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Assessment of Genetic Variation and Zinc Deficient Tolerance in Spring Durum Wheat (*Triticum durum* Desf.) Genotypes in Calcareous Soil with Zinc Deficiency

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Abstract

Low zinc (Zn) availability and its absorption limit wheat production and quality of yield in calcareous soils. In order to identify Zn deficient stress tolerance in wheat, fifteen spring genotypes (Diyarbakir-81; Gediz-75; Svevo; Zenit; Amanos-97; Fuatbey-2000; Balcali-2000; Ceylan-95; Firat-93; Aydin-93; Ozbek; Artuklu; Akcakale-2000; Aday-19; and Ege-88) were evaluated under two conditions (normal and Zn deficient stress) in 2014-2015 growing season. This research was carried out in a factorial experiment based on randomized complete block design with three replications. Results of variance analysis showed that zinc-deficient stress had significant effects on plant height (PLH), spike length (SL), peduncle length (PedL), grains number per spike (GNPS), biomass yield (BY), and grain yield (GY). There were significant differences among genotypes for all studied traits, except spike length, BY, and GY. The interaction effects of genotypes and Zn deficient stress conditions were non-significant for all studied traits. The results showed that zinc-deficient stress caused 7.3, 9.5, 8.0, 20.8, 18.6, and 22.1% reduction in PLH, SL, PedL, GNPS, BY and GY, respectively. But had no significant effect on 1000-grain weight and harvest index. Results showed that 'Gediz-75' genotype with 0.62 g/plant and 14 grains had the highest GY and GNPS under two different conditions. But, 'Aday-19' genotype with 0.36 g/plant and 8.3 grains had the lowest GY and GNPS under two different conditions. The 'Gediz-75' genotype showed the highest STI (1.186), GMP (0.610), MP (0.621), and HARM (0.599) Zn stress indices. However, the 'Aday-19' genotype showed the lowest STI (0.399), GMP (0.354), MP (0.360), and HARM (0.347) Zn stress indices. With consideration, the correlation between indices and grain yield under zinc-deficient stress and non-stress, these indices (except the TOL, SSI, RDI, YSI, DI, ATI, and SSPI) were identified as the best stress indices for isolation and selection of tolerant genotypes.

Key words: Durum wheat; Zinc deficit; Grain yield; Zinc stress index; Calcareous soil.

Introduction

Zinc (Zn) deficiency is a worldwide nutritional constraint in crop production particularly for growth and yield of crops in calcareous soils (Alloway, 2009; Cakmak *et al*., 2010). So, Zn is a micronutrient for living organisms (including animals and plants), which is required in various metabolic processes such as protein synthesis, synthesis of the auxin precursor tryptophan, and maintenance of cell membrane integrity (Vallee and Auld, 1990). Zinc deficiency causes several changes in morphological traits and physiological processes (i.e. decrease in photosynthesis rate, membrane stabilization, and activity of starch and protein synthesis) and finally reduction in crop production (Brown *et al*., 1993). McCauley *et al*. (2009) reported that increase in grain yield and biomass was attributed to improved physiology of plants by addition of Zn in calcareous soil. Ordinarily, Zn is an important nutrient for growth and development of human and its shortage in food causes severe damages economically, due to malnutrition considerations. It is estimated that more than one-third of population is affected by Zn deficiency, particularly children, and pregnant women and low dietary intake of Zn has been discussed as a major reason (White and Broadley, 2009).

Grain filling is a critical growth stage in grain crops such as wheat and involves in various biochemical processes related to leaf assimilation and synthesis of carbohydrates, proteins, and lipids in grains (Saeidi and Abdoli, 2015). Grain yield (GY) and biomass were closely and positively associated with rates of photosynthetic efficiency and chlorophyll content of leaves, suggesting that both aboveground biomass and GY were determined by influence of zinc-deficient treatments on photosynthetic capacity and assimilate transfer to grain (Wang and Jin, 2005; Zhao and Wu, 2017). Abdoli *et al.* (2016) stated that Zn has an important role in the improvement of quantitative and qualitative wheat yield. Zn deficient decreased the GY due to its effect on the number of fertile spikelet per spike and the number of grains per spike. On the other hand, it is stated that enhanced GY with the optimum delivery of Zn, which might be the end result of belated senescence of leaf, continued photosynthesis in leaf at the time of grain filling phase and extensive period of filling of grains (Arif *et al.*, 2017).

Among major crops, wheat is the most important field crop in the world (Emam, 2011), which supplies food for more than 35% of the world population (Amiri and Assad, 2005). However, up to 50% of wheat-cultivated soil in the world is considered poor in plant-available Zn. Under such conditions, wheat genotypes cannot be capable enough for Zn absorption and accumulation, and therefore, Zn concentrations and agronomic traits are reduced that ultimately decreased GY (Cakmak, 2008; Cakmak and Kutman, 2017). Recently, conventional and molecular plant breeding methods, genetic modification techniques (transgenic technologies) accompanied by agronomic interventions including appropriate fertilizer applications have known as major tools that are used and investigated for biofortification of food crops with Zn (Sadeghzadeh *et al.*, 2010; Sadeghzadeh *et al.*, 2015; Abdoli *et al.*, 2016; Cakmak and Kutman, 2017; Pataco *et al.*, 2017). As regards, plant species and genotypes differ in their Zn requirement.

