll a, chlorophyll b and total chlorophyll content of wheat genotypes revealed that these were significantly enhanced on zinc supplementation and increased in progressive manner with increasing levels of zinc for most of the genotypes. $Zn_{20 + F}$ proved to be the best amendment in increasing chlorophylls a & b and total chlorophyll content. Soil application (Zn_{20}) increased chl a by an average of 23% at S1, 22.1% at S2, 12.7% at S3 in 2009–2010 and 12.8% at S1, 3.8% at S2, 2.7% at S3 in 2010–2011 while $Zn_{20 + F}$ enhanced it by 31.1% at S1, 33.1% at S2, 23.8% at S3 during 2009–2010 and 24.7% at S1, 43.4% at S2, 51.6% at S3 during 2010–2011 [Table 1 (B)]. In chl b Zn_{20} gave an increment of 6.8% at S1, 41.8% at S2, 23.9% at S3 in 2009–2010 while 28.9% at S2, 4.6% at S3 during 2010–2011. At S1 a slight reduction of 5.3% was observed. $Zn_{20 + F}$ brought an increment of 17.8% at S1, 37.1% at S2, 32.8% at S3 during 2009–2010 and 4.9% at S1, 16.8% at S2. It was of surprise that at S3 an average decrement of 13.3% was calculated due to the same [Table 2 (A)]. In total chlorophyll content the observed aver-

Table 1. Effect of different Zn levels on photosynthetic rate (μ mol m^{-2} s^{-1}) [A] and chlorophyll a content (mg g^{-1} fresh wt.) [B] at maximum tillering, flowering and grain filling stages in different genotypes of wheat (2009–2010 and 2010–2011)

Genotypes	Maximum tillering						Flowering						Grain filling					
	2009–2010			2010–2011			2009–2010			2010–2011			2009–2010			2010–2011		
	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3
[A] UP262	8.38	8.27	10.64	7.82	9.30	11.10	8.67	10.67	11.27	9.00	10.48	10.99	7.07	8.36	8.44	7.31	8.39	8.97
UP2338	7.93	9.53	11.82	8.40	9.53	11.09	8.93	10.67	10.60	10.18	10.43	10.92	8.10	8.13	8.73	7.23	8.29	9.51
UP2382	7.74	8.39	9.90	8.77	8.57	11.00	9.14	10.23	11.12	10.67	10.40	11.07	8.00	8.49	8.71	7.39	8.27	10.06
UP2572	8.09	8.97	10.81	8.87	10.44	10.32	8.96	10.54	10.11	9.96	11.51	11.04	8.46	9.01	8.37	7.82	8.23	9.50
UP2554	9.26	9.64	10.93	8.94	10.83	11.46	9.73	9.78	11.61	10.16	11.48	10.28	8.14	8.03	8.24	7.62	7.59	9.44
UP2584	8.74	9.48	10.34	8.73	9.98	11.42	10.03	9.97	11.03	9.21	10.73	11.37	8.02	8.07	8.30	7.34	8.77	9.02
