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Selecting High Zinc-efficient and Assessment of Zinc Stress Tolerance of the Wheat Durum Genotypes

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ABSTRACT

At percent, Zn stress tolerance using novel genetic resources is an important mitigation strategy for plant breeding. In this study, thirty-five durum wheat genotypes with different growth habits were evaluated under normal (non-stress) and Zn deficient stress during the 2014-15 cropping season. A total of ten Zn stress tolerance indices including stress tolerance index (STI), relative zinc-deficient index (RDI), yield index (YI), yield stability index (YSI), zinc-deficient resistance index (DI), abiotic tolerance index (ATI), stress susceptibility percentage index (SSPI), sensitive zinc-deficient index (SDI), and modified stress tolerance index (MSTI; K_1STI and K_2STI) were estimated. Results showed the significant influences of Zn stress on grain yield, as well as significant differences among genotypes for grain yield and the indices. The genotype G33 produced the highest grain yield under normal conditions by 0.854 g plant^{-1} while genotype G32 had the highest yield by 0.686 g plant^{-1} under Zn stress conditions. The genotypes G6, G13, G23, and G32 had less grain yield fluctuation, and G1, G21, and G29 genotypes had high grain yield fluctuation in two conditions. Cluster analysis showed that the genotypes, based on indices tended to four groups: tolerant, semi-tolerant, semi-sensitive, and sensitive genotypes, including 10, 17, 7, and 1 wheat genotypes, respectively. Grain yield was strongly positively correlated with STI, YI, DI, K_1STI, and K_2STI under two conditions, while negatively correlated grain yield with SSPI and SDI in Zn deficit stress condition, respectively. Using STI, YI, DI, K_1STI, and K_2STI, the genotypes G32, G33, and G19 were found to be the best genotypes with relatively high yield and suitable for both normal and Zn deficits stressed conditions. Therefore, they may be recommended to cultivate in Zn deficit prone regions of the world and also can be used in wheat breeding programs aimed at improving Zn stress tolerance.

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Introduction

Cereals are considered as the food of most people in the world, and more than 60-70% of the world's food is supplied from this crop. Among cereals, wheat ranked the first crop and it is one of the most important sources of food, which is cultivated more than 9.2-million-hectare areas in the world (FAO, 2014). In between, durum wheat (*Triticum turgidum* L. var. durum Desf.) accounts for around 6-7% of the total production of wheat (USDA, 2017). This plant is one of the plants which have a high adaptation to different conditions and it is suited to be grown in arid and semi-arid regions. However, environmental stresses such as drought, salinity, macro-nutrients, and micro-nutrients deficiencies hurt it.

Micro-nutrients deficit such as zinc (Zn) is a major cause of yield loss for many important crops including wheat. About 50% and 30% of the world's wheat is grown under Zn and iron (Fe) deficit conditions, respectively (Alloway, 2008). Therefore, the use of high yielding wheat genotypes having Zn stress tolerance is an efficient approach to lessen its damaging effects (Royo *et al*., 2005). Increasing Zn deficit stress tolerance in wheat is consequently a challenge for wheat breeders. Identification of suitable durum and bread wheat genotypes for Zn deficient conditions is one of the priority research areas. Generally, several selection criteria have been proposed for selecting genotypes based on their yield in stress and non-stress conditions (Fischer and Wood, 1979; Farshadfar and Sutka, 2002; Anwaar *et al*., 2020). For example, Fernandez (1992) defined stress tolerance index (STI) and geometric mean productivity (GMP). STI index can be used to identify genotypes that produce high yield under both stress and non-stress conditions. It is stated that plants or genotypes are divided into the four groups based on STI index, included: (group A) genotypes that express uniform superiority in stress and non-stress conditions, (group B) genotypes which perform favorably only in non-stress conditions, (group C) genotypes which yield relatively higher only in stress conditions, and (group D) genotypes which perform poorly in non-stress and stress conditions (Fernandez, 1992; Ghasemi and Farshadfar, 2015). Indicators are used in various stresses, including drought stress (Amiri *et al*., 2014; Saeidi *et al*., 2016; Arisandy *et al*., 2017), salinity (Ekbic *et al*., 2017; Gadimaliyeva *et al*., 2020), heat (Agili *et al*., 2012; Khan and Kabir, 2014) in different crops. So that, researchers reported that the SIT, mean productivity index (MPI), and GMP can be used as an alternative for each other to select drought-tolerant genotypes with high yield performance in both stress and non-stress conditions (Khan and Dhurve, 2016; Hooshmandi, 2019). On the other hand, Kamrani *et al*. (2018) reported that using STI, GMP, and mean productivity (MP) were found to be the best genotypes with relatively high yield and suitable for both normal and heat-stressed conditions. Furthermore, the indices stress susceptibility index (SSI), yield stability index (YSI), and stress tolerance (TOL) could be useful parameters in discriminating the tolerant genotypes that might be recommended for heat-stressed conditions (Khan and Kabir, 2014). Several screening methods and selection criteria have been proposed by different researchers, but very few were reported for screening micro-nutrients deficit stress such as Zn deficit stress-tolerant genotypes in wheat. In recent years, Abdoli and Esfandiari (2017) stated that the correlation was between STI, GMP, MP, and harmonic mean (HARM) indices and grain yield under Zn deficient stress and non-stress, these indices were identified as the best stress indices for isolation and selection of tolerant genotypes. Previous studies reported that STI, MP, GMP, and HARM are useful indices for screening Zn stress-tolerant durum wheat genotypes (Esfandiari and Abdoli, 2017; Esfandiari *et al*., 2018b). In another study by Khoshgoftarmanesh *et al*. (2009) reported that the STI could be a better selection criterion compared with Zn efficiency (ZnE) for identifying high yield stress-tolerant genotypes of bread wheat. Various stress indices were developed and used for the selection of stress-tolerant genotypes. But, most researchers use common indicators alike STI, MP, GMP, TOL, HARM, and stress susceptibility index (SSI) indexes to evaluate. In recent years, there are new indicators that have received less attention, such as relative zinc-deficient index (RDI), yield index (YI), yield stability index (YSI), zinc-deficient resistance index (DI), abiotic tolerance index (ATI), stress susceptibility percentage index (SSPI), sensitive zinc-deficient index (SDI), modified stress tolerance index (MSTI), etc. Therefore, the main objectives of this study were to (i) evaluate new stress tolerance indexes and introducing the appropriate indices for screening durum wheat genotypes under Zn stress and non-stress conditions, as well as (ii) identify the high yielding and Zn stress-tolerant genotypes of wheat and to introduce them for the cultivation in Zn deficit stress areas of the world.

Materials and Methods

Experimental site

The experiment was laid out in a factorial design in the randomized complete block design (RCBD) with three replications (21 plants were evaluated in each replication; 3 pots) in calcareous soil with Zn deficiency during winter, spring, and summer seasons on 2014-2015 at the research area of University of Maragheh, Maragheh, Iran. The site is at 37°22' N latitude, 46° 16' E longitude and with the elevation of 1542 m above sea level.

Soil characters

The soil physicochemical analysis revealed a clay-loam texture (39% clay, 45% silt, and 16% sand), pH of 7.2, the electrical conductivity of the saturated paste of 2.3 dS m^{-1}, organic matter of 0.5%, calcium carbonate of 20%, and an extractable Zn of 0.5 mg kg^{-1}. Critical Zn concentration deficiency was considered when the concentration declined below to 0.5-0.6 mg kg^{-1} (Sims and Johnson, 1991).

Plant materials and layout of the experiment

Thirty-five durum wheat (*Triticum turgidum* L. var. durum Desf.) genotypes, consisting of 28 spring genotypes and 7 spring-fall genotypes, were tested under both normal and Zn deficient stress conditions. The details of thirty-five durum wheat genotypes with different growth habits are shown in Table 1. These durum wheat genotypes were provided by the Dryland Agricultural Research Institute (DARI), Maragheh, Iran. Plastic pots (PVC, 20 × 35 cm) were filled with 3.5 kg soil of the combined samples and for Zn treatment pots the concentration raised to 5 mg Zn kg^{-1} soil at planting + a foliar application with 0.44 g Zn L^{-1} water at stem elongation and grain filling stages form the $ZnSO_4.7H_2O$ source (normal Zn supply) and without Zn fertilization (Zn deficit stress). Before sowing, the soils in pots were mixed homogenously with a basal treatment of 200 mg N ($Ca(NO_3)_2.4H_2O$) kg^{-1} and 100 mg P (KH_2PO_4) kg^{-1} fertilizers. Fourteen seeds from every durum genotype were sown into each pot, and the pots were thinned to seven seedlings per pot after emergence and daily watered by using deionized water. Irrigation of plants in the pots and crop management practices such as pests and weeds were controlled from pots close to the maturity of plants.

