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Evaluation of Genetic Diversity of Durum Wheat Genotypes (*Triticum turgidum* var durum) using Agro-morphological Traits for Resistance to Zinc Deficient Stress

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ABSTRACT

Micronutrients deficiency stress is one of the most important dangers for increasing the yield and good production of crops in the world. In order to evaluate genetic diversity of nineteen durum wheat (*Triticum turgidum* var durum) genotypes, to identify the most zinc-deficient stress resistant genotypes, and also finding the best stress tolerance indices, an experiment was carried out in the University of Maragheh, Iran during cropping season of 2014 by using a factorial experiment in the randomized complete block design with three replications. Zinc deficient stress (non-Zn application; -Zn) and normal soil application (5 mg Zn/kg soil + foliar application with 0.44 g Zn/liter water at stem elongation and grain filling stages; +Zn) treatments were evaluated for 19 genotypes. Results indicated that Zn conditions as well as, wheat genotypes differed significantly for all studied agro-morphological traits. Our findings indicated that Zn-deficient stress significantly decreased the spike length (SL), peduncle length (PedL), penultimate length (PenL), plant height (PH), spike weight (SW), peduncle weight (PedW), penultimate weight (PenW), biological yield (BY), grain yield (GY), harvest index (HI), number of grains per spike (NGS), number of fertile spikelet per spike (FS) and 1000 grains weight (TGW) by 14, 10.6, 10.4, 12.5, 25.3, 26.2, 27.9, 27.5, 29.4, 5.0, 25.5, 17.7 and 5.4%, respectively. Among durum wheat genotypes, 'G2' had the highest and 'G10' and 'G19' had the lowest SW, PedW, BY and FS, respectively; while the highest and the lowest GY and NGS were observed for 'G17' (0.763 g/plant and 23.2 grain) and 'G10' (0.372 g/plant and 367) and 'G19' (8.9 g/plant and 9.5 grain) genotypes, respectively. This indicated the presence of variability, which can be exploited through selection for further breeding programs. According to results of stress tolerance indices, 'G17', 'G16' and 'G3' genotypes had higher GY and (Stress tolerance index) STI index than other genotypes in two Zn conditions and for identified as suitable genotypes for production in Zn deficient stress condition.

Keywords: Agro-morphological traits; Breeding; Calcareous soil; Durum wheat; Genetic variability; Zinc deficit.

INTRODUCTION

Micronutrients deficiency stress (such as zinc and iron) is one of the most important abiotic stresses in plants and leads to major damages in crop yield as well as plant growth, structure and metabolism (Cakmak *et al.,* 2010). Also, deficiencies of zinc (Zn) and iron (Fe) are a major environmental stress factors limiting wheat productivity around the globe, particularly in countries of Australia, China, India, Pakistan, Turkey and Iran (Cakmak, 2002).

Bread and durum wheat is one of the most important strategic cereal crops in Iran and the world in terms of production and utilization. Durum wheat (*Triticum turgidum* var durum) is among the most diversified crop species in Iran cultivated on about 200-300 thousand hectares across arable lands. The lower yield of durum wheat in Iran is the result of effects of environmental conditions such as drought, salinity, nutrient deficiencies in the soil, climate change and etc. and also limited diversity in the genome of wheat, which is used in breeding programs. The identification of micronutrient deficiency-tolerant durum wheat genotypes is the starting point for such breeding studies.

The knowledge about the genetic relationships of genotypes provides useful information to address breeding programmes and germplasm resource management. Genetic diversity is a pre-requisite for crop improvement program to develop the superior recombinants. Various researchers from all over the world have made investigations on genetic diversity of cereals such wheat, applying molecular (Hailu *et al.,* 2005; Nielsen *et al.,* 2014; Khan *et al.,* 2015; Zeshan *et al.,* 2016), agro-morphology (Hailegiorgis *et al.,* 2011; Dutamo *et al.,* 2015; Sakina *et al.,* 2016; Esfandiari and Abdoli, 2017) and protein quality (Dessalegn *et al.,* 2011) methods. The morphological and agronomic attributes of wheat have been evaluated to measure genetic variation in their close relatives. Abdoli and Esfandiari (2017) reported that there is a large genetic diversity among wheat genotypes and Zn deficient stress significantly decreased the number of grains per spike, biological yield and grain yield by 20.8, 18.6 and 22.1%, respectively. In the meantime, the evaluation of stress resistance indices is of great importance. There are different stress resistance indices such as stress susceptibility index (SSI), stress tolerance index (STI), geometric mean production (GMP), stress tolerance (TOL), mean production (MP), harmonic mean (HARM) (Rosielle and Hamblin, 1981; Fernandez, 1992; Abdoli and Esfandiari, 2017; Barati *et al.,* 2017; Ekbic *et al.,* 2017). In this regard, Gharib-Eshghi *et al.* (2016) stated that by considering correlation between indices and GY under normal and stress conditions, STI was identified as the best index for selection of drought-tolerant sesame cultivars, which are capable of producing high yields under normal conditions. Also, Pozveh and Golparvar (2016) and Bakhtari *et al.* (2017) reported that STI, GMP and MP indices had the most correlation with yield, therefore, they were used for screening drought-tolerant varieties. In another study, Molla Heydari Bafghi *et al.* (2017) reported that according to correlation analysis between GY in normal and stress conditions and tolerance to stress indices (MP, GMP and STI) as the best indices for selection of tolerant genotypes were detected. Barati *et al.* (2017) stated that the high-yielding varieties were more tolerant based on STI index, but the average of yield stability under stressed conditions (YSI) was significantly higher in the wild barley group of genotypes comparing to cultivated ones, indicating a high level of stress tolerance in wild genotypes.

Accordingly the aim of the present study was to determine the effects of zinc deficient on agro-morphological characteristics of durum wheat genotypes, to evaluate the genetic diversity, and selection of the best genotype for plant breeding programs.