PBW343	9.75	9.29	10.63	8.11	9.56	10.29	9.40	10.14	11.44	9.69	10.76	10.56	7.98	8.53	8.98	7.46	7.59	9.06
PBW550	8.45	9.43	10.93	9.54	9.04	10.73	9.37	10.57	11.24	9.31	9.99	10.92	8.51	8.30	9.31	7.51	8.10	8.70
PBW175	7.50	9.34	11.33	8.41	10.62	10.63	9.86	10.30	10.57	10.16	11.09	10.84	8.32	8.09	8.68	7.64	7.46	8.50
PBW590	9.01	8.59	10.86	8.21	10.46	10.67	9.70	10.56	10.61	10.04	11.18	11.31	7.50	7.98	8.27	7.54	8.82	9.10
[B] UP262	0.350	0.461	0.487	0.476	0.491	0.506	0.812	0.966	0.915	0.958	1.036	1.084	0.733	0.681	0.964	0.723	0.785	1.087
UP2338	0.503	0.524	0.546	0.534	0.443	0.555	0.725	0.657	0.799	0.860	0.698	1.004	0.710	0.913	0.852	0.773	0.876	1.049
UP2382	0.392	0.398	0.484	0.451	0.611	0.537	0.896	1.095	1.109	1.036	1.085	1.076	0.934	1.156	1.172	0.926	0.835	1.200
UP2572	0.366	0.499	0.497	0.411	0.537	0.596	0.643	1.122	1.153	0.655	0.947	1.197	0.896	0.949	1.104	0.878	0.912	1.161
UP2554	0.309	0.436	0.459	0.383	0.535	0.555	0.696	1.054	0.967	0.714	0.932	1.430	0.802	0.868	0.928	0.813	0.758	1.254
UP2584	0.482	0.472	0.543	0.512	0.500	0.539	0.947	0.944	1.230	0.988	0.670	1.436	0.685	0.851	0.915	0.722	0.760	1.124
PBW343	0.324	0.366	0.502	0.511	0.500	0.605	0.703	1.216	1.113	0.787	0.699	1.448	0.770	0.868	1.002	0.780	0.771	1.248
PBW550	0.383	0.548	0.499	0.522	0.549	0.645	0.827	0.952	0.964	1.001	1.031	1.209	0.805	0.948	0.929	0.887	0.905	1.157
PBW175	0.422	0.435	0.426	0.460	0.482	0.584	0.911	0.714	1.246	1.010	1.031	1.397	0.948	1.071	1.209	0.695	0.826	1.396
PBW590	0.301	0.475	0.470	0.340	0.443	0.524	1.032	0.997	1.287	1.134	1.213	1.457	0.995	0.996	1.146	0.857	0.799	1.426
	SEM±	CD		SEM±	CD		SEM±	CD		SEM±	CD		SEM±	CD		SEM±	CD	
[A] T	0.11	0.42		0.11	0.45		0.18	0.71		0.13	0.50		0.21	0.82		0.09	0.37	
V	0.17	0.49		0.23	0.66		0.17	0.47		0.25	0.71		0.17	0.48		0.18	0.52	
V within T		0.86			1.14			0.82			1.23			0.82			0.91	
V across T		0.91			1.16			1.04			1.26			1.12			0.93	
[B] T	0.025	0.098		0.008	0.032		0.039	0.154		0.012	0.047		0.007	0.029		0.051	0.199	
V	0.035	0.100		0.015	0.043		0.044	0.124		0.023	0.064		0.028	0.080		0.036	0.103	
V within T		0.173			0.074			0.213			0.111			0.139			0.179	
V across T		0.190			0.077			0.252			0.115			0.135			0.259	