Grain yield measurement

At the maturity period, all plants from 3 pots per replication were used for recording data on grain yield. Eventually, the grain yield data were recorded for each genotype at both conditions (non-stress and Zn deficit stress) and was subjected to calculate Zn stress tolerance selection indices.

Estimation of Zn efficiency

Zinc efficiency of genotypes, calculated by dividing grain yield under Zn deficient conditions to that obtained under Zn sufficient conditions.

Calculation of stress tolerance indices

Different indices have been developed to measure stress tolerance based on yield performance in Zn stress and non-stress conditions.

Ten selection new indices of stress tolerance including stress tolerance index (Fernandez, 1992), relative zinc-deficient index (Fischer and Wood, 1979), yield index (Lin *et al*., 1986; Gavuzzi *et al*., 1997), yield stability index (Bouslama and Schapaugh, 1984), zinc-deficient resistance index (Lan, 1998; Abdoli and Esfandiari, 2017), abiotic tolerance index (Moosavi *et al*., 2008), stress susceptibility percentage index (Moosavi *et al*., 2008), sensitive zinc-deficient index (Farshadfar and Sutka, 2002; Farshadfar *et al*., 2013), and the modified stress tolerance index (K_1STI and K_2STI; Farshadfar and Sutka, 2002) were calculated according to the following formulas (Table 2). After the analysis of grain yield and indices, ranks were assigned to durum wheat genotypes for each stress tolerance index.

Statistical analyses

The statistical study focused on correlations between the indices and grain yield under two stress and non-stress conditions (Zn deficit and normal, respectively).

Table 1. Names of 35 durum wheat genotypes used in the study.

No.	Code	Pedigree and name of cultivars/lines	GH	DHE (day)	DMA (day)	AS	PH (cm)	TGW (g)	GY (Kg/ha)
1	G1	Dena †	S	159	183	3	48	36	1593
2	G2	4017	SF	167	197	3	65	36	607
3	G3	4025	SF	165	185	4	73	39	1673
4	G4	4303	S	158	191	3	57	45	1093
5	G5	4341	SF	158	185	4	44	28	1333
6	G6	46202	S	164	195	1	44	37	420
7	G7	46046	SF	156	185	3	46	41	1853
8	G8	46020	S	154	185	3	58	39	1760
9	G9	45868	S	155	191	2	52	45	793
10	G10	45717	SF	155	183	4	52	36	1713
11	G11	45704	S	160	187	4	50	38	1733
12	G12	45667	S	162	191	3	65	34	820
13	G13	45632	SF	163	191	2	65	34	533
14	G14	45620	S	156	187	3	54	39	1787
15	G15	45415	S	161	191	2	38	42	1173
16	G16	45430	S	159	187	4	60	42	1807
17	G17	45558	S	156	185	3	52	36	1800
18	G18	KC_3426	SF	162	191	3	66	34	1000
19	G19	Saji †	S	150	177	4	49	30	2656
20	G20	Mrb3/Mna-1	S	150	182	2	50	33	2313
21	G21	RCOL/THKNEE_2/3/SORA/2*PLATA_12//SOMAT	S	153	183	3	48	33	2075
22	G22	GREEN-14//YAV-10/AUK	S	150	180	4	47	29	2238
23	G23	Bisu-1//CHEN-1/TEZ/3/HUI//CIT71/Cll	S	150	180	4	50	29	2300
24	G24	Mrf1/Stj2//Bcrch1	S	153	183	4	54	31	2444
25	G25	Gdr2	S	153	184	5	53	33	3031
26	G26	Geromtel-1	S	150	183	5	57	35	3069
27	G27	Azarbayjan (LR)/Wadalmes IRDW2003-04-140-OMAR-OMAR-OMAR-4MAR-OMAR	S	153	183	4	59	33	2156
28	G28	MEXICALI 75	S	153	185	3	40	35	1825
29	G29	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	S	155	184	3	47	29	1456
30	G30	AJAIA_12/F3LOCAL(SEL.ETHIO.135.85)//PLATA_13/3/SOMBRA_20/4/SNITAN/5/SOMAT_4/INTER_8	S	155	184	2	45	27	1369
31	G31	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	S	158	187	3	47	31	1469
32	G32	RASCON_37/2*TARRO_2/3/AJAIA_12/F3LOCAL(SEL.ETHIO.135.85)//PLATA_13/4/SORA/2*PLATA_12//SOMAT_3	S	158	187	2	53	33	1244
33	G33	SORA/2*PLATA_12//SOMAT_3/3/STORLOM/4/BICHENA/AKAKI_7	S	154	183	2	43	34	2000
34	G34	SHAG_14/ANADE_1//KITTI_1/4/ARMENT//SRN_3/NIGRIS_4/3/CANELO_9.1	S	155	184	3	53	33	1906
35	G35	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	S	156	185	3	52	32	1769

Growth habit (GH), Days to heading (DHE), Days to maturity (DMA), Agronomic score (AS), Plant height (PH), 1000-grains weight (TGW), Grain yield (GY).
S: Spring, SF: Spring-fall (interstitial).
† Modern cultivar.

Table 2. Formulas of zinc stress tolerance indices.

No.	Index	Formula/Equation	Source
(1)	Stress tolerance index (STI)	$STI = \frac{Yp}{\bar{Y}p} \times \frac{Ys}{\bar{Y}s} \times \frac{\bar{Y}s}{Yp} = \frac{Yp \times Ys}{(\bar{Y}p)^2}$	Fernandez (1992)
	The genotypes with high STI values will be tolerant of stress.		
(2)	Relative zinc-deficient index (RDI)	$RDI = \frac{(Ys \times Yp)}{(\bar{Y}s + \bar{Y}p)}$	Fischer and Wood (1979)
(3)	Yield index (YI)	$YI = \frac{Ys}{\bar{Y}p}$	Lin *et al*. (1986), Gavuzzi *et al*. (1997)
	The genotypes with a high value of YI will be suitable for stress conditions.		
(4)	Yield stability index (YSI)	$YSI = \frac{Ys}{Yp}$	Bouslama and Schapaugh (1984)
(5)	Zinc deficient resistance index (DI)	$DI = \frac{Ys \times (Yp \times Ys)}{(\bar{Y}s)}$	Lan (1998), Abdoli and Esfandiari (2017)
(6)	Abiotic tolerance index (ATI)	$ATI = \left[\frac{(Yp - Ys)}{(\bar{Y}p / \bar{Y}s)}\right] \times \sqrt{Yp \times Ys}$	Moosavi *et al*. (2008)
(7)	Stress susceptibility percentage index (SSPI)	$SSPI = \frac{(Yp - Ys)}{2(\bar{Y}p)} \times 100$	Moosavi *et al*. (2008)
	The genotypes with low values of SSPI are more stable in two different (non-stress and stress) conditions.		
(8)	Sensitive zinc deficient index (SDI)	$SDI = (Yp - Ys)/Yp$	Farshadfar and Sutka (2002), Farshadfar *et al*. (2013)
(9)	Modified stress tolerance index, K_1 (K_1STI)	$K_1STI = (Yp^2/ \bar{Y}p^2) \times STI$	Farshadfar and Sutka (2002)
(10)	Modified stress tolerance index, K_2 (K_2STI)	$K_2STI = (Ys^2/ \bar{Y}s^2) \times STI$	Farshadfar and Sutka (2002)

Yp and Ys: Grain yield of each genotype under normal and Zn deficient stress conditions, respectively.
Ȳp and Ȳs: Mean grain yield of all genotypes under normal and Zn deficient stress conditions, respectively.