In most crops, adaptations mechanisms almost are related to morpho-physiological features so morphological traits could be used for genotypes selection as credible indicators in nutrient deficient stress conditions. There are several stress indices proposed by many researchers as introduced as effective tools to identify genotype with better stress tolerance and high yield potential. Khoshgoftarmanesh *et al.* (2009) showed that STI could be better selection criterion compared with other indices to identify high yielding wheat genotypes in zinc stress condition. Singh *et al.* (2016) reported that GMP, MP and STI indices can be efficiently exploited not only for screening drought tolerance but also for identification of superior genotypes suitable for both stress and non-stress field conditions. In another study, Khoshgoftarmanesh *et al.* (2011) expressed that grain yield had significant positive correlation with MP, GMP, and STI under with or without Zn treatments. However, there are few studies in consideration of how micronutrient deficiencies influence on Zn deficient resistance indices. Production of durum wheat (*Triticum durum* Desf.) comprises approximately of 30 million tons from 16 million hectares (Pataco *et al.*, 2015). Also, durum wheat is the most important food supply in world and Iran. The aim of this experiment was to determine the influences of Zn deficient stress on (i) agronomic traits, grain yield, and other components of spring durum wheat (*Triticum durum* Desf.) genotypes and also (ii) to study genetic variation and Zn deficient tolerance in wheat genotypes under zinc-deficient calcareous soil.

Materials and Methods

Experimental site and soil characters

In order to identify Zn stress tolerance in durum wheat, fifteen spring genotypes were evaluated under two conditions (normal and zinc deficient stress) during 2014-2015 growing season in University of Maragheh at Maragheh, Iran (46º, 16'/E; 37º, 22'/ N, altitude 1542 m). The soil of experimental site had a clay loam texture with pH (H_2O) 7.2, 20% $CaCO_3$ and 0.4% organic matter. The concentration of DTPA-extractable Zn was 0.4 mg/kg soil (Lindsay and Norvell, 1978), which is lower than the widely accepted critical Zn concentration of 0.5 mg/kg (Sims and Johnson, 1991). According to soil test and before sowing, the soil was mixed homogeneously with a basal treatment of 200 mg N/kg soil as $Ca(NO_3)_2.4H_2O$ and 100 mg P/kg soil as KH_2PO_4 sources.

Experimental design and treatments

The pot experiment was carried out in a factorial design in the randomized complete block design (RCBD) with 30 treatments (2 Zn conditions, and 15 durum wheat genotypes) in three replications. The first factor was two condition of Zn were (1) zinc deficient stress (non-Zn application; -Zn), and (2) normal soil application (5 mg Zn/kg soil; +Zn), and also the second factor was fifteen spring durum wheat genotypes including ‘Diyarbakir-81’, ‘Gediz-75’, ‘Svevo’, ‘Zenit’, ‘Amanos-97’, ‘Fuatbey-2000’, ‘Balcali-2000’, ‘Ceylan-95’, ‘Firat-93’, ‘Aydin-93’, ‘Ozbek’, ‘Artuklu’, ‘Akcakale-2000’, ‘Aday-19’, and ‘Ege-88’. These fifteen durum wheat genotypes were chosen because they were new modern genotypes with unknown agronomic and physiological characteristics.

Plant material and growth conditions

The seeds of wheat genotypes were provided by Dryland Agricultural Research Institute (DARI) of Iran. The agronomic traits and growth characteristics of genotypes used in the experiments are shown in Table 1. Seeds were planted on 12th March 2014 in plastic pots (PVC) with a diameter of 20 cm and height of 30 cm which was filled with 3.5 kg of soil. Fourteen seeds were sown in each pot and daily watered by deionized water, and the seedlings were thinned to seven seedlings per pot at 3 to 4-leaf stage. Irrigation of plant in the pots (90% of field capacity) and weeds were controlled from pots close to physiological maturity of plants.

Agronomic traits and yield attributes measurements

Plant height, spike length, peduncle length, grains number per spike, 1000-grain weight, biomass yield, grain yield, and harvest index traits were recorded randomly in five plants (individuals) harvested from each pot at the maturity period.

Zinc deficient resistance indices determination

In order to estimates the sensitivity and tolerance indices under Zn deficit stress in different spring durum wheat genotypes, the relationships that proposed by Fischer and Maurer (1978), Fischer and Wood (1979), Rosielle and Hamblin (1981), Bouslama and Schapaugh (1984), Lin *et al.* (1986), Fernandez (1992), Kristin *et al.* (1997), Lan (1998), and Moosavi *et al.* (2008) were used. All of aforementioned indices studied are shown in Table 2.