Table 2. Effect of different Zn levels on chlorophyll b (mg g^{-1} fresh wt.) [A] and chlorophyll content (mg g^{-1} fresh wt.) [B] at maximum tillering, flowering and grain filling stages in different genotypes of wheat (2009–2010 and 2010–2011)

Genotypes	Maximum tillering						Flowering						Grain filling					
	2009–2010			2010–2011			2009–2010			2010–2011			2009–2010			2010–2011		
	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3
[A] UP262	0.245	0.247	0.237	0.220	0.259	0.314	0.447	0.513	0.487	0.453	0.451	0.531	0.274	0.274	0.478	0.300	0.443	0.353
UP2338	0.199	0.259	0.254	0.245	0.338	0.293	0.208	0.333	0.412	0.343	0.573	0.465	0.337	0.337	0.605	0.353	0.432	0.336
UP2382	0.222	0.229	0.267	0.314	0.106	0.331	0.442	0.410	0.438	0.438	0.575	0.542	0.388	0.388	0.501	0.390	0.388	0.393
UP2572	0.257	0.247	0.277	0.275	0.228	0.270	0.279	0.490	0.456	0.467	0.439	0.462	0.392	0.392	0.540	0.418	0.227	0.410
UP2554	0.245	0.244	0.318	0.351	0.251	0.297	0.280	0.398	0.494	0.319	0.356	0.266	0.386	0.386	0.539	0.426	0.360	0.316
UP2584	0.171	0.192	0.211	0.194	0.243	0.281	0.368	0.621	0.092	0.423	0.646	0.190	0.512	0.512	0.566	0.463	0.376	0.417
PBW343	0.214	0.238	0.220	0.231	0.220	0.221	0.302	0.471	0.509	0.300	0.541	0.358	0.378	0.378	0.498	0.390	0.426	0.291
PBW550	0.248	0.228	0.259	0.279	0.262	0.237	0.507	0.472	0.478	0.399	0.287	0.365	0.515	0.515	0.527	0.301	0.474	0.240
PBW175	0.148	0.211	0.221	0.297	0.319	0.254	0.386	0.787	0.965	0.232	0.357	0.453	0.504	0.504	0.516	0.540	0.425	0.285
PBW590	0.204	0.163	0.238	0.297	0.244	0.261	0.568	0.635	0.495	0.204	0.258	0.322	0.448	0.448	0.538	0.310	0.345	0.259
[B] UP262	0.589	0.700	0.715	0.688	0.741	0.811	1.244	1.461	1.524	1.394	1.469	1.595	0.994	1.196	1.425	1.010	1.214	1.422
UP2338	0.693	0.773	0.790	0.770	0.772	0.838	0.920	0.979	1.122	1.188	1.258	1.451	1.034	1.330	1.442	1.112	1.293	1.367
UP2382	0.607	0.619	0.742	0.757	0.706	0.858	1.322	1.486	1.390	1.456	1.641	1.599	1.305	1.635	1.653	1.300	1.208	1.572
UP2572	0.616	0.737	0.765	0.678	0.755	0.856	0.911	1.592	1.705	1.110	1.369	1.638	1.273	1.450	1.624	1.281	1.123	1.551
UP2554	0.548	0.673	0.769	0.726	0.777	0.843	0.964	1.433	1.584	1.021	1.272	1.672	1.174	1.360	1.450	1.224	1.104	1.548
UP2584	0.645	0.656	0.744	0.697	0.734	0.810	1.299	1.548	1.650	1.394	1.304	1.602	1.184	1.302	1.464	1.172	1.122	1.522
PBW343	0.532	0.598	0.712	0.733	0.711	0.815	0.993	1.666	1.733	1.073	1.227	1.782	1.134	1.318	1.483	1.156	1.183	1.518
PBW550	0.624	0.766	0.749	0.792	0.801	0.870	1.319	1.407	1.523	1.382	1.300	1.553	1.305	1.438	1.439	1.173	1.363	1.377
PBW175	0.563	0.638	0.640	0.749	0.793	0.827	1.280	1.488	2.156	1.225	1.370	1.826	1.435	1.536	1.703	1.222	1.236	1.657
PBW590	0.499	0.630	0.700	0.631	0.679	0.775	1.582	1.613	1.917	1.319	1.451	1.754	1.426	1.499	1.664	1.152	1.130	1.661
	SEM±	CD		SEM±	CD		SEM±	CD		SEM±	CD		SEM±	CD		SEM±	CD	
[A] T	0.016	0.062		0.015	0.058		0.043	0.168		0.023	0.089		0.021	0.082		0.020	0.079	
V	0.026	0 .075		0.017	0.049		0.081	0.230		0.024	0.068		0.081	0.084		0.022	0.061	
V within T		0.130			0.084			0.399			0.118			0.144			0.106	
V across T		0.137			0 .097			0.411			0.141			0.145			0.126	
[B] T	0.021	0.082		0.008	0.030		0.055	0.217		0.016	0.063		0.020	0.079		0.036	0.141	
V	0.040	0.112		0.010	0.054		0.080	0.228		0.022	0.063		0.038	0.108		0.029	0.083	
V within T		0.194			0.094			0.394			0.109			0.187			0.143	
V across T		0.200			0.093			0.429			0.120			0.198			0.193	

age enhancement due to Zn_{20} was 15.1% at S1, 27.1% at S2, 15.3% at S3 in 2009–2010 and 3.7% at S1, 9.6% at S2, 2.1% at S3. The increment due to Zn_{20+F} was about 24.5% at S1, 40.8% at S2, 26.1% at S3 during the first crop season and 15.3% at S1, 33.3% at S2, 29.0% at S3 during the second crop season. It exhibited a maximum increment limit of 87.1% in 2009–2010 and 66.1% in 2010–2011 in chlorophyll content [Table 2 (B)].