The study of the analysis of variance (ANOVA) with Duncan's multiple range test (DMRT, $P < 0.05$) were performed with the SAS software ver. 9.1 (SAS Institute, 2011). Cluster analysis of genotypes based on Euclidean distance was analyzed using SPSS software ver. 16.0 (SPSS, 2007). The figures were drawn using Excel software ver. 10.0 and the means ± standard error (SE) was used to compare the data.

Results

Impact of normal and zinc deficit conditions

Analysis of variance (ANOVA) showed significant differences ($P < 0.001$) for yield performance under non-stress and Zn deficient stress conditions (Table 3). The grain yield means under normal and Zn stress conditions were 0.581 g plant^{-1} and 0.406 g plant^{-1}, respectively (Fig. 1A). Grain yield of genotypes varied from 0.148 (± 0.047) to 0.686 (± 0.099) g plant^{-1} at Zn deficient situation and 0.324 (± 0.042) to 0.854 (± 0.058) g plant^{-1} at Zn sufficient condition (Fig. 1A).

Results from ANOVA of grain yield have been presented in Table 3. As it is seen, the result of ANOVA for grain yield shows that studied thirty-five durum wheat genotypes are significant differences ($P < 0.001$), as well as, wheat genotypes are significant differences ($P < 0.05$) between zinc deficit stress and non-stress conditions and this indicates the existence of genetic variation among genotypes in this study. The genotypes G33, G9, G11, G1, G19, G29, and G32 in the non-stress condition and genotypes G32, G33, G19, G15, and G31 in Zn deficit stress condition had the highest performance (Fig. 1A). Whereas, the genotypes G13, G35, G2, G3, and G34 in the non-stress condition and genotypes G21, G2, G3, and G12 in Zn deficit stress condition had the lowest grain yield (Fig. 1A). However, some genotypes like G13 and G35 the grain yield is low in both stress and non-stress conditions. Genotypes G32 and G15 the high yielding genotypes in non-stress conditions, which showed the lowest fluctuation in Zn deficit stress condition in comparison with the non-stress condition (Fig. 1A).

On the other hand, the genotypes G6, G13, G23, and G32 had less grain yield fluctuation, and G1, G21, and G29 genotypes had high grain yield fluctuation in two conditions (Fig. 1A).

Table 3. Analysis of variance (ANOVA) for grain yield of 35 durum wheat genotypes under zinc deficit stress and non-stress conditions.

Source of variation (SOV)	**df**	**Mean squares (MS)**
		Grain yield
Replication	2	0.089 ns
Zinc stress conditions (ZnsC)	1	1.613 **
Genotypes (G)	34	0.078 **
Genotypes × Zinc stress conditions (G × ZnsC)	34	0.022 *
Error	138	0.025
Coefficient of variation, CV (%)	-	32.1

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

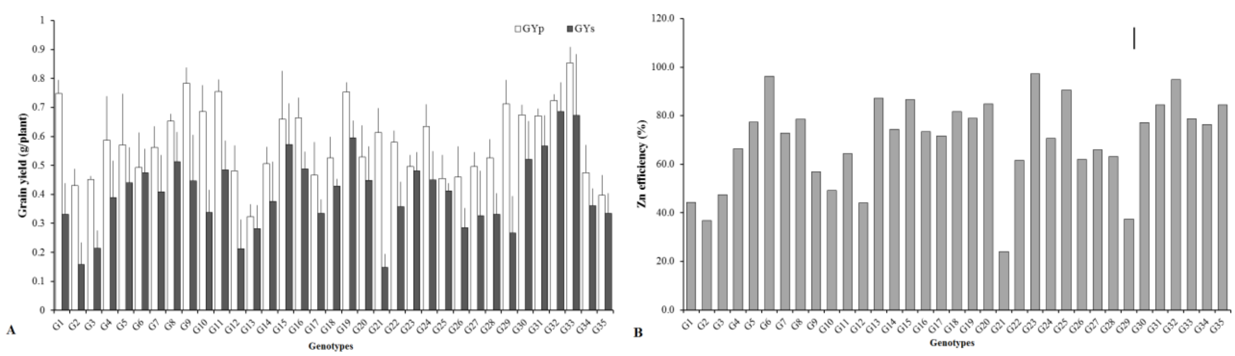

Fig. 1. The amounts of yields in normal (grain yield potential, GYp) and zinc-deficient (grain yield stress, GYs) conditions (A) and Zn efficiency (B) in 35 durum wheat genotypes. Vertical lines indicate standard error (SE) and vertical bar on the corner represent DMRT ($P < 0.05$) for the comparison between the genotypes. The numbers inside the figure are genotypes code (see Table 1). Zinc efficiency was calculated as [(grain yield at Zn stress condition/grain yield at the normal condition) × 100].

Grain yield differences pointed out their differential tolerance and sensitivity of Zn deficit stress which can be elucidated by loss in grain yield as an index. Genotypes G21, G2, G29, G12, G1, G3, and G10 showed highest grain yield reduction (75.9%, 63.2%, 62.5%, 56.0%, 55.7%, 52.5%, and 50.7%) that means these were highly sensitive to Zn stress, while the lowest reduction (less sensitive or resistant) belonged to G23, G6, G32, and G25 (2.7%, 3.7%, 5.2%, and 9.4%), respectively (Fig. 2).

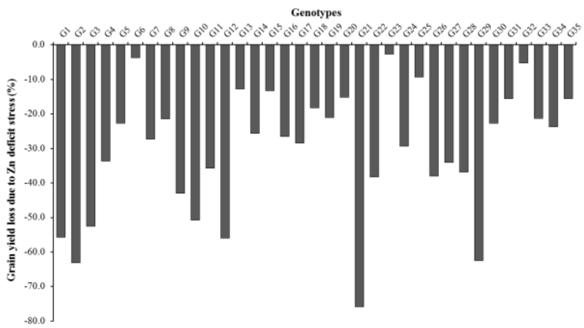

Fig. 2. Percent of grain yield (GY) reduction between environmental conditions with and without zinc deficit stress of 35 durum wheat genotypes. The numbers inside the figure are genotypes codes (see Table 1).

Our study indicated that Zn efficiency (ZnE) was ranged from 24.1 to 97.3% in genotypes G21 and G23, respectively (Fig. 1B). Genotypes with small fluctuations in both Zn deficit stress and non-stress conditions have been identified as Zn-efficient genotypes, such as G23, G6, G32, G25, G13, and G15 genotypes by ZnE of 97.3, 96.3, 94.8, 60.6, 87.3, and 87.7%, respectively (Fig. 1B).

The relationship between the grain yields of durum wheat genotypes under Zn deficit stress and non-stress conditions is presented in Fig. 3. The results of this study showed that the genotypes G32, G33, and G19 with similar good yield in both conditions were in group A, genotypes G9, G10, G1, G29, and G21 with good yield only in non-stress condition were in group B, genotypes G6 and G23 with good yield only in Zn deficit stress condition were in group C, and genotypes G2, G3, G12, and G13 with weak yield in both conditions were in group D (Fig. 3).

This indicates the existence of genetic variation for the attributes studied and the possibility of selection for stress tolerance genotypes. Among all the stress tolerance indices studied, stress tolerance index (STI) varied significantly and the durum wheat genotypes with high values indicated the tolerance to Zn stress condition (Fig. 4, Table 5). Genotypes G33 followed by G32 and G19 with high STI values indicating the tolerance towards the Zn stress while, genotype G2, G3, G13, and G21 showing susceptibility to Zn stress (Fig. 4, Table 5).

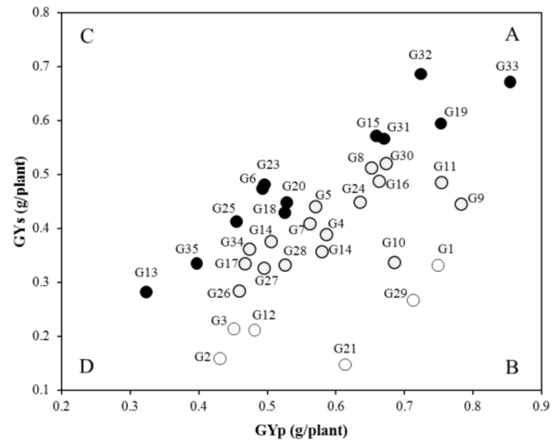

Fig. 3. The relationship between grain yields produced under non-stress (GYp) and zinc deficit stress (GYs) conditions in 35 durum wheat genotypes. The G6, G13, G15, G18, G19, G20, G23, G25, G31, G32, G33, and G35 genotypes which are Zn-efficient genotypes (black circles) and also G1, G2, G3, G12, G21, and G29 which are Zn-inefficient genotypes (white circles). The numbers inside the figure are genotypes code (see Table 1).