MATERIALS AND METHODS

This pot experiment was conducted at the research field of the Department of Plant Production and Genetics, University of Maragheh, Maragheh, Iran during the cropping season from the second week of March, 2014 to the third week of July, 2014. The site is at 37° 22′ N latitude; 46° 16′ E longitude and with elevation of 1542 m above sea level. Long-time average precipitation, temperature and humidity are 309 mm, 13.2 °C and 46%, respectively. Soil texture is clay loam, with pH value = 7.2, organic matters = 0.4%, available K_2O (K) = 360 mg/kg soil, available P_2O_5 (P) = 6.1 mg/kg soil, total nitrogen (N) = 0.09% and $CaCO_3$ = 20%.

A factorial experiment in randomized complete block design with three replications was used. The first factor was two conditions of Zn treatments: (1) zinc deficient stress (non-Zn application; -Zn) and (2) normal soil application (5 mg Zn/kg soil + foliar application with 0.44 g Zn/liter water at stem elongation and grain filling stages; +Zn) and the second factor consisted of 19 durum wheat (*Triticum turgidum* var durum) genotypes and two standard checks (Dena and Saji). Seeds of durum wheat genotypes were obtained from Dryland Agricultural Research Institute of Iran. The agronomic traits and growth characteristics of genotypes used in the experiments are shown in Table 1.

Seeds of each genotype were sown in plastic pots (PVC) with 20 cm diameter and 30 cm height which filled with 3.5 kg of soil with -Zn and +Zn. Fourteen seeds were sown in each pot and daily watered by deionized water. Seedlings were thinned to seven seedlings per pot at 3 to 4-leaf stage. Recommended fertilizer rate of 200/100 mg/kg N/P in the forms of Calcium nitrate tetrahydrate ($Ca(NO_3)_2.4H_2O$) and Monopotassium phosphate (KH_2PO_4) were applied and mixed with soil at the same time during sowing. Weeds were controlled manually and all other agronomic practices were undertaken uniformly to the entire pot.

The observations were recorded on five randomly selected competitive plants from each genotype in each pot. Thirteen agro-morphological characters viz; spike length (SL), peduncle length (PedL), penultimate length (PenL), plant height (PH), spike weight (SW), peduncle weight (PedW), penultimate weight (PenW), biological yield (BY), grain yield (GY), harvest index (HI), number of grains per spike (NGS), number of fertile spikelet per spike (FS) and 1000 grains weight (TGW) were recorded. Harvest index (%) was calculated as grain yield / above ground dry biomass × 100.

Six stress resistance indices including stress susceptibility index (SSI), stress tolerance index (STI), geometric mean production (GMP), stress tolerance (TOL), mean production (MP) and harmonic mean (HARM) were calculated using the following relationships (Fischer and Maurer, 1978; Rosielle and Hamblin, 1981; Fernandez, 1992; Kristin *et al*., 1997):

$$SSI = [1-(Ys/Yp)]/SI$$

$$STI = \frac{Yp}{\bar{Y}p} \times \frac{Ys}{\bar{Y}s} \times \frac{\bar{Y}s}{Yp} = \frac{Yp \times Ys}{(\bar{Y}p)^2}$$

$$GMP = \sqrt{Ys \times Yp}$$

$$TOL = Yp - Ys$$

$$MP = \frac{Ys + YP}{2}$$

$$HARM = \frac{2(Yp \times Ys)}{Yp + Ys}$$

Where Yp is yield of each genotype in non-stress conditions, Ys is yield of each genotype in Zn deficient stress conditions, $\bar{Y}p$ is mean yield of all genotypes in non-stress conditions, $\bar{Y}s$ is mean yield of all genotypes in Zn deficient stress conditions.

Statistical analysis

The data were subjected to analysis of variance by using SAS software version 9.1 (SAS Institute, 1987). Mean comparison was conducted using Duncan's multiple range test at $p < 0.05$ (Duncan, 1955).

RESULTS

Grain yield and agro-morphological traits

The results of analysis of variance for the 13 agro-morphological traits are presented in Table 2. Significant differences were observed between Zn treatments for all studied characters (Table 2). Also, there were significant differences among durum wheat genotypes considering all the studied traits ($p < 0.01$) (Table 2). Significant Zn condition × genotype interaction effects were observed for SL, PedL, PenL, PH, PenW, HI and TGW. This indicated the existence of considerable genetic variation among the genotypes and thus the possibility of identifying tolerant genotypes to Zn deficient stress within the studied germplasm.

The durum wheat genotypes under study showed a wide range of variation both under normal and Zn deficient stress condition (Tables 4 and 5). The results of mean comparisons of the spike length (SL) under non-stress situation showed that, ‘G2’ and ‘G19’ had the highest and lowest value (5.93 and 2.83 cm, respectively). However, under Zn deficient stress condition ‘G2’ and ‘G13’ had the highest (4.80 cm) and lowest (2.67 cm) values, respectively (Table 5). Mean SL was 14.0% lower under Zn-deficient stress than under normal condition, (Table 3).

Table 1. Major specifications and features of 19 studied durum wheat genotypes in this research.