Leaf area

The data concerning the leaf area of wheat genotypes revealed their significant response towards different regimes of zinc. The increasing levels of zinc were found to progressively expand the leaf area at all stages in majority of genotypes. The highest leaf area values were obtained when genotypes were nurtured with Zn_{20+F}. Averaging across all genotypes Zn_{20} caused an expansion of 14.5% at S1, 17.9% at S2, 5.2% at S3 in 2009–2010 and 6.8% at S1, 8.7 at S2, 7.5% at S3 in 2010–2011. Zn_{20+F} produced an expansion of 36.3% at S1, 34.2% at S2, 14.4% at S3 in 2009–2010 and a marked increment of 57.4% at S1, 15.2% at S2, and 12.0% at S3 in 2010–2011. The maximum increment that Zn_{20+F} could bring in leaf area was found to be very high in both the years (97.6% in 2009–2010 and 101.8% in 2010–2011) [Table 3 (A)].

Shoot dry biomass

Interpretation of data concerning shoot dry biomass revealed that different regimes of zinc had a significant effect on shoot dry mass. The rising levels of zinc increased the shoot dry mass progressively at all stages for most of the genotypes with the highest values obtained when genotypes were supplied with Zn_{20+F}. Soil application gave an increment of 27.4% at S1, 14.42% at S2, 11.9% at S3 in 2009–2010 and 14.2% at S1, 10.8% at S2. Combined application (Zn_{20+F}) brought about increments of 5.6% at S1, 31.24% at S2, 18.38% at S3 during first crop season and 14.3% at S1, 9.4% at S2 and 11.5% at S3 during the second crop season. It should be noted that at S3 a slight decrement of 0.4% was observed on application of Zn_{20} during 2010–2011 though it has been found to be influensive in case of rest two stages. Irrespective of the application given and the stage of growth during 2009–2010 the genotypes UP 2554, UP 2584, PBW 550 showed the maximum increments of 86%, 65.12% and 64.12%, respectively, while during 2010–2011 it were PBW 550, PBW 590, PBW 343 exhibiting the maximum increments of 47.3%, 32.1% and 27.1%, respectively [Table 3 (B)].

Plant height

The effect of zinc application on wheat genotypes revealed a significant increment on the plant height as well. Most of the genotypes exhibited a progressive pattern with rising levels of zinc at all growth stages with the highest values obtained on supply of Zn_{20+F}. As an average of all genotypes Zn_{20+F} gave an increment of 13.89% at S1, 8.77% at S2, 6.48% at S3 in 2009–2010 and 7.2% at S1, 7.1% at S2, 4.3% at S3 in 2010–2011 while Zn_{20+F} an enhancement of 23.46% at S1, 8.8% at S2, 9.0% at S3 during first crop season and 13.8% at S1, 9.9% at S2, 4.3% at S3 during second crop season. Zn_{20+F} was found to be capable

Table 3. Effect of different Zn levels on leaf area (cm^2) [A] and shoot biomass (g plant^{-1}) [B] at maximum tillering, flowering and grain filling stages in different agenotypes of wheat (2009–2010 and 2010–2011)