Stress tolerance indices

The Zn stress resistance indices and the genotypic ranks based on the indices are presented in Tables 4 and 5. Zinc stress tolerance indices were varied significantly indicating genotypic variability among durum wheat genotypes (Fig. 4, Tables 4 and 5).

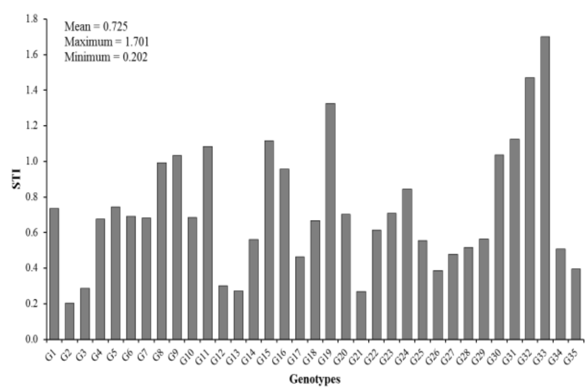

Fig. 4. Stress tolerance index (STI) for 35 durum wheat genotypes. The numbers inside the figure are genotypes code (see Table 1).

In the present study, the average relative zinc-deficient index (RDI) was found to be 0.999 (Table 4). Among the genotypes, G23 was highest (1.392) followed by G6 (1.377) and G32

(1.357) RDI, while G21, G2, and G29 were the lowest (0.345, 0.527, and 0.536, respectively) (Tables 4 and 5). The genotype with high values of yield index (YI) found suitable for Zn deficit condition. The genotype had >1 value considered tolerant, while the genotypes having <1 value denoted as susceptible one. In this experiment, the genotypes G32, G33, and G19 showing higher values as in the case of STI and YI cross-testing the genotypes suitable for Zn deficit stress condition. The similarly lower value of YI was noted in the genotypes G21 and G2 exhibited susceptibility to Zn stress and all other genotypes were intermediate (Tables 4 and 5).

The durum wheat genotypes with high yield stability index (YSI) values can be regarded as stable genotypes under Zn deficit stress and non-stress conditions. Significant differences were found amongst the genotypes for YSI and the genotype G23 had the highest YSI, followed by G6, G32, and G25 exhibited stability to stress. While genotypes G21 followed by G2 and G29 had lower values exhibited un-stability under stress and all other genotypes were intermediate (Tables 4 and 5).

An analysis of the zinc-deficient resistance index (DI) among the genotypes indicated that the DI ranged from 0.088 to 1.603 (Table 4). In between, G32 and G21 genotypes possessed the highest and the lowest DI, respectively (Tables 4 and 5). STI, RDI, YI, YSI, and DI had substantially the same values.

In the present study, the genotypes G1 (0.145) followed by G9 (0.139) and G29 (0.136) were observed to have maximum abiotic tolerance index (ATI), while G23, G6, and G13 genotypes had lowest (0.005, 0.006, and 0.009, respectively) this index (Tables 4 and 5).

The genotypes showed a wide range of variations for the estimated stress susceptibility percentage index (SSPI) (Tables 4 and 5). When studied with the SSPI index we found the lowest SSPI in G23, followed by G6, G32, and G13 (1.2, 1.6, 3.2, and 3.5, respectively). But, the highest this index was in genotypes G21, G29, and G1 by 40.1, 38.3, and 35.9, respectively (Tables 4 and 5). Under normal conditions, these genotypes (G21, G29, and G1) showed high yield but low yield in Zn stress conditions and thus were recognized as sensitive ones.

In this experiment, the highest sensitive zinc-deficient index (SDI) indices were observed for G21, followed by G2 and G29, whereas the genotype G23, G6, and G32 showed the lowest SDI value (Tables 4 and 5).

Regarding the stress tolerance indices, K_1STI ranged from 0.55 to 9.64, and K_2STI ranged from 0.27 to 12.43 (Table 4). For these indices, the highest amount of K_1STI was attributed to genotypes G33, G19, G9, G32, and G11, while genotypes G1, G21, G3, and G12 had the lowest K_1STI. Also, the highest amount of K_2STI was attributed to genotypes G33, G32, G19, G15, and G31, while genotypes G13 and G2 had the lowest K_2STI (Tables 4 and 5). The highest amount of modified stress tolerance index (MSTI; in both K_1STI and K_2STI) was attributed to genotypes G33, G32, and G19, while genotype G2 had the lowest MSTI.

The data also indicated that, based on the mean rank of all indices (Table 5), genotypes G33, G19, and G32 had the highest rankings (by 8, 9, and 11 rankings, respectively), while genotypes G2, G13, G3, and G26 had the lowest rankings (by 27, 26, 25, and 25 rankings, respectively).

Correlation coefficients between traits

The grain yields under Zn deficit stress conditions were positively and significantly correlated with those under non-stress conditions (r = 0.58, $P < 0.001$), suggesting that higher grain yield of genotypes under non-stress conditions does result in improved yield under Zn stress conditions (Table 6). The highest significant positive correlations were found among STI (r= 0.82, $P < 0.001$), YI (r= 0.58, $P < 0.001$), DI (r = 0.34, $P < 0.05$), ATI (r= 0.72, $P < 0.001$), SSPI (r= 0.42, $P < 0.05$), K_1STI (r= 0.96, $P < 0.001$), and K_2STI (r= 0.68, $P < 0.001$) indices and potential yield under non-stress conditions (Table 6). Also, the highest significant positive correlations were found among ZnE (r= 0.75, $P < 0.001$), STI (r= 0.93, $P < 0.001$), RDI, (r= 0.72, $P < 0.001$) YI (r= 1.00, $P < 0.001$), YSI (r= 0.72, $P < 0.001$), DI (r= 0.95, $P < 0.001$), K_1STI (r= 0.71, $P < 0.001$), K_2STI (r= 0.94, $P < 0.001$) indices, and grain yield under Zn deficit stress condition, but highest significant negative correlations were found among SSPI (r= –0.49, $P < 0.001$) and SDI (r= –0.72, $P < 0.001$) with grain yield this condition

(Table 6). In fact, high correlation GYs and GYp with indices is critical for selecting tolerance genotypes. According to this, for regions where micro-nutrients stress such as Zn deficit stress is a recurrent phenomenon, selection of genotypes with high STI, YI, DI, K_1STI, and K_2STI can be useful. No significant correlation was observed between GYs with ATI, hence it can be discarded as the desirable markers for identifying stress-tolerant genotypes.

Table 4. New indices of zinc stress tolerance for 35 durum wheat genotypes.