Code	Genotypes name/pedigree	GC (%)	GH	Vig.Till	DHE (day)	DMA (day)	AS	PH (cm)	TGW (g)	GY (kg/ha)
G1	Dena (check)	100	S	3	159	183	3	48	36	1593
G2	KC_3426	60	SF	2	162	191	3	66	34	1000
G3	Saji (check)	100	S	5	150	177	4	49	30	2656
G4	Mrb3/Mna-1	70	S	3	150	182	2	50	33	2313
G5	RCOL/THKNEE_2/3/SORA/2*PLATA_12//SOMAT	60	S	3	153	183	3	48	33	2075
G6	GREEN-14//YAV-10/AUK	90	S	4.5	150	180	4	47	29	2238
G7	Bisu-1//CHEN-1/TEZ/3/HUI//CIT71/Cll	100	S	5	150	180	4	50	29	2300
G8	Mrf1/Stj2//Bcrch1	85	S	4	153	183	4	54	31	2444
G9	Gdr2	95	S	5	153	184	5	53	33	3031
G10	Geromtel-1	80	S	4	150	183	5	57	35	3069
G11	Azarbayjan (LR)/Wadalmes IRDW2003-04-140-OMAR-OMAR-OMAR-4MAR-OMAR	90	S	4	153	183	4	59	33	2156
G12	MEXICALI 75	80	S	3	153	185	3	40	35	1825
G13	HYDRANASSA30/SILVER_5/3/AUK/GUIL//GREEN/10/PLATA_10/6/MQUE/4/USDA573//QFN/AA_7/3/ALBA-D/5/AVO/HUI/7/PLATA_13/8/THKNEE_11/9/CHEN/ALTAR 84/3/HUI/POC//BUB/RUFO/4/FNFOOT	80	S	3	155	184	3	47	29	1456
G14	AJAIA_12/F3LOCAL(SEL.ETHIO.135.85)//PLATA_13/3/SOMBRA_20/4/SNITAN/5/SOMAT_4/INTER_8	70	S	2	155	184	2	45	27	1369
G15	AAZ//ALTAR84/ALD/3/AJAIA/4/AJAIA_12/F3LOCAL(SEL.ETHIO.135.85)//PLATA_13/5/SOOTY_9/RASCON_37/9/USDA595/3/D67.3/RABI//CRA/4/ALO/5/HUI/YAV_1/6/ARDENTE/7/HUI/YAV79/8/POD_9	80	S	3	158	187	3	47	31	1469
G16	RASCON_37/2*TARRO_2/3/AJAIA_12/F3LOCAL(SEL.ETHIO.135.85)//PLATA_13/4/SORA/2*PLATA_12//SOMAT_3	60	S	2	158	187	2	53	33	1244
G17	SORA/2*PLATA_12//SOMAT_3/3/STORLOM/4/BICHENA/AKAKI_7	85	S	2	154	183	2	43	34	2000
G18	SHAG_14/ANADE_1//KITTI_1/4/ARMENT//SRN_3/NIGRIS_4/3/CANELO_9.1	70	S	2.5	155	184	3	53	33	1906
G19	VRKS_3/7/ENTE/MEXI_2//HUI/4/YAV_1/3/LD357E/2*TC60//JO69/5/BISU/6/RYPS26_2/10/PLATA_10/6/MQUE/4/USDA573//QFN/AA_7/3/ALBA-D/5/AVO/HUI/7/PLATA_13/8/THKNEE_11/9/CHEN/ALTAR 84/3/HUI/POC//BUB/RUFO/4/FNFOOT	60	S	3	156	185	3	52	32	1769

Green coverage (GC), growth habit (GH), vigour at tillering stage (Vig.Till), days to heading (DHE), days to maturity (DMA), agronomic score (AS), plant height (PH), 1000 grains weight (TGW) and grain yield (GY).

S: Spring, SF: Spring-fall (interstitial).

Source: Dryland Agricultural Research Institute (DARI), Agricultural Research, Education and Extension Organization (AREEO), Maragheh, Iran.

Table 2. Result of analysis of variance of grain yield and agro-morphological traits of durum wheat genotypes in tow Zn conditions

Source of variation	df	Mean squares (MS)				
		SL	PedL	PenL	PH	SW
Replication	2	0.931 *	37.6 **	1.27 ns	85.3 *	15644.6 *
Zn conditions (Zn)	1	9.15 **	168.0 **	17.4 **	875.9 **	130901.4 **
Genotypes (G)	18	1.76 **	49.7 **	4.67 **	122.3 **	12409.4 **
Zn × G	18	0.493 *	22.2 **	1.95 **	52.9 **	6731.7 ns
Error	74	0.261	7.38	0.705	23.6	4456.3
CV (%)	-	13.7	12.1	11.7	11.6	28.4
Source of variation	df	PedW	PenW	BY	GY	HI
Replication	2	2414.3 ns	354.7 ns	0.231 ns	0.059 ns	24.1 ns
Zn conditions (Zn)	1	29280.1 **	7537.9 **	3.67 **	0.867 **	155.4 *
Genotypes (G)	18	3202.8 **	1043.6 **	0.271 **	0.080 **	149.3 **
Zn × G	18	1530.4 ns	403.6 *	0.106 ns	0.026 ns	46.7 *
Error	74	1003.0	228.6	0.081	0.021	24.0
CV (%)	-	29.8	30.3	25.3	28.6	11.0
Source of variation	df	NGS	FS	TGW		
Replication	2	22.4 ns	2.75 ns	64.7 **		
Zn conditions (Zn)	1	453.6 **	43.8 **	128.8 **		
Genotypes (G)	18	96.2 **	5.67 **	94.2 **		
Zn × G	18	29.9 ns	2.07 ns	49.7 **		
Error	74	21.2	1.25	12.2		
CV (%)	-	33.5	17.4	9.26		

ns, * and ** : non-significant and significant at 5% and 1% probability levels, respectively.

Peduncle length of durum wheat genotypes ranged from 19.9 to 33.8 cm (‘G19’ and ‘G11’, respectively), with an average value of 23.6 cm under non-Zn deficient stress condition, and from 15.6 to 31.6 cm (‘G13’ and ‘G2’, respectively), with an average value of 21.1 cm, under Zn deficient stress condition (Table 5). Among durum wheat genotypes, penultimate length varied from 6.07 cm in ‘G7’ to 9.70 cm in ‘G11’, with an average of 7.53 cm under non-Zn deficient stress, and from 5.23 cm for ‘G1’ to 9.30 cm for ‘G2’, with an average of 6.75 cm under Zn deficient stress (Table 5). Our findings indicated that Zn-deficient stress significantly reduced length of peduncle (10.6%) and penultimate (10.4%) internodes (Table 3).