Genotypes	Maximum tillering						Flowering						Grain filling					
	2009–2010			2010–2011			2009–2010			2010–2011			2009–2010			2010–2011		
	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3
[A] UP262	72.45	87.54	97.67	65.89	70.87	102	125.31	137.97	146.7	113.22	126.99	141.29	118.55	121.93	137.52	118.33	122.42	136.52
UP2338	69.46	86.97	89.37	61.6	64.77	98.6	144.65	154.58	151	122.16	130.65	149.72	138.23	133.26	126.41	121.7	133.35	126.12
UP2382	65.24	84.78	72.71	69.21	60.2	86	112.99	135.61	140.2	118.87	140.44	129.17	119.19	124.59	126.75	119.73	134.25	133.5
UP2572	58.5	67.35	74.34	56.39	84.03	67.9	102.78	119.57	139.6	120.14	128.78	135.52	107.88	119.3	133.91	113.89	132.32	141.13
UP2554	64.42	66.9	100.8	75.17	67.41	103	120.75	144.75	135.5	126.64	134.2	133.77	121.56	119.56	130.47	118.15	140.22	135.01
UP2584	59.8	66.9	84.59	56.47	61.92	96.6	93.43	119.41	121.2	123.89	130.89	143.81	109.63	121.96	120.82	121.05	118.33	130.06
PBW343	62.9	64.37	72.99	62.51	61.96	100	108.19	176.82	165.8	121.08	136.29	125.12	102.59	99.63	122.07	121.82	117.48	129.71
PBW550	71.99	71.75	109.7	64.5	64.4	107	95.94	93.87	189.6	126.65	134.18	142.89	97.2	109.13	131.28	115.81	129.26	137.26
PBW175	75.18	73.06	118.7	59.32	63.92	120	125.89	127.5	127	117.75	133.4	143.94	118.38	118.5	116.89	124.59	135.18	132.84
PBW590	63.5	88.11	86.6	63.7	72.21	114	101.46	117	169.1	125.15	123.9	162.58	100.6	119.22	136.5	125.43	126.58	140.86
[B] UP262	0.380	0.582	0.430	0.435	0.506	0.442	1.352	1.585	1.585	1.640	2.076	1.993	3.89	4.453	4.954	4.903	4.801	5.077
UP2338	0.373	0.444	0.451	0.467	0.467	0.517	1.564	1.986	1.986	1.687	1.972	1.812	4.33	4.758	5.400	5.147	4.969	5.437
UP2382	0.435	0.403	0.294	0.439	0.518	0.515	1.569	1.734	1.734	1.885	1.910	2.128	4.41	4.046	4.767	4.892	5.138	5.370
UP2572	0.372	0.494	0.323	0.463	0.482	0.578	1.531	2.017	2.017	1.920	2.109	1.908	4.10	4.838	5.197	5.376	4.198	5.627
UP2554	0.268	0.499	0.402	0.473	0.507	0.542	1.692	1.925	1.925	1.846	1.953	1.917	5.61	4.847	6.013	5.149	5.601	5.831
UP2584	0.331	0.380	0.337	0.460	0.520	0.465	1.469	1.852	1.852	1.827	1.930	1.997	3.82	4.954	5.554	4.830	5.271	5.173
PBW343	0.375	0.408	0.346	0.422	0.450	0.496	1.799	1.742	1.742	1.861	2.122	2.006	4.72	5.221	5.100	4.378	4.529	5.428
PBW550	0.266	0.439	0.417	0.451	0.572	0.490	1.682	1.853	1.853	1.880	1.967	2.040	5.04	5.000	5.442	4.799	4.796	6.103
PBW175	0.432	0.401	0.347	0.395	0.465	0.582	1.743	1.946	1.946	1.824	1.927	2.021	4.35	5.610	4.533	4.806	4.277	4.916
PBW590	0.415	0.450	0.359	0.484	0.640	0.484	1.747	1.733	1.733	1.767	2.079	1.984	4.01	5.226	4.979	4.982	5.378	5.858
	SEM±	CD		SEM±	CD		SEM±	CD		SEM±	CD		SEM±	CD		SEM±	CD	
[A] T	0.83	3.20		0.33	13.01		6.83	26.74		1.33	5.21		2.36	9.23		2.00	7.81	
V	0.26	7.43		2.39	6.77			25.45		3.83	10.87			12.08		2.74	7.76	
V within T		12.87			11.72			44.08			18.83			20.80			13.44	
V across T		12.60			16.90			49.18			18.55			21.65			14.33	
[B] T	0.32	0.130		0.006	0.024		0.072	0.280		0.55	0.215		0.087	0.340		0.073	0.285	
V	0.42	0.120		0.025	0.071		0.073	0.210		0.51	0.146		0.190	0.530		0.210	0.596	
V within T		0.210			0.123			0.360			0.252			0.920			1.033	
V across T		0.231			0.119			0.436			0.317			0.930			1.033	

Table 4. Effect of different Zn levels on plant height (cm) at maximum tillering, flowering and grain filling stages in different genotypes of wheat (2009–2010 and 2010–2011)