NO.	Genotypes code	RDI	YI	YSI	DI	ATI	SSPI	SDI	K_1STI	K_2STI
1	G1	0.634	0.817	0.443	0.361	**0.145**	35.9	0.557	5.24	2.14
2	G2	0.527	0.391	0.368	0.144	0.050	23.4	0.632	0.95	**0.27**
3	G3	0.680	0.528	0.475	0.251	0.051	20.4	0.525	1.17	0.55
4	G4	0.949	0.958	0.663	0.635	0.066	17.0	0.337	2.90	2.66
5	G5	1.106	1.086	0.773	0.840	0.045	11.1	0.227	2.85	3.54
6	G6	1.377	1.168	0.963	1.125	0.006	1.6	0.037	2.03	3.92
7	G7	1.041	1.008	0.728	0.733	0.051	13.2	0.272	2.66	2.93
8	G8	1.125	1.263	0.786	0.993	0.056	12.0	0.214	4.29	5.53
9	G9	0.815	1.098	0.570	0.626	0.139	29.0	0.430	6.51	4.40
10	G10	0.705	0.831	0.493	0.410	0.117	29.9	0.507	4.15	2.10
11	G11	0.921	1.195	0.643	0.769	0.114	23.2	0.357	6.11	5.26
12	G12	0.630	0.522	0.440	0.230	0.060	23.2	0.560	1.39	0.56
13	G13	1.249	0.696	0.873	0.607	0.009	3.5	0.127	**0.55**	0.87
14	G14	1.064	0.925	0.743	0.688	0.039	11.2	0.257	1.95	2.24
15	G15	1.240	1.407	0.867	1.220	0.038	7.6	0.133	4.63	7.24
16	G16	1.051	1.200	0.734	0.881	0.070	15.2	0.266	4.39	4.93
17	G17	1.025	0.824	0.716	0.590	0.037	11.4	0.284	1.52	1.62
18	G18	1.169	1.057	0.817	0.864	0.032	8.3	0.183	2.28	3.17
19	G19	1.130	1.465	0.790	1.157	0.074	13.6	0.210	6.62	8.60
20	G20	1.214	1.104	0.848	0.937	0.027	6.9	0.152	2.36	3.54
21	G21	**0.345**	**0.364**	**0.241**	**0.088**	0.098	**40.1**	**0.759**	2.48	0.30
22	G22	0.883	0.880	0.617	0.543	0.071	19.1	0.383	2.72	2.16
23	G23	**1.392**	1.187	**0.973**	1.154	**0.005**	**1.2**	**0.027**	2.08	4.09
24	G24	1.012	1.107	0.707	0.783	0.069	16.0	0.293	3.79	3.95
25	G25	1.297	1.016	0.906	0.921	0.013	3.7	0.094	1.56	2.66
26	G26	0.887	0.701	0.620	0.435	0.044	15.0	0.380	1.36	1.09
27	G27	0.944	0.805	0.659	0.531	0.047	14.5	0.341	1.75	1.58
28	G28	0.903	0.817	0.631	0.516	0.057	16.7	0.369	2.05	1.70
29	G29	0.536	0.658	0.375	0.247	0.136	38.3	0.625	4.31	1.26
30	G30	1.105	1.281	0.772	0.990	0.063	13.2	0.228	4.69	5.82
31	G31	1.209	1.395	0.845	1.179	0.045	9.0	0.155	4.81	7.15
32	G32	1.357	**1.690**	0.948	**1.603**	0.018	3.2	0.052	6.40	11.97
33	G33	1.126	1.655	0.787	1.303	0.096	15.7	0.213	**9.64**	**12.43**
34	G34	1.092	0.891	0.763	0.680	0.032	9.7	0.237	1.63	1.97
35	G35	1.209	0.826	0.845	0.698	0.016	5.3	0.155	1.00	1.49
Mean		0.999	0.995	0.698	0.735	0.058	15.4	0.302	3.28	3.59
Maximum		1.392	1.690	0.973	1.603	0.145	40.1	0.759	9.64	12.43
Minimum		0.345	0.364	0.241	0.088	0.005	1.2	0.027	0.55	0.27

Relative zinc-deficient index (RDI), Yield index (YI), Yield stability index (YSI), Zinc deficient resistance index (DI), Abiotic tolerance index (ATI), Stress susceptibility percentage index (SSPI), Sensitive zinc-deficient index (SDI), Modified stress tolerance index (MSTI; K_1STI and K_2STI). The numbers inside the table are genotypes code (see Table 1).

The study of correlations showed that Zn efficiency was positive and well correlated ($P < 0.001$) to GYs, STI, RDI, YI, YSI, DI, and K_2STI, but this trait was a negative correlation ($P < 0.001$) with the index of ATI, SSPI, and SDI (Table 6). There is a strong positive correlation between (a) ZnE, RDI, YI, YSI, and DI, and among (b) ATI, SSPI, and SDI whereas the correlation between indices in groups (a) and (b) is highly negative (Table 6).

Cluster analysis

The cluster analyses based on grain yield under normal and Zn stress conditions, Zn efficiency (ZnE), and the ten mentioned indices were carried out, and the results are shown in Fig. 5.

Dendrogram clustered the examined 35 durum wheat genotypes into four clusters (Fig. 5). Ten durum wheat genotypes were placed in the first group (G-I), in which these genotypes included G6, G23, G32, G13, G25, G15, G31, G20, G35, and G18. These durum wheat genotypes had high ZnE and grain yield values, thus they were considered the most desirable genotypes for both normal and Zn deficit stress conditions. The second group (G-II) consists of seventeen durum wheat genotypes. The genotypes in this group had mean indicator values (semi-tolerant). Seven durum wheat genotypes included G1, G29, G9, G10, G3, G12, and G2 were clustered in the third group (G-III). In this group, all genotypes had low ZnE, thus they were semi-sensitive to Zn deficit stress. Finally, the fourth group (G-IV) consists of one genotype G21 and this genotype has low ZnE, thus this genotype was susceptible to Zn deficit and only suitable for non-Zn deficiency conditions (Fig. 5).

Table 5. The rank of STI and new indices of zinc stress tolerance for 35 durum wheat genotypes.

NO.	**Genotypes code**	**STI**	**RDI**	**YI**	**YSI**	**DI**	**ATI**	**SSPI**	**SDI**	**K_1STI**	**K_2STI**	**Mean Rank**
1	G1	13	31	27	31	30	1	3	5	6	22	17
2	G2	35	34	34	34	34	19	6	2	34	35	**27**
3	G3	32	30	32	30	31	17	9	6	32	33	**25**
4	G4	19	22	19	22	21	12	11	14	15	19	17
5	G5	12	14	15	14	14	21	24	22	16	14	17
6	G6	16	2	11	2	7	34	34	34	24	13	18
7	G7	18	19	18	19	17	18	19	17	18	17	18
8	G8	9	13	7	13	8	16	21	23	12	7	13
9	G9	8	28	14	28	22	2	5	8	3	10	13
10	G10	17	29	23	29	29	4	4	7	13	23	18
11	G11	6	24	9	24	16	5	8	12	5	8	**12**
12	G12	31	32	33	32	33	14	7	4	30	32	25
13	G13	33	5	30	5	23	33	32	31	35	31	**26**
14	G14	23	17	20	17	19	24	23	19	25	20	21
15	G15	5	6	4	6	3	25	28	30	9	4	**12**
16	G16	10	18	8	18	12	10	15	18	10	9	13
17	G17	28	20	25	20	24	26	22	16	29	26	24
18	G18	20	10	16	10	13	28	27	26	21	16	19
19	G19	3	11	3	11	5	8	18	25	2	3	**9**
20	G20	15	7	13	7	10	29	29	29	20	15	17
21	G21	34	35	35	35	35	6	1	1	19	34	24
22	G22	21	27	22	27	25	9	10	9	17	21	19
23	G23	14	1	10	1	6	35	35	35	22	11	17
24	G24	11	21	12	21	15	11	13	15	14	12	15
25	G25	24	4	17	4	11	32	31	32	28	18	20
26	G26	30	26	29	26	28	23	16	10	31	30	**25**
27	G27	27	23	28	23	26	20	17	13	26	27	23
28	G28	25	25	26	25	27	15	12	11	23	25	21
29	G29	22	33	31	33	32	3	2	3	11	29	20
30	G30	7	15	6	15	9	13	20	21	8	6	**12**
31	G31	4	8	5	8	4	22	26	28	7	5	**12**
32	G32	2	3	1	3	1	30	33	33	4	2	**11**
33	G33	1	12	2	12	2	7	14	24	1	1	**8**
34	G34	26	16	21	16	20	27	25	20	27	24	22
35	G35	29	9	24	9	18	31	30	27	33	28	24

Stress tolerance index (STI), Relative zinc-deficient index (RDI), Yield index (YI), Yield stability index (YSI), Zinc deficient resistance index (DI), Abiotic tolerance index (ATI), Stress susceptibility percentage index (SSPI), Sensitive zinc-deficient index (SDI), Modified stress tolerance index (MSTI; K_1STI and K_2STI). The numbers inside the table are genotypes code (see Table 1).

Table 6. Correlation coefficients between zinc stress tolerance indices and grain yield in normal and zinc-deficient stress conditions.