Under non-stress condition ‘G11’ genotype with a mean of 56.8 cm and ‘G19’ genotype with a mean of 37.2 cm had the highest and lowest plant height (PH), respectively. But, under Zn deficient stress condition ‘G2’ with a mean of 54.8 cm had the highest and ‘G13’ with a mean of 31.3 cm had the lowest PH, respectively (Table 5). Also, Zn-deficient stress decreased PH by 12.2% (Table 3).

The highest and the lowest spike weight were related to ‘G2’ (355 mg) and ‘G10’ (172 mg), respectively (Table 4). Among durum wheat genotypes, ‘G2’ with a mean of 178 mg had the highest and ‘G10’, ‘G1’ and ‘G19’ with a mean of 85, 83 and 80 mg had the lowest peduncle weight, respectively (Table 4). Penultimate weight ranged from 33 to 115 mg (G19 and G2, respectively), with an average value of 58 mg under non-Zn deficient stress conditions, and from 22 to 82 mg ('G1' and 'G2', respectively), with an average value of 41.8 mg, under Zn deficient stress conditions (Table 5). Also, Zn-deficient stress decreased weight of spike, peduncle and penultimate internodes by 25.3, 26.2 and 27.9%, respectively (Table 3).

'G2' had the highest biological yield (BY) mean (1.57 g/plant) while 'G5', 'G19' and 'G10' had the lowest ones (0.91, 0.88 and 0.83 g/plant) (Table 4). 'G17' had the maximum mean of grain yield (GY, 0.763 g/plant) while 'G5', 'G10' and 'G9' had the minimum means (0.381, 0.372 and 0.367 g/plant, respectively) (Table 4). Increase or decrease of this trait can be due to variation of yield components and different responses to environmental conditions. Our findings indicated that Zn-deficient stress condition significantly decreased BY per plant and GY per plant by 27.5 and 29.4%, respectively (Table 3). The present study showed significant correlation between GY and several of the agro-morphological traits known to be components determining the yield, including SL, SW, BY, HI, NGS and FS under normal (non-Zn deficient stress) condition and SL, PedL, PH, SW, PedW, PenW, BY, HI, NGS and FS under Zn deficient stress condition (Table 6).

Harvest index (HI) measured ranged from 30.3 to 56.2% ('G2' and 'G17', respectively), with an average value of 45.6% under non-Zn deficient stress conditions, and also from 27.2 to 49.5% ('G5' and 'G17', respectively), with an average value of 43.3%, under Zn deficient stress conditions (Table 5). So that, HI was thus 5.0% lower under Zn-deficient stress than non-Zn deficient stress condition (Table 3).

The highest and the lowest number of grains per spike (NGS) were observed in 'G17' (23.2 grain) and 'G10' (8.9 grain), genotypes respectively (Table 4). 'G2' and 'G3' with a mean of 8.17 and 8.12 had the highest and 'G12', 'G11' and 'G10' with a mean of 5.55, 5.18 and 4.92 had the lowest number of fertile spikelet per spike (FS), respectively (Table 4). Zinc deficient stress decreased the NGS and FS by 25.5 and 17.7%, respectively (Table 3).

Under non-stress condition 'G8' genotype with mean of 45.4 g and 'G14' genotype with mean of 29.4 g had the highest and lowest 1000 grains weight (TGW), respectively. But, under Zn deficient stress condition 'G7' with a mean of 45.1 g had the highest and 'G18' and 'G2' with a mean of 27.6 and 27.5 g had the lowest TGW, respectively (Table 5). Also, Zn-deficient stress reduced TGW by 5.4% (Table 3).

Table 3. The average values of the studies agro-morphological traits under normal and zinc deficient stress conditions and the percentage change of each trait after the stress treatment in durum wheat.

Traits	Conditions		Percentage change
	Normal (non-stress)	Zinc deficient stress	
Spike length (cm)	3.99 a	3.43 b	-14.0
Peduncle length (cm)	23.6 a	21.1 b	-10.6
Penultimate length (cm)	7.53 a	6.75 b	-10.4
Plant height (cm)	44.7 a	39.1 b	-12.5
Spike weight (mg)	268.5 a	200.7 b	-25.3
Peduncle weight (mg)	122.0 a	90.0 b	-26.2
Penultimate weight (mg)	58.0 a	41.8 b	-27.9
Biological yield (g/plant)	1.31 a	0.95 b	-27.5
Grain yield (g/plant)	0.596 a	0.421 b	-29.4
Harvest index (%)	45.6 a	43.3 b	-5.0
Number of grains per spike	15.7 a	11.7 b	-25.5
Number of fertile spikelet per spike	7.02 a	5.78 b	-17.7
1000 grains weight (g)	38.8 a	36.7 b	-5.4

Similar letters in each row show non-significant difference at 5% probability level according to Duncan's multiple rang test.

Table 4. Mean comparison of some of agro-morphological traits in durum wheat genotypes.