Genotypes	Maximum tillering						Flowering						Grain filling					
	2009–2010			2010–2011			2009–2010			2010–2011			2009–2010			2010–2011		
	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3
[A] UP262	35.59	43.29	48.05	34.22	39.43	40.99	59.45	67.81	63.45	61.38	61.41	65.85	92.16	96.27	101.30	95.23	98.89	104.93
UP2338	31.13	33.97	36.37	35.25	38.55	36.41	45.38	49.32	53.49	56.38	60.21	63.41	85.07	92.50	89.73	88.37	94.70	96.69
UP2382	36.65	39.04	45.03	38.01	35.79	41.57	60.93	63.12	58.05	58.78	63.72	65.84	83.40	88.57	83.67	86.07	91.62	95.07
UP2572	30.73	34.49	37.67	28.63	36.11	38.91	51.79	56.17	59.49	58.79	63.01	61.99	87.87	91.00	95.90	93.85	98.88	101.87
UP2554	24.65	27.90	34.94	31.86	34.00	37.15	49.31	52.46	54.77	51.46	60.40	59.27	82.93	87.50	90.10	82.67	85.59	84.63
UP2584	35.63	33.87	37.75	38.42	37.46	40.03	51.15	49.65	55.11	54.07	59.12	59.46	79.10	82.97	85.43	82.93	85.00	84.65
PBW343	30.50	36.43	34.83	37.95	37.37	38.65	51.19	48.97	51.93	56.31	59.84	60.95	81.47	85.45	88.53	84.90	86.27	89.85
PBW550	33.60	35.97	39.59	37.01	38.20	40.43	61.10	64.89	71.07	62.77	61.64	65.28	70.93	77.87	83.97	81.90	84.07	85.80
PBW175	36.52	47.48	45.25	37.46	40.75	47.19	64.07	64.17	69.49	58.34	61.26	66.59	100.87	109.57	106.53	105.97	109.2	110.57
PBW590	29.17	36.37	38.99	35.04	39.27	39.24	51.65	59.40	55.74	55.91	62.77	61.42	70.86	76.67	81.97	75.86	81.34	93.07
	SEM±	CD		SEM±	CD		SEM±	CD		SEM±	CD		SEM±	CD		SEM±	CD	
[A] T	0.59	2.02		0.44	1.72		0.49	1.92		0.51	2.01		0.62	2.44		0.50	1.94	
V	0.97	2.74		0.66	1.86		0.87	2.46		0.70	1.99		1.30	3.66		0.71	2.02	
V within T		4.76			3.22			4.27			3.45			6.39			3.50	
V across T		4.92			3.48			4.45			3.81			6.50			3.81	

of increasing the tallness of genotypes up to an appreciably higher limit of 41.8% and 35.9% in 2009–2010 and 2010–2011 [Table 4 (A)].

Discussion

An efficient growth and development of plants give an indication of crop productivity and its nutritional value. It is therefore essential to suffice the plants with all the necessary factors required for plants to grow and develop well. Mineral composition (various macronutrients and micronutrients) is one such important determinant. The present study therefore exemplifies how the availability of zinc (one of the cardinal micronutrients) affected the different growth and physiological characteristics of wheat crop whose dearth was otherwise consequential in hidden hunger of plants. Surprisingly, a decrement has also been calculated in few genotypes for some parameters but lastly a synergistic relationship can be figured out among them. First of all it is essential to study photosynthetic efficiency of plants as photosynthesis is the most important phenomenon in plants utilised for growth and development. Zinc application was also positively correlated to the rate of photosynthesis in all the stages. It is attributable to the necessity of zinc in different photosynthetic enzymes such as ribulose bisphosphate carboxylase and carbonic anhydrase, one facilitating the fixation and other absorption of carbon dioxide. Apart from this participation of zinc in improvement of the temperature tolerance of photosynthetic apparatus (Graham and McDonald 2001) and of stomatal conductance (Khan et al. 2004) would have have also contributed. The findings in the present study are in line with those of Ahmed et al. (2009). Since leaves are the primary photosynthetic organs of the plant, it is important to study growth in terms of leaf area. Larger leaves provide a larger surface for many stomata per unit area and a greater number of chloroplasts facilitating the process of photosynthesis and signifying a broader assimilating area of crop, generating an improved nutritional source, carbohydrates in particular. Notably the size of leaf blade may be drastically reduced under zinc deficient conditions (Cakmak et al. 1998). This is mainly due to zinc requirement in tryptophan biosynthesis which in turn is a prerequisite for formation of growth hormone auxin. A rise in the tryptophan content upon zinc fertilization in rice grains also supports this explaination (Brown et al. 1993). Given this a positive relationship was established between leaf area and zinc nutrition in the present investigation. A high accumulation of zinc in meristematic regions of the leaves as studied by Pearson and Rengel (1995) further indicates its role in leaf growth. Our study also seeks support from the work of various earlier workers who reported an increased leaf area index on zinc application (Shukla and Warsi 2000; Chaab et al. 2011). Zinc supplementation was also potent in enhancing chlorophyll content in leaves in the present study. Zinc is considered to play an important role in the construction of chloroplasts' ultra structure. Also, deficiency of zinc can bring about oxidative damage of chlorophyll as well as of chloroplast membrane (Cakmak 2000). This would have been the possible reason of an increased chlorophyll concentration in heat stressed plants receiving higher dose of zinc than those with lower dose in the study of Graham and McDonald (2001). An increase in SPAD value (leaf chlorophyll content) was reported in wheat crop on application of 0.1 mg l^{-1} Zn (Zhao et al. 2011).