Traits	GYp	GYs	ZnE	STI	RDI	YI	YSI	DI	ATI	SSPI	SDI	K_1STI	K_2STI
GYp	1												
GYs	0.58**	1											
ZnE	-0.12	0.72**	1										
STI	0.82**	0.93**	0.43**	1									
RDI	-0.12	0.72**	1.00**	0.43**	1								
YI	0.58**	1.00**	0.72**	0.93**	0.72**	1							
YSI	-0.12	0.72**	1.00**	0.43**	1.00**	0.72**	1						
DI	0.34*	0.95**	0.87**	0.79**	0.87**	0.95**	0.87**	1					
ATI	0.72**	-0.11	-0.69**	0.21	-0.69**	-0.11	-0.69**	-0.39*	1				
SSPI	0.42*	-0.49**	-0.93**	-0.17	-0.93**	-0.49**	-0.93**	-0.70**	0.89**	1			
SDI	0.12	-0.72**	-1.00**	-0.43**	-1.00**	-0.72**	-1.00**	-0.87**	0.69**	0.93**	1		
K_1STI	0.96**	0.71**	0.07	0.91**	0.07	0.71**	0.07	0.50**	0.57**	0.22	-0.07	1	
K_2STI	0.68**	0.94**	0.53**	0.96**	0.53**	0.94**	0.53**	0.86**	0.01	-0.32	-0.53**	0.82**	1

Grain yield potential (GYp), Grain yield stress (GYs), Zn efficiency (ZnE), Stress tolerance index (STI), Relative zinc-deficient index (RDI), Yield index (YI), Yield stability index (YSI), Zinc deficient resistance index (DI), Abiotic tolerance index (ATI), Stress susceptibility percentage index (SSPI), Sensitive zinc-deficient index (SDI), Modified stress tolerance index (MSTI; K_1STI and K_2STI).
* and ** indicate significance at $P < 0.05$ and $P < 0.001$, respectively.

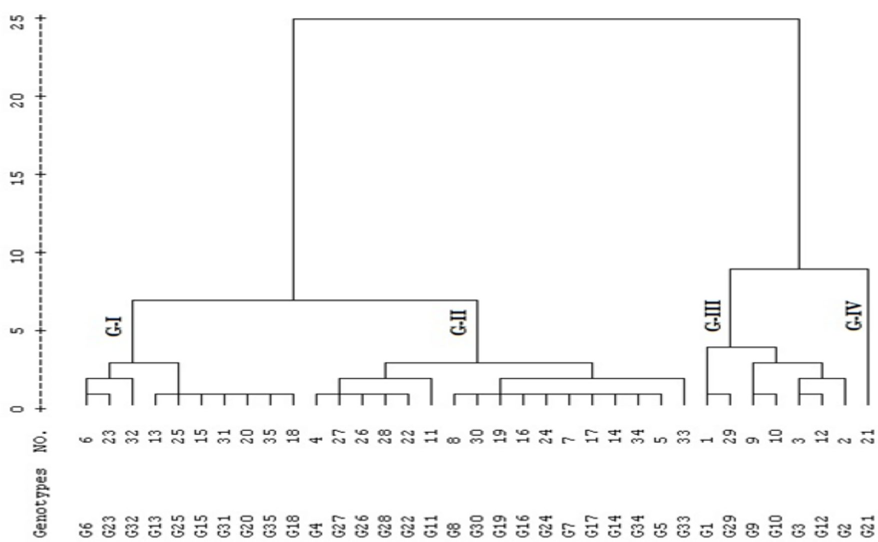

Fig. 5. Dendrogram resulting from cluster analysis of 35 durum wheat genotypes based on ZnE, STI, RDI, YI, YSI, DI, ATI, SSPI, SDI, K_1STI, and K_2STI indices for grain yield in normal (GYp) and zinc stress (GYs) conditions. The numbers inside the figure are genotypes code (see Table 1).

Discussion

In worldwide as well as in Iran, the wheat is the first most important food grain crop. In between, Zn is an important micro-nutrient for both crop growth and human nutrition. Wheat production is affected by micro-nutrients deficit such as Zn in arid and semi-arid regions with calcareous soil. The selection of crop varieties such as wheat with performance adapted to Zn deficit stress has been the subject of numerous studies (Abdoli *et al*., 2016; Esfandiari *et al*., 2018b; Abdoli *et al*., 2019). From a plant breeding point of view, yield loss is the major indicator to evaluate stress tolerance. In the current study, grain yield trait decreased by varying degrees in spring and spring-fall (interstitial) genotypes at Zn deficit stress conditions (Figs. 1A and 2).

Reduction of grain yield under Zn deficit stress conditions was also reported by Abdoli and Esfandiari (2017) and Esfandiari *et al*. (2018a). Some genotypes had lower and higher grain yield fluctuation under both conditions (Fig. 1A). In agreement with our results, Abdoli and Esfandiari (2017) reported a significant loss in grain yield when to evaluate the response of fifteen durum wheat cultivars to different levels of Zn deficit stress and normal situations. In the meantime, genotypes with small fluctuations in both conditions have been identified as Zn-efficient genotypes, such as G23, G6, G32, G25, G13, and G15 genotypes by ZnE of 97.3, 96.3, 94.8, 60.6, 87.3, and 87.7%, respectively (Fig. 1B). Wheat genotypes are different in their mechanisms for improved root Zn uptake; this feature is effective in the superiority of the genotype. Zn efficiency as one of the most important indicators to identify Zn deficit sensitive and resistant genotypes. Zinc efficiency significantly differed among wheat genotypes and ranged from 24.1% to 97.3% for spring durum wheat and from 36.8% to 81.7% for spring-fall durum wheat genotypes (Fig. 1B). Zinc stress tolerance is a complex trait controlled by numerous genes, in addition to crop responses to Zn deficit stress are confounded by several factors such as time, intensity, duration, and frequency of stress as well as interactions by soil, plant, and climate. Large differences in ZnE have been reported among wheat genotypes (Khoshgoftar *et al*., 2006; Bagci *et al*., 2007; Esfandiari *et al*., 2018a; Abdoli *et al*., 2019).

To evaluate the response of plant genotypes to stress, some selection indices based on a mathematical relation between stress and optimum conditions have been proposed. The genotypes with the high-stress tolerance index (STI) values will be tolerant to drought stress (Farshadfar *et al*., 2013). A high amount of STI shows an intensive tolerance and the best advantage of this index is its ability in separating group A, from other groups (Rajaram *et al*., 1990; Pour-Siahbidi and Pour-Aboughadareh, 2013; Anwaar *et al*., 2020). Based on the STI, the genotypes of G33, G32, and G19 were identified that tolerant to Zn stress (Fig. 4, Table 5). In agreement with the results of the present study, previous studies on cereals such as oat indicated that the cultivars with the highest STI have the highest yields under stress and non-stress conditions (Akcura and Ceri, 2011). The STI showed that alfalfa cultivars displayed high tolerance to stress and were more profitable (Bellague *et al*., 2016). Recent evidence demonstrates that the STI was the best index to identify Zn deficiency tolerant genotypes (Khoshgoftarmanesh *et al*., 2011).

This study evaluated the level of stress tolerance in thirty-five durum wheat genotypes. The genotypes with a high YSI are expected to have high yield under both stress and non-stress conditions. Also, found that if RDI >1, the genotype is relatively drought-tolerant, and if RDI <1, it is drought susceptible (Fischer and Wood, 1979). The evaluation results were such that the genotype G23 had the highest RDI and YSI, followed by G6 and G32 exhibited stability to stress, as well as genotypes G21 and G2 had the lowest these indexes (Tables 4 and 5). Probably this has been due to the smaller fluctuations in both Zn deficit stress and non-stress conditions in genotypes G6, G23, and G32 than the other genotypes, which led to an increase in the RDI and YSI. In connection with this index, the genotypes with high YSI values can be regarded as stable genotypes under stress and non-stress conditions (Farshadfar *et al*., 2013). In addition to Khan and Dhurve (2016) indicated that YSI can be used to screen drought-resistant and suitable genotypes of rice under drought stress conditions. Yield index (YI) parameter, proposed by Gavuzzi *et al*. (1997), ranks genotypes only based on their yield under stress conditions.

The genotypes with a high value of YI will be suitable for stress conditions (Farshadfar *et al*., 2013). The results presented in this study demonstrate that the G32 and G33 genotypes displayed the highest, and G21 and G2 genotypes displayed the lowest YI and DI stress indices, respectively (Tables 4 and 5). Therefore, genotypes G32 and G33 are suitable for Zn deficit stress conditions.