Genotypes code	SW (mg)	PedW (mg)	BY (g/plant)	GY (g/plant)	NGS	FS
G1	195 cd	83 d	1.03 c-f	0.540 b-f	13.2 c-g	6.08 c-e
G2	355 a	178 a	1.57 a	0.477 d-f	16.3 b-e	8.17 a
G3	276 a-c	138 b	1.38 a-d	0.674 a-c	17.7 a-d	8.12 a
G4	205 cd	100 b-d	1.05 c-f	0.489 c-f	11.6 d-g	6.45 b-e
G5	201 cd	101 b-d	0.91 f	0.381 f	10.4 e-g	5.72 de
G6	225 b-d	99 b-d	1.04 c-f	0.468 d-f	10.9 e-g	6.18 c-e
G7	239 b-d	97 b-d	1.08 b-f	0.489 c-f	11.3 e-g	6.10 c-e
G8	240 b-d	112 b-d	1.20 a-f	0.542 b-f	12.5 c-g	6.40 b-e
G9	201 cd	93 cd	0.99 d-f	0.434 d-f	10.9 e-g	5.95 de
G10	172 d	85 d	0.83 f	0.372 f	8.9 g	4.92 e
G11	192 cd	109 b-d	0.97 ef	0.411 ef	11.1 e-g	5.18 e
G12	231 b-d	90 cd	1.03 c-f	0.429 d-f	10.4 e-g	5.55 e
G13	212 cd	90 cd	1.07 c-f	0.490 c-f	15.6 b-f	5.78 de
G14	304 ab	95 b-d	1.22 a-f	0.597 a-e	18.2 a-c	7.17 a-d
G15	262 b-d	130 bc	1.36 a-e	0.619 a-d	17.7 a-d	7.20 a-d
G16	271 bc	113 b-d	1.45 ab	0.705 ab	19.7 ab	7.75 ab
G17	267 bc	118 b-d	1.42 a-c	0.763 a	23.2 a	7.50 a-c
G18	220 b-d	105 b-d	1.00 d-f	0.418 ef	12.0 d-g	5.80 de
G19	191 cd	80 d	0.88 f	0.367 f	9.5 fg	5.60 e

Spike weight (SW), peduncle weight (PedW), biological yield (BY), grain yield (GY), number of grains per spike (NGS) and number of fertile spikelet per spike (FS).

Similar letters in each column show non-significant difference at 5% probability level according to Duncan's multiple rang test.

Table 5. Comparison of the mean interaction effects of Zn conditions × genotypes for some agro-morphological traits in durum wheat genotypes under non-stress and zinc deficient stress conditions.

Treatments		SL (cm)	PedL (cm)	PenL (cm)	PH (cm)	PenW (mg)	HI (%)	TGW (g)
Zn conditions	Genotypes code							
Normal (non-stress)	G1	3.90 b-j	24.7 c-g	7.67 c-f	44.4 c-h	50 c-j	53.2 ab	43.3 a-d
	G2	5.93 a	25.8 cd	9.60 a	50.6 a-d	115 a	30.3 ef	32.1 h-l
	G3	4.70 bc	25.1 c-f	7.87 b-e	48.1 a-e	63 b-f	49.0 a-c	39.6 a-g
	G4	3.90 b-j	20.2 e-k	6.90 d-i	38.6 e-l	45 c-j	47.1 a-c	41.3 a-f
	G5	3.90 b-j	23.8 c-h	8.90 a-c	42.6 c-j	64 b-e	47.6 a-c	38.5 a-h
	G6	4.53 b-d	22.1 c-j	6.83 d-j	42.6 c-j	57 b-h	44.5 b-d	45.0 a-c
	G7	3.47 e-m	20.1 e-k	6.07 f-j	38.8 e-l	44 c-j	46.3 b-d	41.4 a-f
	G8	3.83 b-k	21.9 c-j	7.63 c-j	45.6 c-g	56 b-h	44.9 b-d	45.4 a
	G9	3.40 f-m	19.6 g-k	6.50 e-j	38.9 e-l	49 c-j	43.4 b-d	41.2 a-f
	G10	3.60 d-m	22.6 c-j	6.90 d-i	41.6 c-k	50 c-j	44.6 b-d	42.0 a-e
	G11	3.77 c-l	33.8 a	9.70 a	56.8 a	71 bc	41.3 cd	34.8 f-k
	G12	3.60 d-m	23.2 c-i	7.20 d-h	43.6 c-h	54 b-i	41.3 cd	42.6 a-e
	G13	4.17 b-h	25.5 c-e	8.40 a-d	50.7 a-d	68 b-d	46.1 b-d	31.6 i-l
	G14	3.90 b-j	23.2 c-i	7.23 d-h	45.2 c-g	49 c-j	49.7 a-c	29.4 kl
	G15	4.27 b-g	27.3 bc	7.40 c-g	51.2 a-c	62 b-f	43.4 b-d	38.5 a-h
	G16	4.33 b-f	24.3 c-g	7.60 c-g	46.1 b-g	59 b-g	49.7 a-c	32.4 h-l
	G17	4.43 b-e	22.0 c-j	6.83 d-j	43.3 c-h	57 b-h	56.2 a	38.1 b-i
	G18	3.40 f-m	22.4 c-j	7.63 c-g	42.8 c-i	56 b-h	41.4 cd	42.6 a-e
	G19	2.83 k-m	19.9 f-k	6.27 e-j	37.2 g-l	33 f-j	46.4 b-d	37.8 d-i
Zinc deficient stress	G1	2.80 lm	18.0 i-k	5.23 j	32.0 kl	22 j	48.7 a-c	35.7 e-k
	G2	4.80 b	31.6 ab	9.30 ab	54.8 ab	82 b	30.9 ef	27.5 l
	G3	4.00 b-i	24.1 c-g	7.50 c-g	42.8 c-i	56 b-h	48.7 a-c	36.5 d-j
	G4	3.60 d-m	21.0 d-j	7.70 c-f	39.9 e-l	52 c-j	45.0 b-d	42.5 a-e
	G5	3.03 i-m	17.3 jk	5.70 h-j	32.9 j-l	27 h-j	27.2 f	31.9 h-l
	G6	3.30 g-m	18.5 h-k	5.30 ij	33.5 i-l	31 g-j	45.0 b-d	40.3 a-f
	G7	4.07 b-h	20.6 d-k	5.47 ij	38.4 e-l	45 c-j	44.2 b-d	45.1 ab
	G8	3.20 h-m	22.7 c-j	7.33 c-h	41.2 d-k	43 c-j	45.5 b-d	40.9 a-f
	G9	2.83 k-m	21.1 d-j	6.77 d-j	37.3 g-l	39 d-j	44.9 b-d	37.9 d-i
	G10	2.80 lm	18.5 h-k	5.97 g-j	34.7 h-l	27 h-j	43.9 b-d	40.0 a-f
	G11	3.20 h-m	24.7 c-g	7.87 b-e	42.4 c-j	37 e-j	43.4 b-d	38.0 c-i
	G12	3.23 h-m	18.6 h-k	5.70 h-j	35.1 h-l	28 h-j	41.6 cd	39.9 a-g
	G13	2.67 m	15.6 k	5.97 g-j	31.3 l	25 ij	40.3 cd	29.9 j-l
	G14	3.30 g-m	20.2 e-k	7.47 c-g	39.6 e-l	50 c-j	48.1 a-c	38.7 a-h
	G15	3.50 e-m	24.6 c-g	7.20 d-h	44.2 c-h	42 c-j	48.9 a-c	33.1 g-l
	G16	4.27 b-g	23.5 c-h	7.33 c-h	47.2 b-f	55 b-i	47.7 a-c	41.2 a-f
	G17	3.83 b-k	20.9 d-k	6.03 f-j	39.2 e-l	44 c-j	49.5 a-c	32.0 h-l
	G18	2.97 j-m	22.1 c-j	6.93 d-i	39.1 e-l	38 d-j	41.9 cd	27.6 l
	G19	3.70 c-l	17.9 i-k	7.50 c-g	37.9 f-l	52 c-j	36.9 de	38.6 a-h