Measurement of shoot dry mass plays a very important role in growth study because it is often equated with yield of any crop. Shoot biomass should be greater so that greater assimilate partitioning could be achieved during grain filling period. It suggests the efficiency of photosynthesis as it represents the balance between CO_2 uptake, photosynthesis and respiration. Thus why the shoot dry mass enhanced with zinc doses can be easily understood by the above-mentioned correlation between photosynthesis and zinc. The accumulation of photosynthates makes the leaves and stem thicker and stiffer. Being a multifactorial trait it also depends on enlarged leaf area and greater proliferation of tillers brought about by zinc supplementation. The requirement of zinc in zinc regulated transporters for transportation of other important ions participating in metabolism is one more explanation in enhanced shoot biomass. It has also been observed to reduce under zinc starvation while enhanced under zinc supply in the studies of Kumar and Qureshi (2012) and Siddiqui et al. (2013). Improvement or depression in plant height is also a good measure of plant growth. The importance of zinc in the formation of growth regulators is well established therefore zinc deficiency causes a reduction in internodal length which in turn affects plant growth. A reduction of about 95% in plant height has been observed under zinc deficient conditions (Wissuwa et al. 2006). Likewise the present study, reduced growth and its resumption with zinc nutrition is reflected in work of several workers (Gul et al. 2011; Ahmed et al. 2012). The efficacy of a sound growth culminated by zinc nutrition can be easily predicted by enhanced yield and other yield attributes determined in the same experiment but previously published as Bharti et al. (2013). It might have been through better functioning of several processes like photosynthesis, respiration, chlorophyll synthesis, greater assimilate partitioning eventually resulting in accumulation and translocation of more of photosynthates to the grains. Besides, zinc application would have supported growth in two more ways. One by preventing Boron to accumulate at toxic levels in young leaves and tips of branches (Mousavi et al. 2012) and other by increasing the water use efficiency of the plants (Khan et al. 2004).

Conclusively foliarly applied zinc along with soil was most suitable in enhancing the growth of wheat genotypes indicating the capability of wheat leaves to absorb the zinc sulphate solution and its effective translocation to other wheat tissues and organs. The timing and number of foliar application applied in the study was found to be suited in providing improved results. Similar to other studies a variation was observed in genotypes in exhibiting response towards zinc application. Considering the findings of both the growing seasons among all the genotypes PBW 550 was found to be more responsive to zinc application.

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References

Ahmed, H., Khalil, A.H., Rahman, M.K., Abd, E.I., Nadia, A.M., Hamed, A.M. 2012. Effect of zinc, tryptophan and indole acetic acid on growth, yield and chemical composition of valencia orange trees. J. of Appl. Sciences Res. **8**:901–914.

Ahmed, N., Ahmad, F., Abid, M., Aman, U.M. 2009. Impact of zinc fertilization on gas exchange characteristics and water use efficiency of cotton crop under arid environment. Pakistan J. of Botany **41**:2189–2197.

Bharti, K., Pandey, N., Shankhdhar, D., Srivastava, P.C., Shankhdhar, S.C. 2013. Evaluation of some promising wheat genotypes (*Triticum aestivum* L.) at different zinc regimes for crop production. Cereal Res. Commun. **41**:539–549.

Brown, P.H., Cakmak, I., Zhang, Q. 1993. Form and function of zinc in plants, Chap 7. In: Robson, A.D. (ed.), Zinc in Soils and Plants. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 90–106.

Cakmak, I. 2000. Possible roles of zinc in protecting plant cells from damage by reactive oxygen species. New Phytol. **146**:185–205

Cakmak, I. 2002. Plant nutrition research: Priorities to meet human needs for food in sustainable ways. Plant and Soil **247**:3–24.