Measurements of the SSPI indicated that the greatest values were observed in the G21, G29, and G1 genotypes, and the lowest values were observed in the G23, G6, G32, and G13 genotypes (Tables 4 and 5). The genotypes with low values of this index (SSPI) are more stable in two different conditions. Therefore, their genotypes (G23, G6, G32, and G13) are more stable in both different conditions. Alternatively, similar results were obtained with the ATI index. A previous study revealed ATI and SSPI differentiated between relative tolerant and intolerant genotypes better than TOL and SSI in some cases and were considered as a favorite index for the selection of relatively tolerant genotypes (Moosavi *et al*., 2008). The genotypes with the low value of SDI will be more desirable (Farshadfar *et al*., 2013). Based on this indicator, genotypes G23, G6, G32, and G25 showed the lowest SDI value in this study (Tables 4 and 5). Therefore, these durum wheat genotypes will be more desirable for cultivation in Zn deficit areas. The highest K_1STI was attributed to genotypes G33, G19, G9, G32, and G11, as well as, the highest K_2STI was attributed to genotypes G33, G32, G19, G15, and G31 (Tables 4 and 5). To improve the efficiency of STI a modified stress tolerance index (MSTI) was proposed by Farshadfar and Sutka (2002). It was calculated as K_iSTI, where K_i is a correction coefficient, which corrects the STI as a weight. Therefore, K_1STI and K_2STI are the optimal selection indices for stress and non-stress conditions, respectively.

Correlation analysis between grain yield and stress tolerance indices can be a good criterion for screening the best cultivars and indices used. Researchers stated that a suitable index must have a significant correlation with grain yield under both non-stress and stress conditions (Mitra, 2001; Gadimaliyeva *et al*., 2020). According to this, grain yield was strongly positively correlated with STI, YI, DI, K_1STI, and K_2STI under two conditions (Table 6). Hence, STI, YI, DI, K_1STI, and K_2STI were able to identify genotypes producing high yield in both conditions. By using these indexes, the genotypes G32, G33, and G19 were found to be the best genotypes with relatively high yield and suitable for both normal and Zn deficit stress conditions. Plant breeding researchers believed that the most appropriate index for selecting stress-tolerant genotypes is the index which has a partly high correlation with yield under stress and non-stress conditions (Farshadfar *et al*., 2001; Molla Heydari Bafghi *et al*., 2017). In the study conducted by Farshadfar and Elyasi (2012), grain yield in the stress and non-stress conditions were positively correlated with YSI, YI, DI, modified stress tolerance index (MSTI), and RDI. In another study, reported those STI, GMP, MP, HARM, YI, DI, and stress non-stress production indexes (SNPI) were significantly and positively correlated with grain yield in two conditions (Farshadfar *et al*., 2013). A previous study revealed a significant and positive correlation was observed between GYs and GYp with MP, GMP, STI, YI, HARM, SDI, K_1STI, and K_2STI indicated that these indices are the most suitable indices to screen genotypes in stress conditions (Amiri *et al*., 2014).

Understanding responses of crops such as wheat to micro-nutrients stress is of great importance and also a fundamental part of making crops stress-tolerant. In this study, the genotypes G32, G33, and G19 at group A (genotypes with similar good yield in both conditions) genotypes G1, G29, and G21 at group B (genotypes with good yield only in non-stress conditions), genotypes G6 and G23 at group C (genotypes with good yield only in Zn stress conditions), and genotypes G2, G3, G12, and G13 at group D (genotypes with weak yield in both conditions) (Fig. 3). Other researchers have used this pattern for grouping of genotypes of rapeseed (Shirani Rad and Abbasian, 2011), chickpea (Pour-Siahbidi and Pour-Aboughadareh, 2013), bread wheat (Farshadfar *et al*., 2013), and maize (Arisandy *et al*., 2017). Cluster analysis based on grain yield, ZnE, and all indices at normal and Zn stress conditions classified the durum wheat genotypes into four clusters (Fig. 5). In this analysis, the first group had the highest GYp, GYs, ZnE, STI, RDI, YI, YSI, DI, ATI, SSPI, SDI, K_1STI, and K_2STI indices and was thus considered to be the most desirable cluster for both growth conditions (tolerant genotypes such as G23, G6, G32, and G13). Genotypes in the second group had semi-tolerant. In the third and fourth groups (semi-sensitive and sensitive genotypes, respectively), all genotypes had low ten mentioned indices, thus they were susceptible to Zn stress and only suitable for normal conditions. The results of cluster analysis completely agreed by the relationship between grain yields produced under non-stress and Zn deficit stress conditions (Figs. 3 and 5). In recent history, Khoshgoftarmanesh *et al*. (2009) stated that most of the bread wheat genotypes were placed in group A (genotypes that are not affected by stress) and D (genotypes with low yield in both Zn stress and non-stress conditions) based on the STI.

In conclusion, the findings from this study showed that there is a genetic variation for the attributes studied between durum wheat genotypes and the possibility of selection for stress tolerance genotypes. Genotypes with small fluctuations yield in both Zn deficit stress and non-stress conditions have been identified as Zn-efficient genotypes, such as G23, G6, G32, G25, G13, and G15 genotypes. The relative RDI and YSI were superior in the genotype G23 closely followed by G32 and G6 indicated that RDI and YSI can be used to screen Zn stress-resistant and suitable genotypes under stress condition. Genotypes with the low value of SDI will be more desirable; in this study, the genotypes G23, G6, G32, and G25 showed the lowest this index value. The SIT, YI, and DI were superior in genotype G32, G33, and G19 indicating that they can be used as an alternative for each other to select Zn stress-tolerant genotypes with high yield performance in both stress and non-stress conditions. Our results showed that the correlation was between STI, YI, DI, K_1STI, and K_2STI indices and grain yield under Zn deficient stress and non-stress, these indices were identified as the best stress indices for isolation and selection of tolerant genotypes. Therefore, they (G32, G33, and G19) may be recommended to cultivate in Zn deficit prone regions of the world and also can be used in wheat breeding programs aimed at improving Zn stress tolerance.

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Conflicts of Interest

Authors declare no conflicts of interest regarding the publication of this work.

References

Abdoli M, Esfandiari E, Aliloo AA, Sadeghzadeh B, Mousavi SB. 2019. Study of genetic diversity in different wheat species with various genomes based on morphological characteristics and zinc use efficiency under two zinc-deficient growing conditions. *Acta Agric Slov* 113: 147-161.

Abdoli M, Esfandiari E, Sadeghzadeh B, Mousavi SB. 2016. Zinc application methods affect agronomy traits and grain micronutrients in bread and durum wheat under zinc-deficient calcareous soil. *YYU J Agr Sci* 26: 202-214.

Abdoli M, Esfandiari E. 2017. Assessment of genetic variation and zinc deficient tolerance in spring durum wheat (*Triticum durum* Desf.) genotypes in calcareous soil with zinc deficiency. *J Genet Resour* 3: 7-17.

Agili S, Nyende B, Ngamau K, Masinde P. 2012. Selection, yield evaluation, drought tolerance indices of orange-flesh sweet potato (*Ipomoea batatas* Lam) hybrid clone. *J Nutr Food Sci* 2: 1-8.

Akcura M, Ceri S. 2011. Evaluation of drought tolerance indices for selection of Turkish oat (*Avena sativa* L.) landraces under various environmental conditions. *Zemdirbyste* 98: 157-166.

Alloway BJ. 2008. Zinc in Soils and Crop Nutrition. Brussels, Belgium: International Zinc Association.

Amiri R, Bahraminejad S, Sasani Sh, Ghobadi M. 2014. Genetic evaluation of 80 irrigated bread wheat genotypes for drought tolerance indices. *Bulg J Agric Sci* 20: 101-111.

Anwaar HA, Perveen R, Mansha MZ, Abid M, Sarwar ZM, Aatif HM, Umar U, Sajid M, Aslam HMU, Alam MM, Rizwan M, Ikram RM, Alghanem SMS, Rashid A, Khan KA. 2020. Assessment of grain yield indices in response to drought stress in wheat (*Triticum aestivum* L.). *Saudi J Biol Sci* 27: 1818-1823.