Table 1. List of spring durum wheat genotypes used in the experiment.

No.	Genotype name	VT	DHE	DMA	PLH	HGW (g)	GY (kg/ha)	Origin	Year of release
1	Diyarbakir-81	4	156	183	54	40	2155	Turkey	1981
2	Gediz-75	2	161	191	44	34	1591	Turkey	1976
3	Svevo	3	156	183	51	34	2236	Turkey	1997
4	Zenit	3	155	185	39	34	1818	Turkey	1997
5	Amanos-97	3	158	186	47	36	1145	Turkey	1997
6	Fuatbey-2000	3	156	185	48	38	1973	Turkey	2000
7	Balcali-2000	5	160	185	44	38	1536	Turkey	2000
8	Ceylan-95	5	156	187	47	34	2418	Turkey	1995
9	Firat-93	2	157	191	46	38	1418	Turkey	2002
10	Aydin-93	5	155	185	46	32	2691	Turkey	1993
11	Ozbek	1	162	186	46	40	1036	Turkey	2005
12	Artuklu	4	156	183	54	38	2882	Turkey	2008
13	Akcakale-2000	1	166	198	39	36	491	Turkey	2002
14	Aday-19	3	159	189	52	38	2473	-	-
15	Ege-88	2	157	186	50	38	2709	Turkey	1988

Vigoure at tillering stage (VT), days to heading (DHE), days to maturity (DMA), plant height (PLH), 1000-grain weight (HGW), and grain yield (GY). Source: Dryland Agricultural Research Institute, Agricultural Research, Education and Extension Organization (AREEO), Maragheh, Iran.

Table 2. List of zinc stress tolerance indices used in the experiment.

No.	Index	Formula	Reference
1	Stress Susceptibility Index	$SSI = [1 - (Ys / Yp)]/SI$	Fischer and Maurer (1978)
2	Stress Index	$SI = \left(1 - \frac{\bar{Y}s}{\bar{Y}p}\right)$	
3	Stress Tolerance	$TOL = Yp - Ys$	Rosielle and Hamblin (1981)
4	Mean Productivity	$MP = \frac{Ys + YP}{2}$	Rosielle and Hamblin (1981)
5	Geometric Mean Productivity	$GMP = \sqrt{Ys \times Yp}$	Fernandez (1992)
6	Stress Tolerance Index	$STI = \frac{Yp}{\bar{Y}p} \times \frac{Ys}{\bar{Y}s} \times \frac{\bar{Y}s}{Yp} = \frac{Yp \times Ys}{(\bar{Y}p)^2}$	Fernandez (1992)
7	Harmonic Mean	$HARM = \frac{2(Yp \times Ys)}{Yp + Ys}$	Kristin *et al.* (1997)
8	Relative Zinc Deficient Index	$RDI = \frac{(Ys \times Yp)}{(\bar{Y}s + \bar{Y}p)}$	Fischer and Wood (1979)
9	Yield Index	$YI = \frac{Ys}{\bar{Y}p}$	Lin *et al.* (1986)
10	Yield Stability Index	$YSI = \frac{Ys}{Yp}$	Bouslama and Schapaugh (1984)
11	Zinc Deficient Resistance Index	$DI = \frac{Ys \times (Yp \times Ys)}{(\bar{Y}s)}$	Lan (1998)
12	Abiotic Tolerance Index	$ATI = \left[\frac{(Yp - Ys)}{(\bar{Y}p / \bar{Y}s)}\right] \times \sqrt{Yp \times Ys}$	Moosavi *et al.* (2008)
13	Stress Susceptibility Percentage Index	$SSPI = \frac{(Yp - Ys)}{2(\bar{Y}p)} \times 100$	Moosavi *et al.* (2008)

Yp and Ys: Grain yield of each genotype under non-stress and zinc deficient stress conditions, respectively.
$\bar{Y}p$ and $\bar{Y}s$: Mean grain yield of all genotypes under non-stress and zinc deficient stress conditions, respectively.

Statistical analysis

All data were subjected to analysis of variance (ANOVA) using SAS software version 8.0 (SAS Institute Inc., Cary, NC, USA) and MSTAT-C software version 2.10 for DOS (MSTATC, 1989). Mean comparison was conducted using Duncan's multiple range test (DMRT) at $P < 0.05$ (Duncan, 1955).

Results

Grain yield and agronomic traits

Analysis of variance was carried out in order to evaluation of interaction between Zn deficient stress and wheat genotypes based on different wheat traits. Table 3 showed ANOVA results for all measured traits, indicating the level of statistical significance. However, the interaction effects of genotypes and Zn deficient stress conditions (G × C) were non-significant for all studied traits.