Spike length (SL), peduncle length (PedL), penultimate length (PenL), plant height (PH), penultimate weight (PenW), harvest index (HI) and 1000 grains weight (TGW).

Similar letters in each column show non-significant difference at 5% probability level according to Duncan's multiple rang test.

Table 6. Correlation coefficient of grain yield and agro-morphological traits in durum wheat genotypes under non-stress and zinc deficient stress conditions.

Normal (non-zinc deficient stress) condition

Traits	SL	PedL	PenL	PH	SW	PedW	PenW	BY	GY	HI	NGS	FS	TGW
SL	1												
PedL	0.35	1											
PenL	0.53*	0.80**	1										
PH	0.53*	0.93**	0.79**	1									
SW	0.89**	0.36	0.56*	0.59**	1								
PedW	0.83**	0.71**	0.79**	0.82**	0.84**	1							
PenW	0.84**	0.55*	0.80**	0.68**	0.85**	0.89**	1						
BY	0.86**	0.44	0.54*	0.66**	0.92**	0.80**	0.72**	1					
GY	0.46*	0.21	0.14	0.35	0.46*	0.34	0.13	0.74**	1				
HI	-0.28	-0.24	-0.43	-0.29	-0.37	-0.43	-0.62**	-0.06	0.62**	1			
NGS	0.50*	0.32	0.29	0.48*	0.50*	0.40	0.29	0.74**	0.86**	0.43	1		
FS	0.87**	0.26	0.43	0.48*	0.81**	0.68**	0.61**	0.92**	0.77**	0.10	0.78**	1	
TGW	-0.35	-0.42	-0.45	-0.48*	-0.31	-0.34	-0.42	-0.39	-0.23	0.07	-0.68**	-0.41	1

Deficient stress condition.

Traits	SL	PedL	PenL	PH	SW	PedW	PenW	BY	GY	HI	NGS	FS	TGW
SL	1												
PedL	0.69**	1											
PenL	0.53*	0.79**	1										
PH	0.80**	0.95**	0.84**	1									
SW	0.75**	0.56*	0.55*	0.70**	1								
PedW	0.81**	0.88**	0.70**	0.88**	0.70**	1							
PenW	0.87**	0.79**	0.83**	0.89**	0.81**	0.89**	1						
BY	0.85**	0.70**	0.54*	0.82**	0.86**	0.83**	0.83**	1					
GY	0.62**	0.48*	0.31	0.58**	0.73**	0.59**	0.56*	0.90**	1				
HI	-0.07	-0.02	-0.15	-0.03	0.18	-0.05	-0.11	0.31	0.65**	1			
NGS	0.59**	0.55*	0.33	0.60**	0.65**	0.69**	0.55*	0.86**	0.89**	0.45	1		
FS	0.81**	0.63**	0.52*	0.74**	0.85**	0.81**	0.82**	0.94**	0.85**	0.29	0.80**	1	
TGW	0.04	-0.23	-0.18	-0.15	0.07	-0.25	-0.08	0.03	0.16	0.40	-0.27	0.00	1

Spike length (SL), peduncle length (PedL), penultimate length (PenL), plant height (PH), spike weight (SW), peduncle weight (PedW), penultimate weight (PenW), biological yield (BY), grain yield (GY), harvest index (HI), number of grains per spike (NGS), number of fertile spikelet per spike (FS) and 1000 grains weight (TGW).

* ,** Significantly different at 5% and 1% probability levels, respectively.

Zinc tolerance

The stress index values of the durum wheat genotypes are shown in Table 7. The stress intensity (SI) of the experiment was 0.294 (Table 7).