Arisandy P, Bayuardi Suwarno W, Azrai M. 2017. Evaluation of drought tolerance in maize hybrids using stress tolerance indices. *Int J Agron Agric Res* 11: 46-54.

Bagci SA, Ekiz H, Yilmaz A, Cakmak I. 2007. Effects of zinc deficiency and drought on grain yield of field-grown wheat cultivars in Central Anatolia. *J Agron Crop Sci* 193: 198-206.

Bellague D, M'Hammedi-Bouzina M, Abdelguerfi A. 2016. Measuring the performance of perennial alfalfa with drought tolerance indices. *Chil J Agric Res* 76: 273-284.

Bouslama M, Schapaugh WT. 1984. Stress tolerance in soybean. I. Evaluation of three screening techniques for heat and drought tolerance. *Crop Sci* 24: 933-937.

Ekbic E, Cagiran C, Korkmaz K, Arsal Kose M, Aras V. 2017. Assessment of watermelon accessions for salt tolerance using stress tolerance indices. *Cienc Agrotec* 41: 616-625.

Esfandiari E, Abdoli M, Sadeghzadeh B, Mousavi SB. 2018a. Evaluation of Turkish durum wheat (*Triticum turgidum* var. durum) genotypes based on quantitative traits and shoot zinc accumulation under zinc-deficient calcareous soil. *Iranian J Plant Physiol* 8: 2525-2537.

Esfandiari E, Abdoli M, Sadeghzadeh B. 2018b. Evaluation of genetic diversity of durum wheat genotypes (*Triticum turgidum* var durum) using agro-morphological traits for resistance to zinc deficient stress. *Res Crop Ecophysiol* 13: 23-40.

Esfandiari E, Abdoli M. 2017. Variations of grain yield and agro-morphological traits of some promising durum wheat lines (*Triticum turgidum* L. var. durum) at zinc sufficient and deficient conditions. *J Genet Resour* 3: 68-79.

FAO. 2014. Food Supply Database 2014 of Food and Agriculture Organization. Available at: http://faostat.fao.org/site/609/default.aspx#ancor on October 15, 2014.

Farshadfar E, Elyasi P. 2012. Screening quantitative indictors of drought tolerance in bread wheat (*Triticum aestivum* L.) landraces. *Eur J Exp Bio* 2: 577-584.

Farshadfar E, Ghannadha M, Zahravi M, Sutka J. 2001. Genetic analysis of drought tolerance in wheat. *Plant Breed* 114: 542-544.

Farshadfar E, Poursiahbidi MM, Safavi SM. 2013. Assessment of drought tolerance in land races of bread wheat based on resistance/tolerance indices. *Int J Adv Biol Biomed Res* 1: 143-158.

Farshadfar E, Sutka J. 2002. Multivariate analysis of drought tolerance in wheat substitution lines. *Cereal Res Commun* 31: 33-40.

Fernandez GCJ. 1992. Effective selection criteria for assessing plant stress tolerance. Proceedings of the International Symposium on Adaptation of Vegetables and other Food Crops in Temperature and Water Stress, August 13-16, 1992, Shanhua, Taiwan, pp. 257-270.

Fischer RA, Wood JT. 1979. Drought resistance in spring wheat cultivars: III. Yield association with morpho-physiological traits. *Aust J Agr Res* 30: 1001-1020.

Gadimaliyeva G, Akparov Z, Aminov N, Aliyeva A, Ojaghi J, Salayeva S, Serpoush M, Mammadov A, Morgounov A. 2020. Assessment of synthetic wheat lines for soil salinity tolerance. *Zemdirbyste* 107: 55-62.

Gavuzzi P, Rizza F, Palumbo M, Campaline RG, Ricciardi GL, Borghi B. 1997. Evaluation of field and laboratory predictors of drought and heat tolerance in winter cereals. *Can J Plant Sci* 77: 523-531.

Ghasemi M, Farshadfar E. 2015. Screening drought tolerant genotypes in wheat using multivariate and stress tolerance score methods. *Int J Biosci* 6: 326-333.

Hooshmandi B. 2019. Evaluation of tolerance to drought stress in wheat genotypes. *Idesia* 37: 37-43.

Kamrani M, Hoseini Y, Ebadollahi A. 2018. Evaluation for heat stress tolerance in durum wheat genotypes using stress tolerance indices. *Arch Agron Soil Sci* 64: 38-45.

Khan AA, Kabir MR. 2014. Evaluation of spring wheat genotypes (*Triticum aestivum* L.) for heat stress tolerance using different stress tolerance indices. *Cercet Agron Mold* 160: 49-63.

Khan IM, Dhurve OP. 2016. Drought response indices for identification of drought tolerant genotypes in rainfed upland rice (*Oryza sativa* L.). *Int J Sci Environ Technol* 5: 73-83.

Khoshgoftar AH, Shariatmadari H, Karimian N. 2006. Responses of wheat genotypes to zinc fertilization under saline soil conditions. *J Plant Nutr* 29: 1543-1556.

Khoshgoftarmanesh AH, Razizadeh ES, Eshghizadeh HR, Savaghebi Gh, Sadrearhami A, Afuni D. 2011. Screening tolerance of different spring wheat genotypes to zinc deficiency with using different stress indices. *J Water Soil* 25: 287-295.

Khoshgoftarmanesh AH, Sadrarhami A, Sharifi HR, Afiuni D, Schulin R. 2009. Selecting zinc-efficient wheat genotypes with high grain yield using a stress tolerance index. *Agron J* 101: 1409-1416.

Lan J. 1998. Comparison of evaluating methods for agronomic drought resistance in crops. *Acta Agr Bor-Occid Sinic* 7: 85-87.

Lin CS, Binns MR, Lefkovitch LP. 1986. Stability analysis: Where do we stand? *Crop Sci* 26: 894-900.

Mitra J. 2001. Genetics and genetic improvement of drought resistance in crop plants. *Curr Sci* 80: 758-763.

Molla Heydari Bafghi R, Baghizadeh A, Mohammadinezhad G. 2017. Evaluation of salinity and drought stresses tolerance in wheat genotypes using tolerance indices. *J Crop Breed* 9: 27-34.

Moosavi SS, Yazdi-Samadi B, Naghavi MR, Zali AA, Dashti H, Pourshahbazi A. 2008. Introduction of new indices to identify relative drought tolerance and resistance in wheat genotypes. *Desert* 12: 165-178.

Pour-Siahbidi MM, Pour-Aboughadareh AR. 2013. Evaluation of grain yield and repeatability of drought tolerance indices for screening chickpea (*Cicer aritinum* L.) genotypes under rainfed conditions. *Iranian J Genet Plant Breed* 2(2): 28-37.

Rajaram S, Villareal R, Mujeeb-Kazi A. 1990. The Global Impact of 1B/1R Spring Wheats. Agronomy Abstracts, San Antono: American Society of Agronomy (ASA), Madison, USA. 105 p.

Royo C, Miloudi MM, Di Fonze N, Arraus JL, Pfeiffer WH, Slafer GA. 2005. Durum Wheat Breeding: Current Approaches and Future Strategies. Volumes 1 and 2. 1st Edition, CRC Press. 1112 p.

Saeidi M, Abdoli M, Shafiei-Abnavi M, Mohammadi M, Eskandari-Ghaleh Z. 2016. Evaluation of genetic diversity of bread and durum wheat genotypes based on agronomy traits and some morphological traits in non-stress and terminal drought stress conditions. *Cereal Res* 5: 353-369.

SAS Institute. 2011. Base SAS 9.1 Procedures Guide. SAS Institute Inc, Cary.

Shirani Rad AH, Abbasian A. 2011. Evaluation of drought tolerance in rapeseed genotypes under non stress and drought stress conditions. *Not Bot Horti Agrobot Cluj Napoca* 39: 164-171.

Sims JT, Johnson GV. 1991. Micronutrients Soil Tests. In: Mordcvedt JJ, Cox FR, Shuman LM, Welch RM. (eds.), Micronutrients in Agriculture. SSSA Book Series No. 4, Madison, WI. pp. 427-476.

SPSS. 2007. SPSS 16.0 for Windows. 16th Edition. New York, USA.

USDA. 2017. World Agriculture Production, United States Department of Agriculture. Available at: https://www.fas.usda.gov/data/world-agricultural-production.