Results of variance analysis exhibited that zinc-deficient stress conditions had a significant effect on all studied traits, except 1000-grain weight and harvest index (Table 3). Moreover, our results indicated the reduction in plant height (7.3%), spike length (9.5%), peduncle length (8.0%), grains number per spike (20.8%), 1000-grain weight (3.3%), biomass yield (18.6%), and grain yield (22.1%) which were caused by Zn deficient stress (Table 4).

There were significant differences among genotypes for all studied traits except spike length, biomass yield, and grain yield (Table 3). Means comparison showed that the 'Diyarbakir-81' and 'Zenit' genotypes had the highest (47.5 cm) and lowest (36.7 cm) plant height, respectively. Our findings presented that the highest (4.38 cm) and the lowest (3.46 cm) spike lengths were belonged to 'Diyarbakir-81' and 'Firat-93' genotypes, respectively (Table 5). Also, results obtained in this study indicated that 'Artuklu' genotype had the highest (25.2 cm) and 'Zenit' genotype had the lowest (17.2 cm) plant height. Means comparison confirmed that 'Gediz-75' genotype had the highest grains number per spike (14 grains). Although, there were no significant differences between 'Gediz-75' genotype with 'Aydin-93' genotype, 'Aday-19' genotype had the lowest grains number per spike by 8.3 grains. The results showed that the 'Diyarbakir-81' genotype had the highest (49.2 g) and 'Aydin-93' genotype had the lowest (33.5 g) 1000-grain weight (Table 5).

Aboveground biomass (stems, leaves, spikes, and grains) produced by the fifteen genotypes varied from 0.95 to 1.33 g/plant which was not significantly different. Means comparison revealed that 'Gediz-75' and 'Zenit' genotypes had the highest grain yield (0.62 g/plant), and harvest index (48.8%), respectively. Furthermore, 'Aday-19' genotype had the lowest for these traits (Table 5).

Zinc resistance indices

The 'Gediz-75' and 'Firat-93' genotypes produced the highest and lowest grain yield in normal condition, whereas the 'Ege-88' and 'Aday-19' genotypes were found to produce the highest and lowest grain yield in zinc-deficient stress condition (Table 6).

The 'Gediz-75' and 'Ege-88' genotypes showed the highest and the 'Aday-19' and 'Fuatbey-2000' genotypes showed the lowest STI, GMP, MP, and HARM stress indices (Table 6). Results obtained from this experiment displayed that the highest and lowest SSI belongs to 'Zenit' (2.045) and 'Ceylan-95' (0.025) wheat genotypes respectively. Also, the highest and lowest YI belongs to 'Ege-88' (1.305) and 'Aday-19' (0.678) genotypes. The 'Ceylan-95' genotype showed the highest RDI (1.295), and YSI (0.994) Zn stress indices. However, the 'Zenit' genotype showed the lowest RDI (0.684), and YSI (0.525) Zn stress indices. In addition, the highest and lowest DI belonged to 'Ege-88' (1.194) and 'Zenit' (0.442) genotypes, respectively (Table 6). The 'Zenit' genotype presented the highest TOL (0.327), ATI (0.125), and SSPI (29.2) Zn stress indices. Though, the 'Ceylan-95' genotype showed the lowest TOL (0.003), ATI (0.001), and SSPI (0.24) Zn stress indices (Table 6).

In non-stress condition, there were strong correlation between grain yield and the indices, i.e. SSI ($r = 0.60$), STI ($r = 0.81$), GMP ($r = 0.82$), TOL ($r = 0.74$), MP ($r = 0.87$), HARM ($r = 0.75$), ATI ($r = 0.83$), SSPI ($r = 0.74$), RDI ($r = -0.60$), and YSI ($r = -0.60$) (Table 7). In Zn deficient stress condition, there were strong correlation between grain yield and the indices, i.e. STI ($r = 0.81$), GMP ($r = 0.81$), MP ($r = 0.75$), HARM ($r = 0.87$), RDI ($r = 0.55$), YI ($r = 1.00$), YSI ($r = 0.55$), DI ($r = 0.87$), and SSI ($r = -0.55$) (Table 7).

Table 3. Analysis of variance for studied traits of durum wheat genotypes as the factorial experiment based on randomized complete block design. Source of variation (SOV), degree of freedom (df), coefficient of variations (CV), plant height (PLH), spike length (SL), peduncle length (PedL), grains number per spike (GNPS), 1000-grain weight (HGW), biomass yield (BY), grain yield (GY), and harvest index (HI).