Cakmak, I. 2011. Zinc plays critical role in plant growth. Available: http://www.zinc.org/crops/resourceserve/zinc_plays_critical_role_in_plant_growth.

Cakmak I., Pfeiffer, W., Mcclafferty, B. 2010. Biofortification of durum wheat with zinc and iron. Cereal Chem. **87**:10–20.

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

Chaab, G., Savaghebi, R., Motesharezadeh, B. 2011. Differences in the zinc efficiency among and within maize cultivars in a calcareous soil. Asian J. of Agricultural Sciences **3**:26–31.

Coleman, J.E. 1998. Zinc enzymes. Current Opinion in Chemical Biology **2**:222–234.

Graham, A.W., McDonald, G.K. 2001. Effect of zinc on photosynthesis and yield of wheat under heat stress. Proc. 10th Australian Agronomy Conf. Australian Society of Agronomy. Hobart, Tasmania, Australia, Available online at http://www.regional.org.au/au/asa/2001/2/c/graham.htm.

Graham, R.D., Welch, R.M. 1996. Breeding for staple food crops with high micronutrients density. Agricultural strategies for micronutrient. Working Paper no. 3. International Food Policy Research Institute, Washington D.C., USA.

Gul, H., Ahmad, S., Beena, S., Fida, M., Ahmad, I. 2011. Effect of foliar application of nitrogen, potassium and zinc on wheat growth. J. of Agricultural and Biological Sci. **6**:4.

Hiscox, J.D., Israelstam, G.F. 1979. A method for the extraction of chlorophyll from leaf tissue without maceration. Can. J. of Botany **57**:1332–1334.

Hotz, C., Brown, K.H. 2004. Assessment of the risk of zinc deficiency in populations and options for its control. The Food and Nutrition Bulletin **25**:S132– S162.

Khan, H.R., McDonald, G.K., Rengel, Z. 2004. Zinc fertilization and water stress affects plant water relations, stomatal conductance and osmotic adjustment in chickpea (*Cicer arientinum* L.). Plant and Soil **267**:271–284.

Kumar, M., Qureshi, F.M. 2012. Dynamics of zinc fractions, availability to wheat (*Triticum aestivum* L.) and residual effect on succeeding maize (*Zea mays* L.) in inceptisols. J. Agr. Sci. **4**:236–245.

Mousavi, S.R., Galavi, M., Rezaei, M. 2012. The interaction of zinc with other elements in plants: A review. Int. J. of Agriculture and Crop Sci. **4**:1881–1884.

Ohki, K. 1976. Effect of zinc nutrition on photosynthesis and carbonic anhydrase activity in cotton. Plant Physiol. **38**:300–304.

Pearson, J.N., Rengel, Z. 1995. Uptake and distribution of ^{65}Zn and ^{54}Mn in wheat grown at sufficient and defecient levels of Zn and Mn. I. During vegetative growth. J. Exp. Bot. **46**:833–839.

Rhodes, D., Klug, A. 1993. Zinc fingers. Scientific American **268**:56–65.

Shankhdhar, S.C., Pant, R.C. 2003. Improving iron and zinc content of crops for better human health. In: Pant, R.C., Ghildyal, M.C. (eds), Proc. International Congress of Plant Physiology and Sustainable Plant Productivity under Changing Environment. Indian Society for Plant Physiology. New Delhi, India, pp. 39–51.

Shukla, S.K., Warsi, A.S. 2000. Effect of sulphur and micronutrients on growth, nutrient content and yield of wheat (*Triticum aestivum* L.). Indian J. of Agricultural Research **34**:203–205.

Siddiqui, S.N., Umar, S., Iqbal, M. 2013. Searching for chickpea genotypes with high Zn-accumulating capacity: A way to identify nutrient-efficient crop plants. Int. J. of Agronomy and Plant Production **4**:1697–1705.

Wissuwa, M., Ismail, A.M., Yanagihara, S. 2006. Effects of zinc deficiency on rice growth and genetic factors contributing to tolerance. Plant Physiol. **142**:731–741.

Zhao, A.Q., Bao, Q.L., Tian, X.H., Chun, L.X., Jeff, G.W. 2011. Combined effect of iron and zinc on micronutrient levels in wheat (*Triticum aestivum* L.). J. of Environmental Biology **32**:235–239.