The grain yield (GY) quantities of the durum wheat genotypes produced under normal (non-Zn deficient stress) conditions varied between 0.397 and 0.854 g/plant, and the values under Zn-deficient stress conditions varied between 0.148 and 0.686 g/plant (Table 7). According to Table 7, the genotypes ‘G17’, ‘G3’, ‘G1’, ‘G16’ and ‘G13’ had the greatest GY under normal conditions (0.854, 0.753, 0.749, 0.724 and 0.713 g/plant, respectively), the lowest values were observed for ‘G19’, ‘G9’ and ‘G10’ genotypes (0.397, 0.455 and 0.459 g/plant, respectively). While ‘G16’, ‘G17’ and ‘G3’ genotypes had the greatest GY under stress conditions (0.686, 0.672 and 0.595 g/plant, respectively), and the lowest value was observed ‘G5’, ‘G13’ and ‘G10’ genotypes (0.148, 0.267 and 0.285 g/plant, respectively) (Table 7).

Evaluation of stress tolerance index (TOL) of studied genotypes showed that obtained, genotypes with good tolerance to Zn deficient stress didn’t have high potential yield (Table 7). Based on the results ‘G7’ had the lowest TOL but produced desirable yield under Zn deficient stress conditions. In addition, ‘G7’ had the lowest stress susceptibility index (SSI) (Table 7).

Alternatively, ‘G5’, ‘G10’ and ‘G19’ had the lowest values for STI, GMP, MP and HARM. In addition, ‘G5’ genotype had high values for SSI and TOL indices. Therefore ‘G5’, ‘G10’ and ‘G19’ can be introduced as sensitive genotypes to Zn deficient stress (Table 7). The results of this study showed that GMP, MP, HARM and STI indices identified the Zn-deficient tolerant genotypes, and TOL and SSI indices were able to separate sensitive durum wheat genotypes.

Correlation coefficients among the various indices are presented in Table 8. There were highly significant correlations between Yp and Ys with STI (r = 0.77** and 0.93**, respectively), GMP (r = 0.76** and 0.94**, respectively), MP (r = 0.85** and 0.88**, respectively) and HARM (r = 0.67** and 0.97**, respectively) (Table 8).

Table 7. Grain yields and tolerance zinc indices from grain yield data for studied durum wheat genotypes.

Genotypes code	Yp	Ys	SSI	STI	GMP	TOL	MP	HARM
G1	0.749	0.332	1.898	0.699	0.498	0.417	0.540	0.460
G2	0.525	0.429	0.622	0.635	0.475	0.096	0.477	0.473
G3	0.753	0.595	0.717	1.261	0.669	0.159	0.674	0.665
G4	0.528	0.449	0.514	0.667	0.487	0.080	0.489	0.485
G5	0.613	0.148	2.584	0.256	0.301	0.465	0.381	0.238
G6	0.579	0.357	1.305	0.583	0.455	0.222	0.468	0.442
G7	0.496	0.482	0.096	0.672	0.489	0.014	0.489	0.489
G8	0.635	0.449	0.997	0.804	0.534	0.186	0.542	0.526
G9	0.455	0.413	0.319	0.529	0.433	0.043	0.434	0.433
G10	0.459	0.285	1.293	0.369	0.362	0.174	0.372	0.352
G11	0.496	0.327	1.159	0.456	0.403	0.169	0.411	0.394
G12	0.526	0.332	1.255	0.491	0.418	0.194	0.429	0.407
G13	0.713	0.267	2.130	0.536	0.436	0.446	0.490	0.388
G14	0.674	0.520	0.777	0.986	0.592	0.154	0.597	0.587
G15	0.671	0.567	0.528	1.070	0.616	0.104	0.619	0.614
G16	0.724	0.686	0.177	1.399	0.705	0.038	0.705	0.705
G17	0.854	0.672	0.727	1.616	0.758	0.182	0.763	0.752
G18	0.474	0.362	0.807	0.483	0.414	0.112	0.418	0.410
G19	0.397	0.336	0.529	0.375	0.365	0.062	0.367	0.364
Max	0.854	0.686	2.584	1.616	0.758	0.465	0.763	0.752
Min	0.397	0.148	0.096	0.256	0.301	0.014	0.367	0.238
Mean	0.596	0.421	0.970	0.731	0.495	0.175	0.509	0.483
SI	0.294							

Grain yield of any genotype under non-stress conditions (Yp), grain yield of any genotype under zinc deficient stress conditions (Ys), stress susceptibility index (SSI), stress tolerance index (STI), geometric mean production (GMP), stress tolerance (TOL), mean production (MP), harmonic mean (HARM) and stress intensity (SI).

Table 8. Correlation coefficient between studied zinc tolerance indices in durum wheat genotypes and yields in non-stress and zinc deficient stress conditions.

Indices	Yp	Ys	SSI	STI	GMP	TOL	MP	HARM
Yp	1							
Ys	0.51*	1						
SSI	0.21	-0.73**	1					
STI	0.77**	0.93**	-0.44	1				
GMP	0.76**	0.94**	-0.47*	0.99**	1			
TOL	0.41	-0.58**	0.97**	-0.25	-0.28	1		
MP	0.85**	0.88**	-0.33	0.99**	0.99**	-0.13	1	
HARM	0.67**	0.97**	-0.57*	0.98**	0.99**	-0.39	0.96**	1

Grain yield of any genotype under non-stress conditions (Yp), grain yield of any genotype under zinc deficient stress conditions (Ys), stress susceptibility index (SSI), stress tolerance index (STI), geometric mean production (GMP), stress tolerance (TOL), mean production (MP) and harmonic mean (HARM).

* ,** Significantly different at 5% and 1% probability levels, respectively.

DISCUSSION

The durum wheat genotypes under study showed a wide range of variation for grain yield (GY) and agro-morphological traits both under normal and Zn deficient stress condition (Tables 4 and 5). These results are in agreement with the findings of Abdoli and Esfandiari (2017) who reported differential response of durum wheat genotypes under Zn deficient stress condition. Similarly, Kalimullah *et al*. (2012) and Dutamo *et al*. (2015) reported that number of grains per spike (NGS), number of tillers per plant, 1000 grains weight (TGW) and GY per plant showed significant differences between various bread wheat genotypes.