SOV	df	Mean squares							
		PLH	SL	PedL	GNPS	HGW	BY	GY	HI
Replication	2	10.3^{ns}	0.262^{ns}	2.82^{ns}	8.76^{ns}	8.44^{ns}	0.082^{ns}	0.009^{ns}	13.6^{ns}
Conditions (C)	1	235.2^{**}	3.32^{**}	78.0^{**}	163.2^{**}	45.5^{ns}	1.29^{**}	0.337^{**}	45.7^{ns}
Genotype (G)	14	56.9^{**}	0.427^{ns}	24.6^{**}	18.2^{*}	76.6^{**}	0.079^{ns}	0.026^{ns}	88.6^{*}
Genotype × conditions (G × C)	14	10.6^{ns}	0.235^{ns}	3.63^{ns}	10.9^{ns}	15.9^{ns}	0.083^{ns}	0.017^{ns}	11.7^{ns}
Error	58	20.5	0.263	7.22	10.3	25.3	0.089	0.023	41.6
CV (%)	-	10.6	13.5	12.0	27.7	11.7	25.4	31.1	15.3

ns, * and ** indicate non-significant, significant in $P < 0.05$ and $P < 0.001$ respectively.

Table 4. The average values of the studies traits under normal and zinc stress conditions, and the loss percent of each traits after the stress treatment in durum wheat (*Triticum durum* Desf.).

Traits	Normal condition	Zinc stress condition	The loss percent (%)
Plant height (cm)	44.4 a	41.1 b	7.3
Spike length (cm)	3.97 a	3.59 b	9.5
Peduncle length (cm)	23.3 a	21.4 b	8.0
Grains number per spike	12.9 a	10.3 b	20.8
1000-grain weight (g)	43.5 a	42.1 a	3.3
Biomass yield (g/plant)	1.29 a	1.05 b	18.6
Grain yield (g/plant)	0.56 a	0.43 b	22.1
Harvest index (%)	42.8 a	41.4 a	3.3

Conditions for each trait with the same letters are not significantly different from each other at $P < 0.05$.

Table 5. Mean comparison of different traits of studied durum wheat genotypes using Duncan's multiple range test (DMRT) method. Plant height (PLH), spike length (SL), peduncle length (PedL), grains number per spike (GNPS), 1000-grain weight (HGW), biomass yield (BY), grain yield (GY), and harvest index (HI).

Genotypes	PLH (cm)	SL (cm)	PedL (cm)	GNPS	HGW (g)	BY (g/plant)	GY (g/plant)	HI (%)
Diyarbakir-81	47.5 ^{a}	4.38 ^{a}	24.3 ^{ab}	10.4 $^{a\text{-}c}$	49.2 ^{a}	1.29 ^{a}	0.51 $^{a\text{-}c}$	39.4 ^{cd}
Gediz-75	43.5 $^{a\text{-}c}$	3.78 ^{ab}	24.0 ^{ab}	14.0 ^{a}	44.3 ^{ab}	1.28 ^{a}	0.62 ^{a}	48.4 ^{ab}
Svevo	40.3 $^{b\text{-}d}$	3.59 ^{ab}	21.4 ^{bc}	13.0 ^{ab}	39.7 ^{b}	1.09 ^{a}	0.52 $^{a\text{-}c}$	46.4 $^{a\text{-}c}$
Zenit	36.7 ^{d}	4.01 ^{ab}	17.5 ^{d}	12.6 $^{a\text{-}c}$	40.2 ^{b}	1.11 ^{a}	0.52 $^{a\text{-}c}$	48.8 ^{a}
Amanos-97	46.5 ^{ab}	3.79 ^{ab}	22.5 $^{a\text{-}c}$	13.2 ^{ab}	41.8 ^{b}	1.32 ^{a}	0.55 $^{a\text{-}c}$	41.3 $^{a\text{-}d}$
Fuatbey-2000	39.6 ^{cd}	3.48 ^{b}	20.6 $^{b\text{-}d}$	9.6 $^{a\text{-}c}$	41.3 ^{b}	0.95 ^{a}	0.41 ^{bc}	41.9 $^{a\text{-}d}$
Balcali-2000	44.0 $^{a\text{-}c}$	3.56 ^{b}	23.4 ^{ab}	11.0 $^{a\text{-}c}$	44.6 ^{ab}	1.17 ^{a}	0.50 $^{a\text{-}c}$	42.3 $^{a\text{-}d}$
Ceylan-95	44.7 $^{a\text{-}c}$	3.53 ^{b}	23.4 ^{ab}	11.4 $^{a\text{-}c}$	41.1 ^{b}	1.10 ^{a}	0.46 $^{a\text{-}c}$	41.7 $^{a\text{-}d}$
Firat-93	40.6 $^{b\text{-}d}$	3.46 ^{b}	22.1 $^{a\text{-}c}$	8.9 ^{bc}	45.8 ^{ab}	1.03 ^{a}	0.41 $^{a\text{-}c}$	39.9 $^{b\text{-}d}$
Aydin-93	40.8 $^{b\text{-}d}$	3.75 ^{ab}	23.1 ^{ab}	13.5 ^{a}	33.5 ^{c}	1.12 ^{a}	0.46 $^{a\text{-}c}$	39.5 ^{cd}
Ozbek	43.6 $^{a\text{-}c}$	3.68 ^{ab}	23.2 ^{ab}	11.1 $^{a\text{-}c}$	44.9 ^{ab}	1.25 ^{a}	0.50 $^{a\text{-}c}$	39.3 ^{cd}
Artuklu	46.1 ^{ab}	3.83 ^{ab}	25.2 ^{a}	11.1 $^{a\text{-}c}$	44.7 ^{ab}	1.21 ^{a}	0.51 $^{a\text{-}c}$	41.6 $^{a\text{-}d}$
Akcakale-2000	44.9 $^{a\text{-}c}$	4.06 ^{b}	23.3 ^{ab}	12.9 ^{ab}	42.6 ^{ab}	1.25 ^{a}	0.54 $^{a\text{-}c}$	42.9 $^{a\text{-}c}$
Aday-19	39.2 ^{cd}	3.63 ^{b}	19.1 ^{cd}	8.3 ^{c}	42.5 ^{ab}	1.05 ^{a}	0.36 ^{c}	33.7 ^{d}
Ege-88	43.4 $^{a\text{-}c}$	4.14 ^{ab}	22.1 $^{a\text{-}c}$	13.0 ^{ab}	45.2 ^{ab}	1.33 ^{a}	0.59 ^{ab}	44.1 $^{a\text{-}c}$

Similar letters of each trait within different genotypes show no significant differences between genotypes at $P < 0.05$.

Table 6. The amounts of yields in normal and zinc deficient conditions and zinc resistance indices in studied durum wheat genotypes.

Genotypes	Yp	Ys	SSI	STI	GMP	TOL	MP
Diyarbakir-81	0.533	0.485	0.388	0.825	0.509	0.048	0.509
Gediz-75	**0.737**	0.505	1.358	**1.186**	**0.610**	**0.232**	**0.621**
Svevo	0.640	0.395	1.653	0.806	0.503	0.246	0.518
Zenit	0.688	0.361	**2.045**	0.793	0.499	0.327	0.525
Amanos-97	0.568	0.530	0.286	0.961	0.549	0.038	0.549
Fuatbey-2000	0.445	0.365	0.771	0.519	0.403	0.080	0.405
Balcali-2000	0.520	0.472	0.398	0.782	0.495	0.048	0.496
Ceylan-95	0.465	0.462	0.025	0.685	0.464	0.003	0.464
Firat-93	0.414	0.406	0.087	0.536	0.410	0.008	0.410
Aydin-93	0.521	0.392	1.070	0.650	0.452	0.129	0.456
Ozbek	0.604	0.386	1.550	0.744	0.483	0.217	0.495
Artuklu	0.583	0.437	1.079	0.812	0.505	0.146	0.510
Akcakale-2000	0.653	0.427	1.489	0.890	0.528	0.226	0.540
Aday-19	0.429	0.291	1.382	0.399	0.354	0.138	0.360
Ege-88	0.613	**0.561**	0.366	1.097	0.586	0.052	0.587

Genotypes	HARM	RDI	YI	YSI	DI	ATI	SSPI
Diyarbakir-81	0.508	1.185	1.128	0.910	1.027	0.019	4.29
Gediz-75	**0.599**	0.892	1.173	0.685	0.803	0.109	20.7
Svevo	0.488	0.803	0.918	0.616	0.566	0.095	21.9
Zenit	0.474	0.684	0.841	0.525	0.442	**0.125**	**29.2**
Amanos-97	0.549	1.216	1.234	0.934	1.152	0.016	3.36
Fuatbey-2000	0.401	1.069	0.850	0.821	0.698	0.025	7.11
Balcali-2000	0.495	1.182	1.097	0.908	0.996	0.018	4.29
Ceylan-95	0.464	**1.295**	1.075	**0.994**	1.069	0.001	0.24
Firat-93	0.410	1.276	0.943	0.980	0.924	0.003	0.74
Aydin-93	0.447	0.979	0.910	0.752	0.684	0.045	11.6
Ozbek	0.471	0.834	0.899	0.640	0.575	0.081	19.4
Artuklu	0.499	0.976	1.016	0.749	0.761	0.057	13.0
Akcakale-2000	0.517	0.852	0.994	0.654	0.650	0.092	20.2
Aday-19	0.347	0.884	0.678	0.679	0.460	0.037	12.3
Ege-88	0.586	1.192	**1.305**	0.915	**1.194**	0.023	4.65

Grain yield of each genotype under non-stress conditions (Yp), grain yield of each genotype under zinc deficient stress conditions (Ys), stress susceptibility index (SSI), stress tolerance index (STI), geometric mean productivity (GMP), stress tolerance (TOL), mean productivity (MP), harmonic mean (HARM), relative zinc deficient index (RDI), yield index (YI), yield stability index (YSI), zinc deficient resistance index (DI), abiotic tolerance index (ATI), and stress susceptibility percentage index (SSPI).