Micronutrients deficiency stresses (such as Zn and Fe) are the most significant constraint for agricultural production in arid and semi-arid regions. Thus, genetically improved stress tolerant varieties are needed for the future. Our findings indicated that Zn-deficient stress significantly decreased all agronomic and morphological traits especially GY per plant (Table 3). Our results also showed a reduction in plant height of durum wheat genotypes under Zn-deficient stress that resulted in reduced length of peduncle and penultimate internodes (Table 5). Abdoli and Esfandiari (2017) also reported significant reduction in PH and dry matter under Zn deficient stress in 15 durum wheat genotypes. In the present study, NGS was highly affected by Zn deficiency condition compared to TGW. The losses in GY per plant, TGW, number of fertile spikelet per spike (FS) and NGS at Zn deficiency stress reached 29.4, 5.4, 17.7 and 25.5% (Table 3). It is stated that, decrease in TGW and even the number of fertile spikelet per plant are other reasons for the reduction of GY of cereals under different stress conditions (Guolan *et al*., 2010). Furthermore, Esfandiari and Abdoli (2017) reported that Zn deficient stress decreased NGS, FS, TGW, BY, GY and harvest index (HI) in durum wheat by 29.2, 15.5, 5.1, 24.1, 32.5 and 10.5%, respectively.

The existence of genetic diversity is of great importance in improving wheat traits and developing strategies for optimal conservation of germplasm. Progress in plant breeding is facilitated by accurate information about genetic structure and diversity. The present study provided a detailed understanding of high genetic diversity in the durum wheat genotypes. Zn-deficient is one of the major production constraints in wheat. Development and planting of Zn-deficiency tolerant wheat genotypes can reduce yield losses due to Zn deficiency. Four durum wheat genotypes including 'G3', 'G15', 'G16' and 'G17' were found Zn-deficient tolerant. 'G5', 'G10' and 'G19' genotypes were sensitive to Zn deficiency (Tables 4, 5 and 7). Abdoli and Esfandiari (2017) reported that GY of tolerant durum wheat genotypes was significantly higher than the sensitive durum wheat genotypes. Furthermore, they found that the NGS, SL and biomass of tolerant genotypes were significantly higher than the sensitive genotypes and recommended using these traits for identification of tolerant wheat genotypes under Zn deficient stress condition. We found strong positive correlation between different yield components such as NGS and GY. Also, we found strong positive correlation between different agro-morphological traits such as length and dry weights of spike, peduncle and penultimate, and PH (Table 6). Similar significant correlation between PH and plant biomass have been previously reported (Bhowmik *et al*., 2009, Mansuri *et al*., 2012; Esfandiari and Abdoli, 2017). In contrast, Saeidi *et al*. (2016) reported high negative significant correlation between GY and length of penultimate internode and also between biomass and HI under both non-stress and stress conditions. In present study, total dry biomass showed a greater reduction in sensitive genotypes than tolerant genotypes. The sensitive genotypes exhibited various symptoms of Zn deficient stress injury such as yellowing of leaf and reduction in shoot growth (data not shown).

Various stress indices have been developed and used for the selection of stress-tolerant genotypes by measuring plant yield under stress and taking normal conditions into account (Fischer and Maurer, 1978; Rosielle and Hamblin, 1981; Fernandez, 1992; Saeidi *et al*., 2016; Krishnamurthy *et al*., 2016; Abdoli and Esfandiari, 2017). Correlations between Zn tolerance indices (such as STI, GMP, MP and HARM) and GY were positive (Table 8). Therefore, STI, GMP, MP, and HARM were the best indices for identification of high yielding genotypes in both conditions. The STI, GMP, MP and HARM indices indicated that 'G3', 'G15', 'G16' and 'G17' genotypes could be prominent sources to develop Zn deficiency stress-tolerance (Table 7). According to the results of this research, Abarshahr *et al*. (2011) stated that STI, GMP, MP and HARM had the most correlation with yield, therefore, they were used for screening drought-tolerant varieties. In addition, Azizi-Chakherchaman *et al*. (2008) and Saeidi *et al*. (2016) indicated that MP, HARM, GMP and STI were considered as the best indices for lentil and wheat genotypes responses to drought stress. Krishnamurthy *et al*. (2016) indicated that GMP and STI indices identified the salt-tolerant genotypes, and TOL and SSI indices were able to separate sensitive rice genotypes. Also, Safaei Chaeikar *et al*. (2008) stated that MP, GMP, HARM, STI and RWC indices had a positive and significant correlation with yield in stress and non-stress environments and would be suitable indices for selection of drought-tolerant rice genotypes. Furthermore, Ekbic *et al*. (2017) reported that the tolerant genotypes had positive correlations with stress tolerance indices of MP, GMP and STI. The Zn-deficient tolerant genotypes identified in this study may prove to be useful in the development of Zn-deficient tolerant durum wheat genotypes in the adapted genetic background.

CONCLUSIONS

In conclusion, the results of this research showed the presence of that highly significant difference among the wheat genotypes for grain yield and agro-morphological traits under both normal and limited Zn conditions. In general, the results of the present study indicated that Zn-deficient stress significantly decreased grain yield and agro-morphological traits. Under the two Zn conditions, 'G17' and 'G16' produced the highest and 'G5', 'G10' and 'G19' genotypes produced the lowest grain yield, number of grains per spike and harvest index, respectively. Results showed that the correlations between Zn resistance indices (such as STI, GMP, MP and HARM) and grain yield were positive. In other words results revealed that yield and studied agro-morphological traits react to Zn stress condition, therefor these traits could be useful and effective for screening wheat tolerant genotypes. Interestingly, the superior genotypes in this study were 'G2' and 'G17' genotypes which are recommended as the best genotypes for regions suffering from Zn deficient as germplasm for breeding program.

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