Discussion

Micronutrients deficiencies (such as zinc and iron) have been widely noticed in wheat and other crop plants which causes low yield and finally increases malnutrition (White and Broadley, 2009; Narwal *et al.*, 2012; Cakmak *et al.*, 2017). Zinc deficiency can be overcomed by addition of Zn fertilizer. However alternative strategy to use of efficient plant genotype that can more effectively grow on soil with low available zinc (Cakmak *et al*., 2010).

Our results revealed that there were significant differences among the studied traits of genotypes except spike length, biomass yield, and grain yield. The high range of variation for the measured traits showed that there was a great genotypic variation among spring durum wheat genotypes on the basis of the measured traits. Despite being non-significant, results displayed that 'Zenit' and 'Aday-19' genotypes had the highest and lowest harvest index, respectively. In the current research, the reduction of biomass yield due to Zn deficient stress was estimated about 18.6%. Our results are in agreement with Cakmak (2008), who reported that Zn plays an important role in the biomass production. In plants, Zn deficiency results in reduction of crop production, nutritional quality of grain and nutritional quality of human diet (Cakmak *et al*., 1996; McDonald *et al*., 2001; Cakmak, 2008).

Indeed, low levels of Zn within plants constitute a stress affecting plant growth and development. Thus, the main symptom of plants suffering Zn deficiency is a loss of biomass as it has been reported in some crop plants such as durum and breed wheat (Abdoli *et al*., 2016), rice (Ghasal *et al*., 2017), carrot, lettuce, onion, and tomato (Alloway, 2008). Likewise, it was found that Zn deficiency is the most widespread micronutrient deficiency in wheat and it causes significant crop losses (Abdoli *et al*., 2016; Esfandiari and Abdoli, 2016). So that the soil Zn deficiency can cause significant reductions in yield and agronomic traits, and induces changes in plant metabolic processes such as cell division, photosynthesis, and protein synthesis (Marschner, 1995). Abdoli *et al*. (2016) stated that Zn has an important role in improvement of quantitative and qualitative wheat yield. Hence, Zn deficient decreased the grain yield due to its effect on the number of fertile spikelet per spike and number of grains per spike.

Here, we found the reduction of 1000-grain weight in all genotypes under zinc-deficient stress conditions (about 3.3%). So it could be noted that a part of the grain yield loss in zinc-deficient stress conditions is related to reduction of grains weight. Zinc is a necessary component of a several enzymes participating in the synthesis of carbohydrates, lipids, proteins, and nucleic acids as well as in the metabolism of other micronutrients, and plays an important role in the production of plants (Cakmak, 2008). Therefore soil Zn deficiency can cause considerable reductions in yield by reducing of the agronomic traits affecting yield e.g., 1000-grain weight and number of grains per spike as well as induces changes in plant metabolic processes (Marschner, 1995; Abdoli *et al*., 2014). In other studies decreasing 1000-grain weight and agronomic characteristics in wheat has also been reported under zinc-deficient stress conditions (Abdoli *et al*., 2016; Esfandiari and Abdoli, 2016; Arif *et al*., 2017). The results revealed that 'Diyarbakir-81' genotype had the highest and 'Aydin-93' genotype had the lowest 1000-grain weight. These results indicate genetic variation among durum wheat genotypes. Other researchers also noted the existence of genetic variation among genotypes and cultivars of wheat (Torun *et al*., 2001; Khoshgoftarmanesh *et al*., 2005; Genc and McDonald, 2008; Narwal *et al*., 2012) and rice (Wissuwa *et al*., 2006; Vanitha *et al*., 2016) under the zinc deficiency conditions.

According to the results of this research, many researchers have reported that grains number per spike of bread and durum wheat genotypes decreased under zinc-deficient stress conditions (Narimani *et al*., 2010; Nadim *et al*., 2012; Abdoli *et al*., 2014; Arif *et al*., 2017). The 'Gediz-75' genotype had the highest and 'Aday-19' genotype had the lowest grains number per spike (Table 5). In zinc-deficient stress condition, tolerant genotypes produced significantly higher yields than the other genotypes, which correlated positively with spike and grain numbers (data not shown). Resistant genotypes had larger grains, which could be linked to higher carbon assimilation and sucrose transport, than sensitive genotypes (Saeidi and Moradi, 2011). According to our results, it seems that main part of the grain yield loss in zinc-deficient stress conditions is due to loss of 1000-grain weight and grains number per spike. In this study, the number of grains per spikes was sensitive to Zn deficient stress. Gregorie (2007) reported that the abiotic stress such as nutrients deficient by restricting the supply of assimilates for grain filling period influenced number of seeds per spike.

The reduction of plant height under zinc-deficient stress indicates that the effects of environmental changes on plant height trait (Wissuwa *et al*., 2006; Abdoli *et al*., 2014; Arif *et al*., 2017). Cell growth is the most sensitive process affected by environmental stresses such as drought stress, nutrient deficiencies, and etc. With decreasing cell growth, organ size is limited and causes a reduction in plant height and leaf size (Hsiao, 1973). Plant height is one of the main vegetative growth parameters of wheat plant which represents genetic variation and nutrients deficient effect (Arif *et al*., 2017). Zn deficient in soil significantly decreased plant height via decreasing internodes distances (Kaya *et al*., 2000; Abdoli *et al*., 2014).

The reduction of average spike length is in the accordance with Arif *et al*. (2017) who concluded that plant height and spike length was decreased in the nutrient deficient condition but in nutrient deficient condition improved these traits by addition of appropriate amounts of zinc and potassium. The 'Artuklu' genotype had the highest and 'Zenit' genotype had the lowest peduncle length. Also, under Zn deficient stress conditions has been decreased peduncle length compared to normal conditions (Tables 4, 5). It seems that in this study the main part of the plant height loss under zinc-deficient stress conditions due to loss of spike length and peduncle length.

Table 7. Correlation coefficients between studied zinc resistance indices in durum wheat (*Triticum durum* Desf.).

Indices	Yp	Ys	SSI	STI	GMP	TOL	MP	HARM	RDI	YI	YSI	DI	ATI
Ys	0.32	1											
SSI	0.60*	-0.55*	1										
STI	0.81**	0.81**	0.04	1									
GMP	0.82**	0.81**	0.04	1.00**	1								
TOL	0.74**	-0.40	0.97**	0.21	0.21	1							
MP	0.87**	0.75**	0.14	0.99**	0.99**	0.31	1						
HARM	0.75**	0.87**	-0.06	0.99**	0.99**	0.11	0.98**	1					
RDI	-0.60*	0.55*	-1.00**	-0.04	-0.04	-0.97**	-0.13	0.06	1				
YI	0.33	1.00**	-0.55*	0.81**	0.81**	-0.40	0.75**	0.87**	0.55*	1			
YSI	-0.60*	0.55*	-1.00**	-0.04	-0.04	-0.97**	-0.14	0.06	1.00**	0.55*	1		
DI	-0.18	0.87**	-0.89**	0.41	0.41	-0.80**	0.32	0.50*	0.89**	0.87**	0.89**	1	
ATI	0.83**	-0.26	0.92**	0.35	0.35	0.98**	0.45	0.25	-0.92**	-0.26	-0.92**	-0.70**	1
SSPI	0.74**	-0.40	0.97**	0.21	0.21	1.00**	0.31	0.11	-0.97**	-0.40	-0.97**	-0.80**	0.98**

* and ** indicate significant in $P < 0.05$ and $P < 0.001$ respectively.

In the present study, the 'Gediz-75' and 'Aday-19' genotypes displayed the highest and lowest STI, GMP, MP, and HARM stress indices, respectively. With consideration of correlation between STI, GMP, MP, and HARM indices and grain yield under zinc-deficient stress and non-stress condition, these indices were identified as the best stress indices for isolation and selection of tolerant genotypes. There are few studies in consideration of how micronutrient deficiencies influence on Zn deficient resistance indices. However, Farshadfar *et al*. (2001) believed that most appropriate index for selection of stress-tolerant cultivars is an index which has partly high correlation with grain yield under stress and non-stress conditions. In this regard, Saeidi *et al*. (2016) reported that the correlation analysis among grain yield under non-stress and stress conditions with different stress tolerance indices showed that stress tolerance index (STI), mean productivity (MP) and geometric mean productivity (GMP) indices were appropriate indicators to identify potential genotypes with high grain yield. Also, Singh *et al*. (2016) reported that correlation coefficients and multivariate analyses showed that GMP, MP and STI indices were able to discriminate drought-sensitive and tolerant genotypes. Khoshgoftarmanesh *et al*. (2011) and Sriramachandrasekharan and Muthukumararaja (2012) stated that MP, GMP, and STI were the most suitable indices for identifying and selecting Zn-deficiency tolerant wheat and rice genotypes. Overall, we can say that MP, GMP, and HARM along with STI identify genotypes which could perform well under both Zn stress and Zn adequate condition.

Conclusion

The results obtained in this work show that durum wheat genotypes have different responses to Zn deficiency, such as a change in morphological and structural features. The high range of variation based on the measured traits in this study showed that there was a great genotypic variation among spring durum wheat genotypes. Agronomic traits and morphological characteristics under Zn deficient can be used for assessment of wheat genotypes and may be useful criteria in screening large genotypes aiming at developing molecular markers for Zn efficiency. Based on this concept which, whenever in terms of the STI, GMP, MP, and HARM indices is superior, in both non-stress and Zn deficient stress conditions have higher grain yield, on this basis 'Gediz-75' and 'Ege-88' durum wheat genotypes are probably the best and recommended this genotypes for cultivation by farmers under the zinc-deficient situation.

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